UNDERSTANDING SCIENTIFIC INQUIRY

The effective use of scientific inquiry is one hallmark of outstanding science teachers. Science teachers who use this approach develop within their students an understanding that science is both a product and a process. Not only do the students of these teachers learn the rudimentary knowledge and skills possessed and employed by scientists, they also learn about the nature of science. There are many reasons why established in-service science teachers fail to teach using inquiry. Among these reasons is that science teachers often do not themselves possess a holistic understanding of the scientific endeavor. This in all likelihood stems from the nature of traditional science teaching at the university level that commonly uses a didactic—teaching-by-telling—approach.

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In many teacher education programs little attention is given to how the processes of scientific inquiry should be taught. It is often assumed that once teacher candidates graduate from institutions of higher learning they understand how to conduct scientific inquiry and can effectively pass on appropriate knowledge and skills to their students. Scientific inquiry processes, if formally addressed at all, are often treated as an amalgam of non-hierarchical activities. There is a critical need to synthesize a framework for more effective promotion of inquiry processes among students at all levels. This chapter presents a hierarchy of teaching practices and intellectual processes with examples from buoyancy that can help physical science teachers promote an increasingly more sophisticated understanding of inquiry among their students.

As science teachers introduce inquiry-oriented instruction to students who have not previously experienced it, they sometimes encounter resistance from students, parents, administrators, and even teaching colleagues. In advance of and following changes in classroom procedures, it is imperative that teachers properly consider and take actions to set and maintain an appropriate atmosphere. Teachers must also be prepared to react to negative external influences that might originate with parents, administrators, and fellow teachers. This chapter also describes forms of resistance, and offers techniques for climate setting that, if used properly, can alleviate concerns and help create a classroom atmosphere conducive to student learning via scientific inquiry.

Scientific Inquiry

Stephen is a student teacher at a local high school. He is nearing graduation with a degree in physics teaching, but comes from a university where didactic teaching is indirectly promoted through his physics content courses, and inquiry teaching is ineffectively promoted during his science teaching methods courses. Stephen begins his lesson with the statement, "Today we are going to learn about the law of reflection." He tells his students that light travels in a straight line, and that when it hits a reflecting object such as a mirror, there is a particular relationship between the angle of incidence and the angle of reflection. He talks about the normal line, and how the angles of incidence and reflection are measured relative to the normal line. Finally, he states, "You see, the angle of incidence equals the angle of reflection." He then uses a bright green laser pointer in a darkened room to demonstrate this relationship.

Fatima is also a student teacher. She is also about to graduate from the same physics teacher education program where now, years later, inquiry practice is promoted indirectly through content courses, directly in introductory laboratory activities, and directly in science teaching methods courses. She begins her class by providing students with plane mirrors and two different colored threads emanating from a point at the base of the mirror. She tells the students to stretch one string and hold it in place with a pushpin. She then tells the students to arrange the other string in such a way that it lines up with the image of the first string in the mirror. She directs the students to look into the mirror along the line of sight of the second string. What do they see? The image of the pushpin! Fatima prompts, "Why do you see the image of the pushpin?" The students reply, "Because light from the pushpin hits the mirror, and is reflected to our eyes along the path of the thread." The path of the light thus being firmly established, students are asked to draw a line perpendicular from the mirror at the point where the two strings converge, and to measure the angle of the incoming and outgoing light rays. Fatima then asks the students, "What is the relationship between the angles of the incoming and outgoing light rays?" They respond that the two angles are equal.

The key difference between these two student teachers and their lessons is substantial. In Stephen's case, he is teaching by telling. In Fatima's case, she is helping students to construct their knowledge from experience. These differences may well result from different understandings of what the phrase "scientific inquiry" actually means. Only by having a clear expectation of both teacher and student performance can one objectively say whether or not a teacher's practice is inquiry oriented.

