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ABSTRACT

This paper is the written account of a panel presentation about inquiry-oriented teaching practices. The purpose of this group of papers is to provide an opportunity to explore the state of knowledge of inquiry-oriented teaching based on direct observation of teachers, and analysis of those observations from an inquiry perspective. The paper begins with a synopsis of the presentations followed by the full text of each paper. The various positions taken by the six panel members include focusing research on teaching practices in support of inquiry, understanding the concepts of freedom and privilege in inquiry teaching and learning, changing roles for teachers and students, post laboratory reflections, and teacher conceptions of inquiry and related teaching practices. These papers highlight the intense reform rhetoric surrounding inquiry-oriented teaching and inconsistencies in the literature on the actions of teachers engaged in these teaching practices. The panel members were Lawrence B. Flick, Carolyn W. Keys, Susan L. Westbrook, Barbara A. Crawford, and Nathan G. Cames. (DDR)

National Association for Research in Science Teaching
Oak Brook, IL, March 22, 1:00-2:30 p.m.
Panel Presentation

Perspectives on Inquiry-Oriented Teaching Practice: Conflict and Clarification

Lawrence B. Flick, Oregon State University
Carolyn W. Keys, Georgia State University
Susan L. Westbrook, North Carolina State University
Barbara A. Crawford, Oregon State University
Nathan G. Carnes, University of South Carolina

The following is a synopsis of the panel presentations written by Flick, the organizer of the panel. The full text of each paper follows the synopsis.

The purpose of this interactive session will be for participants to each state a finely drawn position on the nature of successful inquiry teaching practice applied to middle and high school classrooms. The resulting diversity of views will offer an opportunity to explore state of our knowledge concerning inquiry-oriented teaching. All panel members have conducted research that includes the direct observation of teachers and analyzed teaching practice from an inquiry perspective. Despite the intense reform rhetoric around inquiry-oriented teaching, the literature is inconsistent and often strangely silent about the actions of teachers engaged in inquiry-oriented instruction. Panel members represent experienced as well as new researchers who together represent a diversity of views on inquiry teaching with pre-adolescent and adolescent students.

What follows is a brief synopsis of the position taken by each panel member. We are hoping for a spirited discussion that will stimulate new ideas. The paper set will be available at the session.

Focusing Research on Teaching Practices in Support of Inquiry (Larry Flick)

Contemporary pressures on education in general mean that leaders in science education must be clearer about the purposes, practices, and benefits of inquiry-oriented teaching. Flick's perspective is that our knowledge about inquiry teaching has developed more from the perspective of how students behave and what they experience than from how teachers generate and manage those experiences. To begin the process of sharpening our view of inquiry teaching, Flick makes three proposals. The first is to clarify the nature of inquiry as it applied in the classroom. The second proposal is to direct research toward a greater variety of teaching practices used in the service of inquiry teaching. The third proposal is to produce reports of research that make a clear distinction between discussion of learning theories and theories of instructional design.

Understanding the Concepts of Freedom and Privileging in Inquiry Teaching and Learning (Carolyn Keys)

An underlying difficulty with inquiry teaching is the juxtaposition between freedom and privileging. Students need freedom to develop authentic knowledge, by building on their own ideas, yet science is an enterprise that has been constructed through the privileging of some ideas over others. Keys believes that the majority of science teachers are confused and frustrated by rhetoric which calls on the one hand for students to design and conduct their own inquiries, and on the other hand for teachers to design inquires that guide students to an understanding of difficult science concepts. Keys makes suggestions for addressing this issue in two categories: (a) Decide what is to be learned through inquiry experiences and (b) decrease tension between freedom to follow curiosity and learning consensual scientific views.

A Community of Inquiry: Changing Roles for Teachers and Students (Barbara Crawford)

One possible reason that inquiry-based instruction remains a vision in the reforms, but an enigma in the classroom may lie in the fact that teachers have few operational models. In searching for models of inquiry-based instruction, Crawford examines inquiry-based environments in science classrooms from three perspectives: (a) As a member of a project-based science team of researchers and teachers, (b) as a teacher-researcher studying her own teaching, and (c) as a teacher-educator collaborating with preservice teacher to develop a case study. Crawford synthesizes her work by developing the construct "community of inquiry" and proposes a model for articulating the roles of teacher and students.

The Lab's Done...Now What? (Susan Westbrook)

Westbrook explores two possible explanations for the lack of inquiry-oriented instruction in the science classroom and proposes a focus for efforts to attend to this problem. First, science teachers do not invest in inquiry-oriented practices because they do not perceive the laboratory as a source of instruction - as a teacher - in the science classroom. Second, science teachers, for the most part, do not know how to meld the processes and outcomes of laboratory investigations with students' construction of science content. Westbrook proposes that researchers focus on the daily practices of a variety of teachers toward the goal of developing strategies for classroom discourse that support more productive use of inquiry-oriented experiences.

Teacher Conceptions of Inquiry and Related Teaching Practices (Nate Carnes)

Carnes examines the work of three urban middle school teachers who implemented inquiry teaching practices after completing an intensive professional development program. Carnes asks two questions: (a) What were the teachers' definitions of inquiry? and (b) how were the teachers incorporating inquiry teaching, as they defined it, in their classrooms? Previous work has tended to oversimplify the answers to these questions. The teachers in Carnes study articulated a definition of inquiry and taught in a manner consistent with those definitions. However, harder questions remain. How did these teachers form a definition of inquiry that guided instruction and how robust is it in the face of the daily routine of instruction?