Defining "Scientific Inquiry"

Scientific inquiry has been variously defined. For instance, the *National Science Education Standards* defines scientific inquiry as follows:

> 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. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (NRC, 1996, p. 23)

Project 2061 gives a slightly different definition in *Benchmarks for Science Literacy*:

> Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of "making a great many careful observations and then organizing them." It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as "the scientific method." It is much more than just 'doing experiments,' and it is not confined to laboratories. More imagination and inventiveness are involved in scientific inquiry than many people realize, yet sooner or later strict logic and empirical evidence must have their day. Individual investigators working alone sometimes make great discoveries, but the steady advancement of science depends on the enterprise as a whole. (American Association for the Advancement of Science [AAAS], 1993, p. 9)

The National Science Teachers Association defines scientific inquiry somewhat differently still:

> Scientific inquiry is a powerful way of understanding science content. Students learn how to ask questions and use evidence to answer them. In the process of learning the strategies of scientific inquiry, students learn to conduct an investigation and collect evidence from a variety of sources, develop an explanation from the data, and communicate and defend their conclusions. (NSTA, 2004, p. 1)

While such statements are true—and several specific examples of scientific inquiry are given in the associated texts—these broad characterizations and specific examples are of little help to science teachers and teacher candidates who are looking for a detailed operational definition that can serve as a guide for inquiry-oriented instruction.

For the purpose of operationally defining scientific inquiry at a level appropriate for secondary schools, the author provides a listing of fundamental scientific inquiry skills in Table D-1. These processes have been roughly organized into "stages" of scientific inquiry, and are patterned on the inquiry processes described in Wenning (2007).

While the listing in Table D-1 might at first appear to be based on a rather naïve understanding of the nature of scientific inquiry, it was developed in light of works by Kneller, Bauer, Wynn, Popper, Gould, Root-Berstein, Sayer and a number of others whose writings have been included in *Science and Its Ways of Knowing* edited by Hatton and Plouffe (1997). The author is fully cognizant of the fact that there is no "scientific method" per se, and that science more often than not develops along ways that are not consistent with the traditional Baconian approach. Further, this listing was developed in light of the fact that most scientific work at the secondary school level is not driven by hypothesis/theory development or model generation, but that typically data are collected for the purpose of formulating principles or developing empirical laws. Finally, this listing was prepared with the understanding that not all inquiry processes will be experimental in nature. Sometimes logic will be used to draw scientific conclusions on the basis of evidence. At other times scientific conclusions simply will be based on repeatable, verifiable observations. Additionally, not all scientific inquiry skills will be used in any one investigation. Scientific inquiry based on observations will likely differ significantly form scientific inquiry based on experimentation. Geologist, biologists, chemists, and physicists, for example, all have different approaches to conducting scientific investigations and will use various elements of the listing to different degrees.

Table D-1

A Listing of Scientific Inquiry Skills Inherent in the Stages of Scientific Inquiry

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Stages of Scientific Inquiry:

- Identify a problem to be investigated.
- Using induction, formulate a hypothesis or model incorporating logic and evidence.
- Using deduction, generate a prediction from the hypothesis or model.
- Design experimental procedures to test the prediction.
- Conduct a scientific experiment, observation or simulation to test the hypothesis or model:
    - Identify the experimental system
    - Identify and define variables operationally
    - Conduct a controlled experiment or observation
- Collect meaningful data, organize, and analyze data accurately and precisely:
    - Analyze data for trends and relationships
    - Construct and interpret a graph
    - Develop a law based on evidence using graphical methods or other mathematic model, or develop a principle using induction
- Apply numerical and statistical methods to numerical data to reach and support conclusions:
    - Use technology and math during investigations
    - Apply statistical methods to make predictions and to test the accuracy of results
    - Draw appropriate conclusions from evidence
- Explain any unexpected results:
    - Formulate an alternative hypothesis or model if necessary
    - Identify and communicate sources of unavoidable experimental error
    - Identify possible reasons for inconsistent results such as sources of error or uncontrolled conditions
- Using available technology, report, display, and defend the results of an investigation to audiences that might include professionals and technical experts.

Note. This framework is suggestive, not definitive.

Characterizing Scientific Inquiry

Even with the formal definitions of scientific inquiry and the stages of scientific inquiry given in Table 1, some student teachers and in-service teachers might still get it wrong. Studies of teachers new to inquiry-based instruction show that many novice candidates have misconceptions about inquiry and misunderstandings about the role of both teacher and students in inquiry-based instruction (Reiff, 2002). Sometimes one or more non-examples can help to make clear what scientific inquiry is not. Some teachers think that having students respond to lots of questions constitutes inquiry. They ask questions that lead students in a stepwise fashion to a particular solution. This does not constitute authentic inquiry. Scientific inquiry is NOT a teacher asking lots of questions, and neither is it having students solve "puzzles" at the end of a textbook chapter, looking up vocabulary definitions, or completing worksheets. And is it not letting students run wild without the benefit of a curriculum or instruction.

Rankin (2000) points out that there are a number of strongly held misconceptions related to inquiry instruction. Among these are the following:

- *Inquiry is an either/or proposition*—While proponents of inquiry often promote it to the exclusion of didactic methods, this is not to suggest that inquiry is an all-or-nothing proposition. In an effort to adequately address the depth-versus-breadth problem, it is appropriate to provide roughly equal amount of instruction that are inquiry oriented and didactic. Approaches such as lectures, readings, discussions, demonstrations, videos worksheets, problem sets, and such do have their place even in an inquiry-oriented classroom. Didactic approaches will help students learn the broader content of science while inquiry approaches will help students better learn the processes of science. More often than not, available instructional materials determine which topics are taught in depth and which in breadth in the typical science classroom.

- *All hands-on activities constitute inquiry; all inquiry activities are hands-on*—Not all hands-on activities constitute inquiry. For instance, students following step-by-step instructions to perform a laboratory activity in cookbook fashion

might appear to be doing inquiry, but they are merely following instructions that overtly mimic inquiry. Students following a set of cookbook-like instructions rarely come to understand the inquiry process. Students can conduct different types of inquiry, only some of which require working with materials. Developing hypotheses or models, for instance, are intellectual processes that are part of scientific inquiry but that do not necessarily require the use of manipulatives. Inquiry will allow students opportunities to identify questions, and develop and follow procedures to answer those questions.

- *A dichotomy exists between content and process*—Science is a combination of both process and product; it is a way of constructing knowledge from experience. To separate ways of knowing from the knowledge itself is, in effect, to teach on the basis of mere belief. Science teaching based on authority is more akin to preaching than teaching. Effective science teachers will often move back and forth between practices that emphasize one approach over the other in order to provide sufficient understanding of both the processes and products of science.

- *Inquiry teaching is chaotic*—Appropriate inquiry teaching is often structured. In these cases, the teacher prepares conditions under which students can best learn. The teacher is seen as a mentor, a facilitator of learning, and not as a wise sage who provides answers to all student questions. Students take responsibility for their own learning. Teachers help students develop their own understandings, and address their misunderstandings. During inquiry processes teachers will move around the classroom assisting students in making clarifications, and asking questions that can lead students to a fuller understanding of the subject matter.

Fortunately, the *National Science Education Standards* (NRC, 1996) gives a detailed explanation of what it means to teach using inquiry when they characterized the actions of both teachers and student:

The teacher:

- presents lessons that are student-centered (teacher builds on knowledge students bring to or develop from the learning situation; teacher helps students construct meaning from experiences; focus on student as active inquirer rather than passive receiver of knowledge).

- focuses on one or more questions as the active mode of inquiry (lesson, many guiding questions; lab, one guiding question).

- encourages student thinking and questioning.

- engenders debate and discussion among students.
- provides a variety of levels and paths of investigation.
- is a mentor and guide, giving as little direction as possible.
- shows an active interest in students and promotes an active quest for new information and ideas.
- avoids appeals to authority and avoids acting as an authority figure.
- maintains a classroom atmosphere conducive to inquiry.
- places emphasis on "How do I know the material of this course?" rather than "What must I know in this course?"
- uses appropriate questioning skills such as wait time, variety, distribution, and formulation
- responds appropriately to what students have to say or do that contributes to lesson

The students:

- make observations and collect data.
- formulate predictions based on observations and create and conduct experiments in order to validate conclusion.
- work out relationships of cause and effect.
- relate independent and dependent variables to establish meaningful relationships.
- use reasoning ability.
- make decisions and draw conclusions on the basis of data.
- defend conclusions on the basis of data.
- interpret collected data or observations.
- devise their own way to report their findings to class members.

Teaching via inquiry is the backbone of the current science education reform movement. While some teacher candidates and in-service science teachers might be skeptical of the use of inquiry as an effective instructional practice, or dismiss it because it reduces the amount of content that can be "covered" (a word that, ironically, means to hide from view), a strong case can be made for incorporating inquiry practice into day-to-day instruction. Every teacher candidate and in-service teacher should be fully aware of the case that can be made in favor of incorporating inquiry into the practices of science instruction.