Focusing Research on Teaching Practices in Support of Inquiry

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Documents promoting national reform in science education have strongly emphasized the importance of inquiry-oriented teaching across K-12 classrooms. An inquiry emphasis has been more or less in vogue most of this century, but there is some urgency associated with contemporary discussions about science teaching. Education in general has come under broad criticism as a result of international comparisons. National concern for the quality and content of education has also risen even as education competes for fewer state and federal dollars across the country. Teachers and science educators are faced with promoting a more complex and less familiar form of teaching to a more circumspect and often more contentious clientele. Leaders in science education must be clear about the purposes, practices, and benefits of inquiry-oriented teaching.

Our knowledge about inquiry teaching has developed more from the perspective of how students behave and what they experience than from how teachers generate and manage those experiences. Data has accumulated in support of inquiry teaching from a broad range of studies that have focused on classroom features such as hands-on or laboratory activities, classroom discourse, writing and portfolios, and small group work. However, if inquiry is to become a viable, mainline approach to teaching science, researchers and teachers must become more explicit about the behaviors and thoughts of teachers engaged in inquiry teaching. Broad <u>descriptions</u> presented in the National Science Education Standards are derived from a research base that only indirectly apprehends teacher thought and action. Broad <u>prescriptions</u> also carry the possible connotation that classroom inquiry is conducted in ways similar to the work of professional science. To begin the process of sharpening our view of inquiry teaching, I make three proposals.

First, the common model of inquiry as a scientific investigation or controlled experiment should be understood as having limited pedagogical use. Instruction should proceed from a base of inquiry elements which can be explicitly taught to students and which they can eventually apply in inquiry lessons. An example of an inquiry element would be identifying and/or understanding a scientific problem. Models of inquiry teaching that broadly apply inquiry processes in an open-ended fashion to teach science content where students are expected to derive original conclusions grounded in data that have been generated from classroom-based procedures are, and are likely to remain, a rarity in science classrooms. The knowledge, skills, and dispositions as well as self-confidence necessary to participate in this type of instruction is not suitable for all students and may, in fact, be harmful to the learning of some students (Welch, Klopfer, Aikenhead, & Robinson, 1981; Reid & Hodson, 1987). The problem is that the structure and function of inquiry teaching models confuse methods <u>for</u> teaching K-12 science with methods <u>of</u> professional scientific inquiry. Methods for teaching science content and process assume a student working under the tutelage of more capable mentors. The professional scientist is assumed to be far more independent. Clearly, these are points on a continuum and a student may well act independently while learning directly from the environment. However, in the structure of schools, that student is directed, along with classmates, in a program of work in which there is specific accountability for specific performances.

The second proposal is to direct research toward a greater variety of teaching practices used in the service of inquiry teaching. A possible first move would be to eliminate the artificial dichotomy between explicit teaching and the conduct of inquiry teaching (Good & Brophy, 1997). Skilled science teachers achieve an inquiry-oriented atmosphere in moderate to highly controlled conditions by explicitly teaching about inquiry skills and habits of mind and requiring students to apply those skills and scientific attitudes to specific problems in science. Some of the outcomes may indeed be original conclusions grounded in classroom-generated data but most will be partially constructed ideas generated in fits and starts that the teacher must specifically weave together to create or maintain purpose, focus, and continuity. Research should help illuminate planning, procedures, and decisions highly qualified teachers make as they establish and maintain the cognitive demands of inquiry instruction.

The third proposal is to produce reports of research that make a clear distinction between discussion of learning theories and theories of instructional design. Studies that make prescriptions about teaching behavior based on an analysis student behavior leave the operationalization of teaching behavior unspecified. Theoretical models of how students learn are necessarily antecedent to instructional models. However, teaching models themselves must be designed and tested in regular classrooms to determine how desired outcomes can be achieved. Reigeluth (1983) argues that instructional design theories are typically stated in terms of conditions, methods, and outcomes. A "descriptive" theory of inquiry teaching would describe the possible outcomes given conditions and methods. A "prescriptive" theory of inquiry teaching would state what methods are necessary given conditions and specified outcomes. We need a richer set of theories of both types presented in reports that do not commingle discussion of learning theory with instructional design theory. Studies based on either type of theory would help enrich our vocabulary about teaching practice. Contrasts such as "traditional" or "lecture" versus "inquiry" or "constructivist" simply reveal a lack of understanding or sophistication about the array of teaching practices skilled teachers integrate to achieve outcomes under varying conditions.

Current models of inquiry-oriented teaching tend to sharpen the horns of a dilemma. Teachers are not sure whether to provide advice on how to conduct the inquiry and slow the process of understanding science content or to provide content-specific information and short-circuit the process of investigating. Better models of instruction would blunt the effect of this natural dilemma by offering principles for making decisions that move into and out of inquiry modes of instruction. Improved instructional models would facilitate the integration of broader base of pedagogical knowledge into more robust and serviceable strategies that allow teachers to adapt instruction to diverse classrooms and conditions. New models would also help improve the currently fuzzy area of assessing inquiry by making clearer links between hands-on, investigative behavior and specific types of learning outcomes.

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Understanding the Concepts of Freedom and Privileging in Inquiry Teaching and Learning

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An underlying difficulty with inquiry teaching is the juxtaposition between *freedom* and *privileging*. Students need freedom to develop authentic knowledge, by building on their own ideas, yet science is an enterprise that has been constructed through the privileging of some ideas over others. The argument for freedom implies that if inquiry is a tool for constructing personal meanings of science concepts, the learner must be given freedom to work from her own experiences. Teaching derived from a freedom perspective allows learners to choose content related to their interests, to generate their own inquiry questions, to invent methodologies, and to collect and make sense of empirical data. A proponent of the freedom perspective, Lijnse (1995, p. 192), made the following assertion, "we could say that we should not teach the concepts of science (as a product), not even in an above-mentioned constructivist way, but guide students in the activity of 'scientificalizing' their world." Allowing students freedom to make their own scientific decisions may foster a deep understanding of the connections between questions, methodologies, data, and knowledge claims.

The privileging perspective posits that learning science is essentially an enculturation into scientific ideas and ways of thinking. Teaching associated with this view emphasizes mediation into the concepts and understandings that are held in high regard by the scientific community. Writing from a privileging perspective, Driver, Asoko, Leach, Mortimer, and Scott (1994, p. 6) stated, "Scientific entities and ideas, which are constructed, validated, and communicated through the cultural institutions of science, are unlikely to be discovered by individuals through their own empirical enquiry; learning science thus involves being initiated into the ideas and practices of the scientific community and making these ideas and practices meaningful at an individual level. The role of the science educator is to mediate scientific knowledge for learners, to help them to make personal sense of the ways in which knowledge claims are generated and validated, rather that to organize individual sense making about the natural world." While some skillful teachers are able to design inquiry instruction that harmonizes both freedom and privileging (Roth and Roychoudhury, 1993), I believe that the majority of science teachers are confused and frustrated by rhetoric which calls on the one hand for students to design and conduct their own inquiries, and on the other hand for teachers to design inquiries that guide children to an understanding of difficult science concepts. Resolving the tension between freedom and privileging, or at least recognizing it, putting language to it, and learning to work between the ends of the continuum may be critical for the success of fostering inquiry learning in the classroom.

The National Science Education Standards (NRC, 1996) acknowledges some of the tensions associated with learner freedom and privileging, yet does not clearly articulate any criteria by which teachers may choose between more free or more tightly mediated instructional modes. In the "Science Teaching Standards" section of the document, inquiry is touted as a primary means of instruction. For example, the Standards describe successful practices the following way, "In successful science classrooms, teachers and students collaborate in the pursuit of ideas, and students quite often initiate new activities related to the inquiry. Students formulate questions and devise ways to answer them, they collect data and decide how to represent it, they organize data to generate knowledge, and they test the reliability of the knowledge they have generated (NRC, 1996, p. 33). These guidelines would seem to suggest a great deal of learner freedom (and responsibility) in the generation of science knowledge. What the Standards don t address are very real problems for teachers, preservice teachers, and teacher educators surrounding students generation of counter-intuitive or abstract concepts, such as air pressure, motion, heat, photosynthesis, the structure of matter, or light energy. The Standards suggestion to organize inquiry around secondary sources of data and information may help, but the Standards stop short of giving clear guidelines for when and how to design mediated, tightly structured inquiry activities to develop specific conceptual understandings.

I believe that both free inquiries and mediated inquiries are desirable in the science classroom. The research community needs to clearly communicate their findings in terms of the success of various inquiry activities for achieving particular instructional goals. The recognition, identification, and articulation of several different forms of pedagogy that meet different science objectives would support teacher planning and implementation of inquiry practices. I offer the following suggestions for collaborative dialogue between researchers and teachers.

Decide what is to be learned through inquiry experiences.

- Clarify instructional goals that are to be taught by inquiry processes.
- Develop a menu of inquiry pedagogies that correspond to instructional goals.
- Match the type of inquiry pedagogy to the goals of instruction.

The following table shows a potential starting point for correlating goals, pedagogical types, and specific inquiry activities.

Instructional Goals	Form of Inquiry Pedagogy	Activity Examples
conceptual change; development of accurate scientific knowledge	tightly structured laboratory activities and demonstrations with teacher questioning	air pressure demonstrations pendulum swing factors plant responses to gravity
explore contexts and materials surrounding scientific concepts	open-ended, divergent inquiries that allow free manipulation of materials and stimulate questions	batteries and bulbs exploration plant structures observation solutes and solvents exploration
describe and compare local phenomena; collect data, infer meanings for data	teacher/students pose real world problem; students design and implement investigations; generate claims	water quality studies zoo animal behavior studies weather observations
develop skills to conduct experiments with underlying multiple hypotheses; gather evidence; construct explanations	teacher/students pose experimental problem; design and implement investigations; report conclusions with supporting evidence	factors affecting photosynthesis inheritance of genetic factors factors affecting rate of reaction

Decrease tension between freedom to follow curiosity and learning consensual scientific views

- Make it clear when students can ask authentic questions without regard for the teacher s agenda.
- Provide opportunities for both structured inquiry to learn targeted concepts and divergent investigation.
- Recognize the importance of failure in developing understandings.

A compromise between free and privileged perspectives on teaching suggests that children need to engage in both free/authentic inquiry and structured/guided inquiry. Teachers may need to become comfortable with initiating frank discussions with their students about agendas for free inquiry versus the learning of specific concepts. Similarly, researchers and teachers need to work together to develop curriculum materials that overtly address the process of failure in scientific investigation. In order to build an understanding of scientific inquiry, students may need to conduct investigations that do not result in clear and reliable data. The power of generating unsuccessful investigations and learning from them is rarely, if ever, addressed in the literature. Students engaged in inquiry may be able to learn more from their mistakes than they do from their successes. At present, the process of making errors, revising, posing new questions, and retesting is sidestepped in most published inquiry materials.

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The Lab's Done . . . Now What?

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Documents communicating the reform agenda for science education make bold statements about the importance of student activity in the classroom. In the National Science Education Standards (NRC, 1996), for example, science is proposed as being "something students do, not something that is done to them" (p. 20). Yet, few K-12 students experience science class as a do-rather-than-done-unto event (Weiss, 1994). I would like to explore two possible explanations for the lack of inquiry-oriented instruction in the science classroom and propose a focus for efforts to attend to that problem.