Making the Case for Scientific Inquiry

A strong case can be made on behalf of teaching science using inquiry. The points below stem from sources as diverse as Francis Bacon's *Novum Organum* of 1620 (Anderson, 1985), *Goals of the Introductory Physics Laboratory* (AAPT, 1998), and *Inquiry and the National Science Education Standards* (NRC, 2000). Among the key philosophical arguments and research-based claims that can be made in favor of inquiry-oriented instruction are the following:

1. *Through inquiry-oriented instruction students learn about science as both process and product***.** Understanding science consists of more than just knowing facts. An authentic science education will help students understand what is known as well as how it is known. Like the first true scientists, we reject Aristotelian scholasticism that would have us learn on the basis of the authority of others rather than from scientific observations, experiments, and critical thinking. Properly constructed inquiry-oriented laboratory activities that include some experience designing investigations engage students in important hands-on, minds-on experiences with experimental processes. As

with any well-rounded education, we should seek to teach our students how to think rather than what to think.

2. *Through inquiry-oriented instruction students learn to construct an accurate knowledge base by dialoguing***.** Regardless of the type of classroom instruction, a student will build new knowledge and understanding on what is already known and believed. A student does not enter the classroom as a *tabula rasa*—a blank slate—as philosopher John Locke first suggested. Rather, students come to a classroom with preconceived notions, not all of which are correct. In the inquiry-based classroom, students formulate new knowledge by modifying and refining their current understanding and by adding new concepts to what they already know. In an inquiry-oriented classroom, the quality of classroom discourse is dramatically improved with the use of such things as whiteboards and Socratic dialogues. Teachers conducting Socratic dialogues come to understand what students know, and can identify, confront, and resolve preconceptions that limit students' understanding.

3. *Through inquiry-oriented instruction students learn science with considerable understanding*. Rather that merely memorizing the content of science only to be rapidly forgotten, students learning science through personal experience learn with increased conceptual understanding. Appropriate classroom and laboratory activities help students master basic physics concepts. Experiential learning results in prolonged retention, and refines students' critical thinking and problem-solving skills helping them improve standardized test scores. A deep understanding of subject matter is critical to the ability to apply knowledge to new situations. The ability to transfer learning to new situations is strongly influenced by the extent to which students learn with understanding. Learning

via inquiry is learning that lasts, and not learning that merely suffices for the demands of schooling.

4. *Through inquiry-oriented instruction students learn that science is a dynamic, cooperative, and accumulative process*. The work of scientists is mediated by the social environment in which they interact with others; the same is true in the inquiry-oriented classroom. Directly experiencing natural phenomena and discussing results helps students understand that science is the work of a community of real people, and that in science "genius" does not always matter—great progress can be made following the accumulation of many small steps. While the process of inquiry is slower than direct instruction, with its sometimes non-linear approach (allowing for the detection and correction of mistakes) it is more realistic and gives a better understanding to students of the social context of science. Only in cooperative settings such as laboratory work can students develop collaborative learning skills that are critical to the success of so many real world endeavors.

5. *Through inquiry-oriented instruction students learn the content and values of science by working like scientists*. The way we educate our students has profound implications for the future. We can encourage them to show submission of intellect and will thereby becoming uncritical consumers of information, or we can help them learn the nature and values of science by having them work like scientists gaining a scientific worldview. Do not we want to graduate students who are rational and skeptical inquirers rather than intellectual plebiscites? A great deal of student learning should come directly from experience. The inquiry approach avoids presumptive authority, and inculcates students with a healthy skepticism. Inquiry-oriented instruction helps students confront

pseudoscience by arming them with the skeptical, rational philosophy of Bayle, Bacon, Pascal, Descartes, and Locke.

6. *Through inquiry-oriented instruction students learn about the nature of science and scientific knowledge*. Students come to know how scientists know what they know. They learn to adopt a scientific epistemology. Students are moved from mere uncritical belief to an informed understanding based on experience. Inquiry-oriented instruction helps students to understand the role of direct observation, and to distinguish between inferences based on theory and on the outcomes of experiments. Inquiry-oriented laboratory work helps students develop a broad array of basic tools of experimental science, as well as the intellectual skills of critical thinking and problem solving. Students learn to use nature itself as the final arbiter of claims.

Lastly, teaching science through inquiry can serve as an important motivational tool for getting students to consider careers in the sciences to helping maintain classroom control. Students who experience the joy and wonder of creativity and discovery are more likely to become scientists (or science buffs) than any other process.

Teachers and teacher candidates need to realize that scientific inquiry is suitable subject matter for study at all grade levels. First and foremost, only when a science teacher understands essential concepts, methods of inquiry, use of technology, structure of science and the science disciplines can he or she create meaningful learning activities for students. Teachers cannot share what they themselves do not possess. Additionally, teachers should be aware that students often do not come to understand scientific inquiry processes merely through "example." Teachers can help students learn about scientific inquiry processes both implicitly and explicitly. Students will learn more by directly

speaking with the teacher and each other about the nature of scientific inquiry, its tenets and assumptions, and processes and products.

Types of Scientific Inquiry

As a study of the history of science shows, there are many types of scientific inquiry. Scientific inquiry can range from making passive observations of a natural phenomenon, to finding the relationship between two variables in a controlled experiment, to something as complex as developing and testing hypotheses in an attempt to find out why a particular relationship between two variables holds.

The Physics and Astronomy Education Research (PAER) Group at Rutgers University has identified three forms of experimental inquiry that would be appropriate to many middle and high school physical science classrooms: (a) an observation experiment used to investigate a new phenomenon such as determining if there is a relationship between pressure and temperature of a gas when its volume is kept constant, (b) a testing experiment used to test a hypothesis or model such as whether or not an object always moves in the direction of the net force exerted upon it, and (c) an application experiment used to solve a practical problem or determining a physical quantity such as finding the coefficient of static friction between two surfaces.

While these are suitable types of inquiry for middle and high school science students, a teacher would be well advised to understand that not all students can conduct these forms of inquiry without having an understanding of various levels of scientific inquiry.

Levels of Scientific Inquiry

The strength of a concept rests in its ability to organize information. What at first appears to be disorganized body of knowledge is made comprehensible and useful when a unifying framework is developed. Scientific inquiry is often presented as a jumble of disorganized but interrelated procedures. Teachers and teacher candidates are regularly encouraged to use inquiry processes in demonstrations, lessons, and labs, but there is little organizational pattern provided to relate inquiry to these approaches. This often leaves teachers and teacher candidates with questions about differences between demonstrations, lessons, and labs, and what role inquiry plays in each. For instance, could not a good lesson consist of an interactive demonstration? If so, how would the interactive demonstration differ from a lesson? A good lab activity would seem to be a good lesson. So, what is the difference between a lesson and a lab activity? The differences between demonstrations and labs seem readily apparent; the real problem resides in defining the transitional phase between a demonstration and a lab—the lesson. Clearly, there must be identifiable differences between all such activities, but science education literature in this area appears to make no clear distinction between them with but a few rare exceptions. (See for instance Colburn, 2000; Staver & Bay, 1987.)

The NRC, AAAS, and NSTA, while providing a definition of scientific inquiry, provide precious little guidance about how inquiry processes are to be taught to teacher candidates or otherwise uninformed teachers. It evidently is assumed that once a teacher candidate learns how to conduct inquiry in the university setting (often a poor assumption given the generally didactic nature of science lectures and the common use of "cookbook" laboratory activities) that procedural knowledge will somehow flow from

the teacher to his or her students. This is much akin to the incorrect assumption that problem-solving skills can be readily learned through observation of numerous examples. At least one case study shows that this is not always the case (Wenning, 2002). The scientific reform movement literature is replete with calls for teachers to use inquiry as a regular part of teaching practice. Unfortunately, this does not always happen. One of the chief reasons cited in the literature about the failure of science teachers to implement inquiry practice is that the teachers themselves are inadequately prepared to use it (Lawson, 1995). Science education literature appears to be devoid of information about how one actually goes about teaching inquiry skills—one of the most central goals of science teaching.

Randomly speaking with teacher candidates about inquiry processes will not help them teach in such a way that systematically will lead to their students becoming scientific inquirers. A hierarchy must be provided for effective transmission of this knowledge. Failure to do so can result in undesirable consequences. For instance, the author's recent experience with a secondary-level student teacher resulted in the revelation of a significant pedagogical problem. The student teacher was supposedly well prepared to use various inquiry processes with his high school physics students, but his teaching practice resulted in confusion. The physics students being taught were rather new to inquiry, the cooperating teacher having used more of a didactic approach with traditional lecture and "cookbook" labs prior to the student teacher's arrival. The student teacher gave his students a clear performance objective, provided the students with suitable materials, and essentially told them to "do science." The students leapt out of their seats and moved into the lab with joyful anticipation. After about 15 minutes of lab

activity it became painfully obvious to both the student teacher and the university supervisor that the students were floundering. One student called out, "This is a waste of time!" Another vocalized, "We do not know what's going on." Yet another blurted, "We need some help over here." It turned out that the students had no idea how to "do science" at the specified level of performance. It became clear to the teacher educator that this student teacher needed to know more about how to teach students to "do science." Student teachers—indeed all science teachers—must have a comprehensive understanding of the hierarchical nature and relationship of various pedagogical practices and scientific processes if they are to teach science effectively using inquiry.