State-mandated, accountability-directed examinations are becoming the norm in schools in this country. Teachers are, in general, hesitant to implement instructional practices that do not help "cover" the content objectives. More specifically, science teachers do not invest in inquiry-oriented practices because they do not perceive the laboratory as a "source" of instruction--or as a "teacher"--in the science classroom. If experimentation were viewed as being a source of content, rather than a time-and-money consuming attempt to "play scientist," teachers might be more willing to invest themselves and their students in active investigation. Preservice and inservice teachers I have polled over the years typically ascribe to the notion that the science lab can be used to motivate student interest and vary the class routine after the science content has been "taught" by lecture and text reading. The laboratory is considered "important," but plays a far-second role to the actual avarice of teaching--the content. That perception has, for the most part, been generated from personal "school science" experiences where content was "told" in large lecture halls and non-investigative labs were separate in space, time, and often even in content.

Flick (1997), in his contribution to our conversation, gives us little hope that the "lab-as-teacher" metaphor will become the norm in science classrooms: Models of inquiry teaching that broadly apply inquiry processes in an open-ended fashion to teach science content where students are expected to derive original conclusions grounded in data that have been generated from classroom-based procedures are, and are likely to remain, a rarity in science classrooms (p. 2). Why is it so unlikely that teachers will universally adopt data-driven instructional models? Science teachers, for the most part, do not know how to meld the processes and outcomes of laboratory investigations with the students' constructions of science content. If the students' understanding of the content is perceived as having occurred prior to the laboratory exercise, there is no need to focus on instructional strategies that support knowledge construction within the context of the scientific investigation. Shifting laboratory experiences to the front of the instructional "line-up" will open both space and reason for opportunities to allow students to build understanding of science concepts around data collected in their own inquiries. That "shift" will also necessitate rethinking the nature and the purpose of the "talk" that occurs in the classroom. The authors of Pathways to the Science Standards (NSTA, 1996) claim that tomorrow's teachers "will recognize the social component of learning. Collaboration and discourse will be constant components of lessons . . . ." (p. 9). In order for that future to be realized, teachers will need to begin to value both the process and product of student-and-data-centered discourse.

Discussion is an essential--and often missing--element of what we refer to as "inquiry-oriented instruction." Through verbal interactions with their peers and teacher, students work to make sense of the data gathered in the laboratory investigation. Questioning by the teacher and students draws out discrepancies and patterns among the data, stimulates new ideas and perceptions, and builds a community of co-inquirers. Discussion promotes accountability for student engagement in laboratory investigations. Discussion also supports sense-making and knowledge construction. Laboratory experiences are necessary, but usually not sufficient, to allow students to build new understandings. Open, verbal interactions perturb the social and conceptual environment of the classroom and set the stage for the students' construction and reconstruction of science concepts. Class discussions provide students with opportunities to develop the contextual and conceptual frameworks necessary for future purposeful inquiries. Verbal interactions serve not only as a source of information, but also as a "think tank" for producing finer drawn, probing questions to be investigated by the students.

The Standards (NRC, 1996) and Pathways (NSTA, 1996) documents support the importance of physical and verbal interactions in the science classroom. In the Standards we read that "teaching must involve students in inquiry-oriented investigations in which they interact with teachers and peers" (p. 20). Teachers are told in Pathways that lecturing "doesn't work" (p. 9) and that "'thinking out loud'". . .

[and] . . . "offering constructive arguments . . . are part of a constructivist classroom" (p. 14). The Pathways authors also contend that lecture persists as an instructional strategy because teachers "may not have the skills or the facilities and the support to abandon this approach" (p. 9). There is little in either of the aforementioned documents, however, to provide direction for teachers' development of strategies that will blend the "tools" and "talk" of science teaching.

What specifics about classroom discussions could be generated? Are there any "tried-and-true" blueprints for the perfect class discussion? Data-driven discussions are unpredictable and "fickle." What students will ask or say or think cannot really be predetermined and packaged in a teacher's guide. The more "open" and student-directed the inquiry, the less generalizable the discussions will be. The success of discussions about laboratory data is not only dependent on the type of questions the teacher asks, but also on the resulting interplay among students (Roth, 1996). What do students need to know to be able to interact in these environments? What do teachers need to know to be able to teach students to engage in meaningful discussions?

Where do we go from here? From a researcher's perspective, we need to take closer looks at what teachers--from all manners of personal philosophy--really do during verbal exchanges in the classroom. The goal of these inquiries would be to assess "real" teacher behaviors in classroom settings. We have to have the courage to identify "not-so-good" as well as "good" strategies. That is a difficult task; we don't want to play judge to the professional skills of the teachers we know. If we continue to shy away from negative exemplars, however, we will never fully understand the processes and strategies that constitute exceptional science teaching. Using what we learn from our explorations in teachers' classrooms, we must build--and refurbish--instructional models and assist preservice and inservice teachers with the development of the strategies and skills necessary to facilitate productive, student-centered discussions.

Inquiry is more than a procedure or a method. It is a process of investigating how or why or what and then making sense of the resultant findings. Direct teaching methods generally fail in this process because students are not given cognitive "permission" to personally and collectively go past the data to the meanings represented. National mandates encourage science teaching that reflects the "cultural traditions that characterize the practice of contemporary science" (NRC, 1996, p. 21). Talking and sense-making are essential features in that larger culture known as "scientific practice." As we consider how to encourage teachers to implement the tools and processes of inquiry in the science classroom, we must also ponder how we will help build understandings of the verbal interactions that assist students in making sense of--and constructing knowledge from--the information gathered during those investigations.

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A Community of Inquiry: Changing Roles for Teachers and Students

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Planning and implementing inquiry-based science instruction surfaces as an important theme of recent national reform documents (AAAS, 1993; NRC, 1996). Since inquiry is the heart of scientific practice, involving all students in authentic, developmentally appropriate, scientific investigations stands out as an important goal for science teachers at all levels. In fact, the National Science Education Standards states that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (NRC, 1996, p 31). Having students solve problems and do "real" science stems from the writings of John Dewey. Dewey believed that children learn from activity, through their own experiences, and from the writings of others (Dewey, 1938). A number of researchers have applied Deweyian ideas by fashioning projects and long-term investigations that are student-centered and contextualized (Krajcik et al., 1994; Roth, 1994; Roup, 1993; Schwab, 1976; Tinker, 1991).