Basic Hierarchy of Pedagogical Practices—Based on the earlier work of Colburn (2000), Staver and Bay (1987), and Herron (1971), the author here proposes a more extensive continuum to delineate the levels of pedagogical practice and offer some suggestions as to the nature of associated inquiry processes. Table D-2 shows the various levels of inquiry mentioned thus far in relation to one another. It should be noted from the table that levels of inquiry differ primarily on two bases: (a) intellectual sophistication, and (b) locus of control. Thus the locus of control shifts from the teacher to the student moving from left to right along the continuum. In discovery learning the teacher is in nearly complete control; in hypothetical inquiry the work depends almost entirely upon the student. That the intellectual sophistication likewise increases continuously from discovery learning through hypothetical inquiry is less evident because someone involved in the experiment, either teacher or student, is cognizant of the high degree of sophistication required to conduct any activity. The thought processes required to control an activity are always present but are shifted from the teacher to the student as practices

progress toward the right along the continuum. As will be seen, inquiry labs and hypothetical inquiry can be subdivided further.

Table D-2

A Basic Hierarchy of Inquiry-Oriented Science Teaching Practices

Discovery Learning	Interactive Demonstration	Inquiry Lesson	Inquiry Lab	Hypothetical Inquiry
Low	← Intellectual Sophistication →			High
Teacher	← Locus of Control →			Student

Note. The degree of intellectual sophistication and locus of control are different with each level of pedagogical approach.

In the following sections, each practice will be defined and operationally described. The author will use a common topic from physical science—buoyancy—to demonstrate how different levels of pedagogical practice can be employed to address this important physical topic and use appropriate pedagogical practices to effectively promote the learning of inquiry processes. Examples of the various types of pedagogical practices will be provided as sidebar articles.

Discovery Learning—Discovery learning is perhaps the most fundamental form of inquiry-oriented learning. It is based on the "Eureka! I have found it!" approach. The focus of discovery learning is not on finding applications for knowledge but, rather, on constructing knowledge from experiences. As such, discovery learning employs reflection as the key to understanding. The teacher introduces an experience in such a way as to enhance its relevance or meaning, uses a sequence of questions during or after

the experience to guide students to a specific conclusion, and questions students to direct discussion that focuses on a problem or apparent contradiction. Employing inductive reasoning, students construct simple relationships or principles from their guided observations. Discovery learning is most frequently employed at the elementary school level, but at times it is used even at university level.

Example of Discovery Learning—In this activity, students are first questioned about the phenomenon of buoyancy. They are asked to recollect certain everyday experiences, say, while swimming and manipulating such things as beach balls or lifting heavy submerged objects such as rocks. If students have not had such experiences, they are asked to submerge a block of wood under water. They perceive the presence of a "mysterious" upward or buoyant force. They then can be led, with effective questioning strategies and instructions, to develop the concept of buoyant force. The teacher might then present one or more guiding questions relating to sinking and floating, "What determines whether an object floats or sinks in water?" The teacher provides students with objects of varying density, suggesting ways to use them. Perhaps the objects are labeled with density values if the students have already developed an understanding of the concept. Various objects are then placed in a container filled with water. Some sink, others float. The students are asked to state a relationship between the densities of the objects and whether or not they sink or float in water. If provided with the density of water, students can generate a more concise statement of sinking and floating—that objects with densities less than that of water float in water whereas objects with densities greater than that of water sink in water. Alternatively, students conclude that objects with densities of less than one float in water, whereas objects with densities greater than one sink in water.

Interactive Demonstration—An interactive demonstration generally consists of a teacher manipulating (demonstrating) a scientific apparatus and then asking probing questions about what will happen (prediction) or how something might have happened (explanation). The teacher is in charge of conducting the demonstration, developing and asking probing questions, eliciting responses, soliciting further explanations, and helping students reach conclusions on the basis of evidence. The teacher will elicit preconceptions, and then confront and resolve any that are identified. The teacher models at the most fundamental level appropriate scientific procedures, and thereby helps students learn implicitly about inquiry processes.