However, orchestrating this kind of instruction in not a simple endeavor. "Teaching through inquiry" as well as "teaching inquiry" remains a rarity in science classrooms. One possible reason that inquiry-based instruction remains a vision in the reforms, but an enigma in the classroom may lie in the fact that teachers have few operational models. In searching for models of inquiry-based instruction I researched efforts to create inquiry-based environments in science classrooms from three perspectives.

First, as a member of a project-based science team of researchers and teachers, I studied George, an eighteen-year veteran teacher, over the course of a year. George struggled to involve his eighth grade students in solving contextualized, authentic problems when using two National Geographic Society (NGS) project-based units; *What's in Our Water?* and *Acid Rain* (National Geographic Kids Network, 1989,1991). One key constraint appeared to be the teacher's desire to maintain control over content, and reluctance to allow student collaboration to promote thoughtful engagement of ideas (Marx et al., 1994). George focused his students on carrying out specific procedures in hands-on activities, and often interpreted data himself rather than promoting an atmosphere of collaborative inquiry. This teacher referred to days he taught the NGS inquiry-based activities as "running the program". On other days the teacher referred to fact-laden lectures as "back in the book." Clearly this teacher viewed inquiry as separate from content, and his role as disseminator of information, not as collaborator with his students.

From a second perspective, that of a teacher-researcher, I gained an immense appreciation for the demands placed on teachers in designing and carrying out inquiry-based instruction. In a systematic study of teaching my own 8th grade group of physical science students, I was struck with the importance of situating the inquiry in authentic tasks and the challenge of changing roles from teacher-as-director to teacher-as-facilitator (Crawford, 1996). A main goal of instruction was to engage my students in designing and carrying out investigations of possible hazardous substances or "poisons" in their lives. It was my intention that students develop understandings of matter, changes in matter, and acids and bases through inquiry. Students initially struggled to work in groups and engage in thoughtful discussions. When the tasks were related to real-world issues and students were allowed to select their own questions to explore, the focus of student discussions shifted from debating how to follow <u>procedures</u> to debating and exchanging <u>ideas</u>.

In my middle school classroom, the balance between my giving too much direction and too little direction appeared critical to students taking responsibility. Thus, the teacher and students " playing active but often asymmetrical roles" appears a key condition of an inquiry-based classroom (Rogoff, 1994, p.209). In addition to the importance of situating instruction in authentic tasks and the interchange of roles, collaboration with experts outside the classroom appeared to spark students' engagement in inquiry. These experts included personal connections such as parents and community resource people as well as contacts made using telecommunications.

Finally, my third perspective on designing and carrying out inquiry-based instruction is that of a teacher-educator. Given that preservice teachers have to deal with all the complexities of the classroom as novices, and that inquiry-driven instruction is perhaps the most challenging form of instruction, the question emerges: How can preservice teachers construct these complex, inquiry-based learning environments? To explore this question I developed a collaborative case study of Denise, a preservice teacher. One of 22 cohort students in the twelve-month Masters in Arts in Teaching (MAT) program at a northwestern university, Denise was unique in her attempts to plan and carry out two inquiry-based units for a 10th grade general biology class.

In her first unit Denise engaged her students in designing and carrying out group aquaculture/hydroponics investigations as a context for learning the role biotic factors play in the balance of cycling (Crawford, 1997). To elucidate some of the forms of nitrogen in the cycle, Denise designed an innovative lab that focused students on testing nitrogen levels in horse manure and barn shavings. During this lab students followed procedures for extracting nitrogen from both aged and fresh manure, carefully recorded data, drew conclusions, and discussed sources of error. Although the lab protocol emphasized procedures, the inquiry was contextualized and afforded students opportunity to collaborate about problems related to the real-world. Later Denise reflected that students asked some interesting questions about mushroom growth and manure relationships, effects of burying manure, and how manure from different animals varied with the animal. Not as successful were Denise's lecture-style parts of lessons during which she targeted terminology and failed to engage students in interacting about conceptual understandings. One of her students wrote on a student response sheet that "you used some words and explained things without relating to what we would understand."

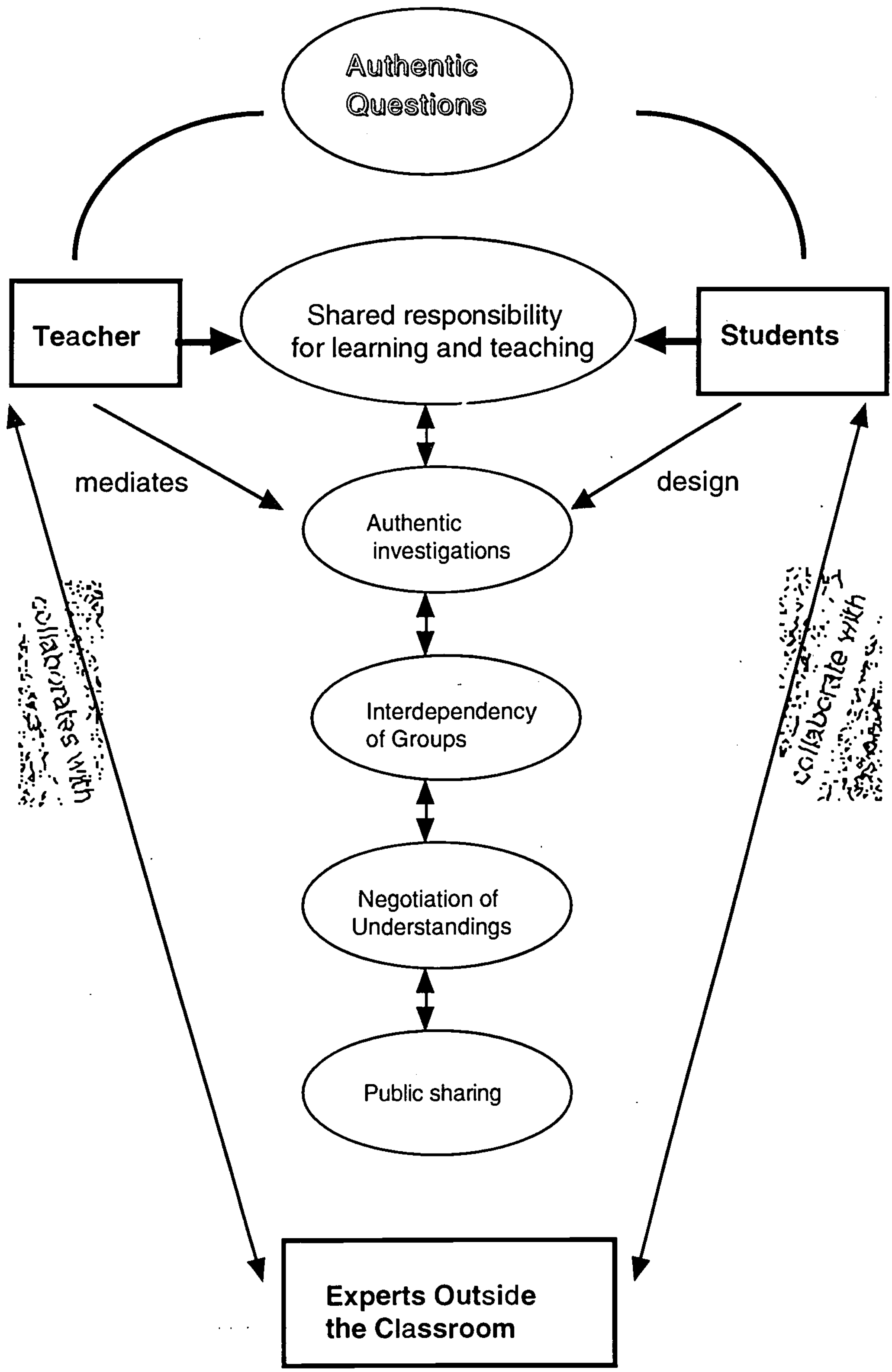
The central hydroponics/aquaculture investigation in Denise's unit was open-ended, allowing groups of students to manipulate variables (such as number of plants or fish) to determine the effect on nutrient levels. From the case study six key factors appeared to support Denise in her efforts to create an inquiry-based environment. These factors included: 1) prior research experience; 2) volunteering in project-oriented classrooms;
3) extensive planning and having a clear vision of her unit goals; 4) developing a trust relationship with her mentor teacher; 5) collaboration with experts outside the classroom; and 6) consistent and thoughtful reflection on practice.

From viewing successes and failures in classrooms from three perspectives, I have developed a belief that one kind of setting that has potential as a model for inquiry-based teaching is a learning community. In this *community of inquiry* students, teacher, and people outside the classroom collaborate to investigate authentic, real-world questions. Learning communities have been described as having both academic and social applications by involving students in debating ideas, distributing knowledge, and gaining social responsibility (Brown, Collins & Duguid, 1989; Rogoff, 1994). Key to developing a community of inquiry in a science classroom is directing the instruction with important questions. The exploration of these questions by the teacher and the students creates a context for the development of science concepts and an understanding of the nature of scientific inquiry.

A model suggesting the articulation of the roles of teacher and students in this community appears in Figure 1. In this model, the ovals represent critical elements of a community of learners based in the literature, while the rectangles represent the key players in this community of inquiry: the teacher, the students, and experts outside the classroom. Using the "poisons project" as a classroom-based example, the teacher selected an *authentic question* that focused the inquiry on important science concepts. Working in small groups students selected a possible poison to investigate, and then *designed investigations* involving data collection to answer student-generated sub-questions. For example, one group asked "Is the chlorine in the school swimming pool harmful?" Once groups made a final decision on which poison to study, group discussions moved from superficial kinds of talk to more thoughtful discussions centered on *negotiating understandings of concepts* and how to set up a fair test. The chlorine team researched secondary sources and elicited *help from outside resource people*, either through personal contact or using telecommunications. Over time (in some cases, this took six weeks) *groups developed interdependency* and began to rely on group members instead of only the teacher. Often students would share newly discovered information with the teacher, or with other members of the class, and *shared responsibility for learning and teaching. Public sharing* involved groups presenting findings in a formal presentation.

This paper suggests a model for inquiry-based instruction grounded in social-constructivist foundations. The model highlights teacher and student roles that differ from the traditional teacher as knowledge-giver and student as knowledge-receiver. Instead the teacher and students collaborate to develop conceptual understanding through a shared endeavor with experts outside the classroom. Admittedly, my perspectives are limited to case studies of three teachers; three classrooms. However, drawing from these three cases, I believe that to move from a vision of inquiry-based instruction to reality in the classroom requires teachers and students to see themselves as equally important participants, whose roles change over the course of the instruction as different expertise comes into play.

Figure 1. Roles of Teacher and Students in a Community of Inquiry



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Teacher Conceptions Of Inquiry And Related Teaching Practices

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Introduction

As Henson (1986) indicated, there appears to be much confusion over the definition of inquiry instruction. For example, it is sometimes defined as a group of science processes or a scientific method (Henson, 1986; Uno, 1990; American Heritage College Dictionary, 1992; Martin, 1997). From a different perspective, inquiry teaching and learning consists of more than scientific processes that learners apply to gather information that is interesting to them. It consists of scientific processes and content knowledge (National Research Council, 1996; McDermott & The Physics Education Group at the University of Washington, 1991; Gabel, 1997). From yet another viewpoint, inquiry teaching is an interrelationship of scientific processes, attitudes, and knowledge (Haury, 1995).