Example of Interactive Demonstration—A guiding question might be, "What is the relationship between the weight of an object suspended in air, the weight of that object suspended in water, and the buoyant force?" The teacher restricts the discussion to sinking objects, then brings out a small spring scale and asks how the spring scale might be used to measure the buoyant force on a sinking object. Clearly, the buoyant force appears to operate in the upward direction, but that the object in question still has a propensity to sink when suspended in water. If the students are familiar with force diagrams, they might quickly conclude that for objects that sink, the weight is greater than the buoyant force.

Students then are asked to press down on a floating object. They experience the upward buoyant force. If students are careful observers, they can see that buoyant force increases as more and more of the volume of the floating body is submerged in the water. Once the object is entirely submerged, the buoyant force appears to become constant. For floating objects held entirely immersed in water the buoyant force is

greater than their weight. When such objects are released, they float upward until their weight is precisely counterbalanced by the buoyant force; the object is then in an equilibrium state.

With appropriate questioning, the teacher can move the discussion from one that is purely qualitative (conceptual) to one that is more quantitative. Eventually, the students realize that the buoyant force (F_b) for sinking objects is the difference between the weight of the object in air (W_a) and the weight of the same object when completely immersed in the fluid (W_f). This will then lead to the students concluding that the difference between these two values is the buoyant force. When asked to define that relationship mathematically, students will quickly respond by providing an equation similar to $F_b = W_a - W_f$ where a positive F_b is defined as acting in the upward direction. Students then use this relationship to find the buoyant force on a floating object. Consider the following "dialogue" in relation to this interactive demonstration. (For more details about this general approach see Gang, 1995.)

- Note: Place a metal object on a spring balance with the object suspended in air above the surface of a container full of water.

Q. How can one determine the buoyant force experienced by an object submerged in a liquid?

- Note: Following student responses, submerge the object entirely in water.

Q. Why is there a difference between weight of this object in air (W_a) and its weight when suspended in the fluid (W_f)?

- Note: It's because of the buoyant force.

Q. How might we calculate the buoyant force due to the liquid given the object's weight in air and in water?

- Note: $F_b = W_a - W_f$. Next, slowly immerse a wooden object on a scale into the water. Read out the changing weight until it reaches zero.

Q. What is the buoyant force exerted on a piece of wood floating on the surface of the water?

- Note: $F_b = W_a$ because $F_b = W_a - 0$

After this interactive demonstration, a series of questions is then directed at students asking them to predict which physical factors affect buoyancy.

Inquiry Lesson—In many ways the inquiry lesson is similar to the interactive demonstration. However, there are several important differences. In the inquiry lesson, the emphasis subtly shifts to the process of scientific experimentation. The pedagogy is one in which the activity is based upon the teacher taking charge of providing guiding, indeed leading, questions, and giving guidance through appropriate questioning strategies. The teacher places increasing emphasis on helping students to formulating experimental approaches, identifying and controlling variables, and defining the system, etc. The teacher now addresses the scientific process explicitly by providing an ongoing commentary about the nature of inquiry. The teacher models fundamental intellectual processes and explains the fundamental understandings of scientific inquiry while the students learn by observing and listening, and responding to questions. This is in effect scientific inquiry using a vicarious approach with the teacher using a "think aloud" protocol. This approach will more fully help students understand the nature of inquiry processes.

For instance, it is unreasonable to assume that students can use more sophisticated experimental approaches before they are intimately familiar with those less complex. Therefore, students must be able to distinguish between independent, dependent, and controlled variables before they can develop a meaningful controlled scientific experiment.

Example of an Inquiry Lesson—Again turning to the topic of buoyancy, what might an inquiry lesson involving buoyancy look like? An example would be a teacher who asks the single guiding question, "What factors influence the amount of buoyancy experienced by an object that sinks?" In response, students provide a list of possible factors such as the density of immersing liquid, orientation of the object in liquid, depth of the object in liquid, and weight, composition, density, shape, size, and volume of the object. They then are asked to suggest ways to test whether or not each of these factors does indeed influence buoyancy. (At this point the teacher might want to restrict the discussion to the buoyant forces acting only on sinking objects for simplicity's sake, noting that work with floating objects will come later.)

Q. Which factor should we test first, and does it make a difference?

Note: It does make a difference. We must be able to control all variables. Depth would be a good place to start.

Q. Is the buoyant force exerted by a liquid dependent upon the depth? How might we test this?

Note: Check buoyant force at varying depths controlling for other variables.

Q. Is the buoyant force experienced by a submerged object related to its shape? How might we test this?

Note: Test with a clay object formed into different shapes.

Q. Does the buoyant force experienced by a submerged object depend on its orientation? How might we test this?

Note: Test with a rectangular metallic block oriented along three different axes.