As Flick has stated earlier in this paper set, there has been a greater focus on student behaviors associated with inquiry instruction and lesser attention given to teacher actions. Particularly, there is little known of middle school science teachers' images and practices of inquiry teaching. This paper brings an empirical perspective to the paper set. Condensed from a larger study, it focuses on three urban middle school teachers who implemented inquiry teaching practices after completing an intensive professional development program. Specifically, the following questions are addressed.

1. After completing the professional development program, what were the teachers' definitions of inquiry?
2. How were the teachers incorporating inquiry teaching, as they define it, in their classrooms?

Overview of the Professional Development Program

A brief overview of the professional development program and the research methods that were used to gather the data provide a context for understanding the teachers' responses to these questions.

Recently, the National Science Foundation (NSF) has initiated comprehensive and multifaceted programs that support states in reforming science and mathematics education (Williams, 1994). For example, NSF's Statewide Initiative Systemic Initiative (SSI) for reforming mathematics and science has provided an opportunity for states to play a central role in meeting the educational needs of their students (Raizen, 1994). Ohio was one of the first ten states that received an SSI award.

Project Discovery, Ohio's Statewide Systemic Initiative, was jointly funded by the NSF and the Ohio General Assembly. It focused on systemic change in the teaching and learning of mathematics and science through the professional development of practicing science and mathematics middle/junior high school teachers (Kahle, Wilson, & Walters, 1990). The selected teachers participated in the life science, mathematics, or physics summer institute for six weeks, attended six one-day academic year seminars, and were observed during classroom visits made by regional leadership teams. After the completion of the academic year component, there was no structured follow-up for the teachers, although members of the regional leadership team may have contacted them.

The teachers in this study participated in the Physics by Inquiry Summer Institute. The summer physics instructors used an inquiry-based course, developed by University of Washington's Physics Education Group (McDermott & others, 1991), to deepen teachers' content knowledge and ability to use inquiry strategies (Kahle & others, 1990). Working in small cooperative groups, teachers developed a sound understanding of basic physical science concepts such as properties of matter, electricity, and light and optics through a variety of investigations. While there was little or no time for each group of learners to investigate their own questions, they proceeded through the modules in an autonomous fashion. The instructors used discrepant events and intensive questioning to facilitate learning. During the six Academic Year Seminars, the teachers focused on issues associated with inquiry instruction that included gender and ethnic equity, alternative and authentic assessment, uses of technology, and the implementation of inquiry teaching strategies. There were no lectures on the nature of inquiry teaching or learning.

Methods

Teacher Selection

The teacher participants were selected with an eye toward having them all teach in the same building. At the time of selection, the teachers taught at the same urban middle school in a large midwestern city. Even though Teacher 1 transferred to another middle school at the beginning of the study, she still taught in the same school district. Prior to their involvement with the SSI professional development program, all three teachers were trained to incorporate the Paidea philosophy into their science teaching.

Data Collection

The research questions required the use of qualitative research methods. The best known components of qualitative research are participant observation and semi-structured interviews (Lincoln & Guba, 1985,1989; Bogden & Bicklen, 1992; Ely, Anzul, Friedman, Garner, & Steinmetz, 1991). Therefore, classroom observations and interviews were used to generate data to investigate the selected teachers' inquiry definitions and teaching behaviors. In doing so, the researcher obtained thick descriptions (Geertz, 1973; Lincoln & Guba, 1989; Bogden & Bicklen, 1992) with which he constructed his understanding of how the Discovery teachers defined inquiry and how they taught within their classrooms. The researcher visited each of the three Project Discovery teachers over the period of eight months. Classroom visits were made two to five times a month, based on agreements between him and the teachers.

Data Analysis

The constant comparative method was used to analyze the interview data. Glaser & Strauss (1967) have outlined four steps in their discussion of this method. The steps include: (a) recording events in as many categories as possible, (b) merging categories and their properties that are similar in concept, (c) solidifying the theory that emerges from the comparison of incidents and categories in a way that modifications become fewer, and (d) writing about the theory that has emerged (Glaser & Strauss, 1 967). Qualitative data analysis (Nonnumerical, Unstructured Data Indexing, Searching, and Theorizing [NU-DIST]) software was used to help manage and categorize the data throughout this analysis. All transcriptions of the interviews were entered via keyboard into Microsoft Word. After dividing its contents into text units, each interview was saved as a text file, introduced to NUD-IST, and entered into an archival system that was created with identifying notes and descriptive details about the data source.

As categories were created, they were entered into the theoretical tree as nodes, that served as the index system. The report for each node provided the titles, definitions, memos, and text units associated with that node. These data were sorted further into subcategorize or moved to a new node in a manner in which the researcher's claims were consistent with the data. The node reports were the foci for further discussions with the teachers. The researcher revised assertions and misconceptions that were inconsistent with relevant data. The use of negative case data provided caveats to his assertions. In doing so, the theoretical tree was altered or further explained.

Results

Teachers' Definitions of Inquiry

During the interviews, the teachers provided brief definitions of inquiry. In their most simplistic interpretation, their responses were mostly alike. Researcher: What is your definition of inquiry? Teacher 1: I think inquiry is asking questions, discovering, and finding ways to answer those questions... that you might have about some things, situations, processes, and arriving at the answer. It might not be the answer for everyone, but it might bring about new questions. Inquiry is like trying to satisfy that curiosity, basically (Interview, 10/1 7/94). Teacher 2: A lot of people say, and I've heard this, "Hands on minds on". I like that because it's fairly simple. An extension of that would be it involves some discussion and debate among and between students. Giving ideas, being open to ideas, and testing ideas. You know, testing their beliefs (Interview, 10/ 17/94). Teacher 3: Inquiry is creating the situation to allow students to learn by actively experiencing something, rather than me telling them something didactically (Interview, 10/17/94J. The teachers' inquiry definitions were alike in that they depicted students as active learners. In all cases, students should be mentally and physically engaged in their learning. Also, each definition emphasized the use of science processes. Only Teacher 1 suggested that content knowledge and a scientific attitude were important components of inquiry. Each teacher believed that her experiences in the SSI professional development program shaped her definition.

Discovery Teachers' Practices

After several lesson observations, the researcher asked the teachers to describe their typical lessons. Based on their responses and the patterns of observed events that emerged in the class activities, the researcher created summaries of typical lessons. In discussing these overviews with the teachers, the researcher learned what typically happened in the teachers' classrooms. Discovery teachers reported that they typically incorporate some inquiry teaching strategies in their lessons. For example, Teacher 1 indicated that her students were active participants during the science lessons. The following dialogue represents a type of exchanges that sometimes took place between the students and her.

JJ: You inhale. You inhale oxygen.
Bo: Yes. You can inhale it but it doesn't fill up the room.
Ms. Cole: But does it have volume?
Bo: Yeah.
Ms. Cole: Does it take up space?
Bo: It doesn't fill up the room.
Ms. Cole: But does it take up space?
Bo: Yeah.
JJ: Yes! That's what I said.
Bo: But you can't measure it with a ruler.

In this case, Teacher 1 had joined a group who were debating some characteristics of gaseous substances after competing an investigation. As suggested in the dialogue, she asked many questions that required her students to construct, justify, and defend their conceptions. Very little time was devoted to telling students exactly what to think and do.

When asked to describe her typical lessons, Teacher 2 responded, "I move around the room a lot and ask them questions. [The students] have to support their beliefs with observations from their lives, or from labs, or things that they see or witness. Visits to her classroom indicated that lab activities and investigations were generally the mode of instruction. She developed and distributed written activity sheets that guided the students' through the activities. During their investigations that were generally planned by Teacher 2, the researcher observed the students working in an autonomous fashion. They held discussions within their groups without the teacher's guidance. At various points in the lessons, students approached a cart of materials or secured materials from the lab supply room to gather the items needed for their investigations. Also, they had access to and used textbooks or other printed resources as needed. At various stages of the group discussions, a group member solicited assistance from the teacher. Otherwise, Teacher 2 would join a group without invitation. While Teacher 3 used didactic methods to review concepts or to reinforce learning, most of the class time was spent supervising and assisting her students who were conducting investigations. During the lab investigations, she visited student groups frequently. Meanwhile, the groups proceeded through the assigned activities more or less at their own pace. Teacher 3 met with the groups on an as-needed basis. In describing her typical lesson, Teacher 3 indicated this to be her normal teaching behavior. Teacher 3: In general, a typical lesson is more of what is going on today, where people were at different stages in the procedures that they were doing. It was totally non-teacher centered. They determined when they needed my assistance rather than me determining anything like that. At this point, that's more my typical lesson (Interview 10/27/94). Similar to the behavior of her colleagues, Teacher 3 questioned the students about what they were doing rather than telling them what to do. These questions served different purposes. Sometimes they were used to address discrepancies in explanations, assess student learning, guide students beyond superficial responses, or to point out inaccuracies in data collection.

Discussion

The Physics by Inquiry modules that were used in the Physics by Inquiry institute place equal stress on scientific processes and content. Students were characterized as active learners who conduct investigations and use their observations to construct an understanding of physical concepts. In addition, the types of reasoning that are central to the work of scientists were developed through the use and interpretation of scientific representations (i.e. graphs and diagrams). Also, the students were provided with opportunities to relate their laboratory experiences to real world phenomena (McDermott, 1991). There is a close fit between the three middle school teachers' definitions of inquiry and the one that was implied in the Physics by Inquiry course materials. In both cases, the student is an active participant in the learning process. To place both perspectives in present day terms, inquiry consists of hands-on and minds-on activities. The hands-on component includes the manipulation of materials and data during an investigation. The minds-on component consist of reasoning and mental constructions that are defended or altered in social negotiations of meaning. While the teachers credited their professional development experiences as the basis for their inquiry definitions, they explained that their definitions were personal ones. For the most part, the teachers implemented instructional practices that were consistent with their inquiry definitions. They pressed their students for viable explanations through the use of open-ended questions and provided opportunities for their students to debate findings and conclusions. Their lessons were primarily investigations and experiments that required students to use one or more scientific processes. None of the teachers spent any significant amount of time seated at or behind her desk. Also, they refrained from lecturing and other teacher-centered behaviors to a large extent.

Conclusion

The findings of this study contrast sharply with those of Kozol (1991). In an informal account of the inequities that existed between America's urban schools and their affluent suburban counterparts, he included a vignette that described science instruction in the same school district as the one used for this study. Within a particular eighth grade science classroom, Kozol described a teacher who predominantly used didactic instruction methods. Specifically, she religiously followed a printed lesson plan, engaged her students in a superficial investigation, and asked only knowledge level questions. As was previously presented, the teachers in this study practice inquiry teaching that provides their students with very different learning opportunities. Therefore, Kozol (1991) may have over generalized the type of instruction that takes place in many of the classrooms in this school district. The teachers in this study were able to articulate a definition of inquiry. addition, they typically taught in a manner that was consistent with those definitions. However, there are other questions that need to be studied to avoid the oversimplification drawn by Kozol. Specifically, the teachers initially had difficulty defining inquiry. Were their conceptualizations a direct result of the ongoing conversations with the researcher? How likely is it that the teachers would have been able to articulate a definition of inquiry on their own? How long will the teachers use inquiry teaching as a typical mode of instruction? Even without answers to these questions, there is evidence that inquiry teaching occurs in some urban middle school classrooms.

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