Q. Is the buoyant force experienced by a submerged object related to its volume? How might we test this?

Note: Test using two different sized objects of the same weight.

Q. Is the buoyant force exerted on a body dependent upon the weight of an object? How might we test this?

Note: Test with aluminum and copper ingots of identical volume.

Q. From what you have seen, does the buoyant force depend upon the density of an object?

Note: It does not.

Q. Is the buoyant force exerted by a fluid dependent upon the density of the liquid? How might we test this?

Note: Test using liquids of different density such as fresh water, alcohol, oil, glycerin, and honey.

As the steps of this inquiry lesson are carried out, the teacher makes certain that proper experimental protocols are observed such as the control of variables (e.g., one independent and one dependent variable tested at one time). This will require that certain of the above experiments be conducted in proper relative order. (For instance, the shape or orientation tests might be affected by depth if depth is not first ruled out.) There is a regular discussion of scientific methodology, making students aware of the procedures of a controlled experiment. Once the factors that significantly affect buoyancy are identified, students will next design and carry out an inquiry lab to determine the actual relationships between buoyancy and those factors empirically shown to be related to the buoyant force – density of the immersing liquid and the volume of the object immersed.

Inquiry Labs—An inquiry lab is the next level of inquiry practice. Inquiry labs generally will consist of students more or less independently developing and executing an experimental plan and collecting appropriate data. These data are then analyzed to find a law—a precise relationship among variables. This inquiry lab approach is not to be confused with the traditional "cookbook" laboratory activity. The distinction between

traditional cookbook labs (sometimes called "structured inquiry") and true inquiry-oriented labs is profound. The major distinguishing factors are presented in Table D-3.

Table D-3

Some Major Differences Between Traditional Cookbook and Authentic Inquiry-Oriented Lab Activities

Cookbook labs:	Inquiry labs:
are driven with step-by-step instructions requiring minimum intellectual engagement of the students thereby promoting robotic, rule-conforming behaviors.	are driven by questions requiring ongoing intellectual engagement using higher-order thinking skills making for independent thought and action.
focus students' activities on verifying information previously communicated in class thereby moving from abstract toward concrete.	focus students' activities on collecting and interpreting data to discover new concepts, principles, or empirical relationships thereby moving from concrete toward abstract.
presume students will learn the nature of scientific inquiry by "experience" or implicitly; students execute imposed experimental designs that tell students which variables to hold constant, which to vary, which are independent, and which are dependent.	require students to create their own controlled experimental designs; require students to independently identify, distinguish, and control pertinent independent and dependent variables; promote student understanding of the skills and nature of scientific inquiry.
rarely allow students to confront and deal with error, uncertainty, and misconceptions; do not allow students to experience blind alleys or dead ends.	commonly allow for students to learn from their mistakes and missteps; provide time and opportunity for students to make and recover from mistakes.
employ procedures that are inconsistent with the nature of scientific endeavor; show the work of science to be an unrealistic linear process.	employ procedures that are more consistent with authentic scientific practice; show the work of science to be recursive and self-correcting.

Example of an Inquiry Lab—Very specific student performance objectives are given, but little to no instruction depending on the precise nature of the lab (see following sections). An example of a general lab approach with the current topic, buoyancy experienced by a sinking object, would be typified by the following series of questions. Because only two variables have been experimentally identified as being related to the buoyant force—volume of an immersed object and density of the immersing liquid—the following two objectives are given:

O. Determine how the buoyant force depends upon the volume of the object immersed.

O. Determine how the buoyant force depends upon the density of the immersing liquid.

Students then independently design and perform experiments to find relationships between the buoyant force (F_b) and volume (V) in one case, and F_b and density of the immersing liquid (r) in the other case. The teacher can use a jigsaw approach to speed up the process of finding the final form of the empirical law for buoyant force. The first group of students finds that F_b is directly proportional to V. The second group finds that F_b is directly proportional to r. The students as a group are then are asked to predict the nature of the full relationship between all variables. There are several possibilities such as sum, product, quotient, and difference. The only relationship that satisfied both experimental findings (buoyancy is proportional to both V and r) is a product of terms. Students are then asked to assume this form of the function and find the values of any constants. By using data already available to them and a *physical interpretation of the data* (knowing that F_b would have to be zero if either V or r were zero), they are able to find that the constant of proportionality has the magnitude and units of acceleration due to

gravity, g. The final physical relationship can then be predicted to be $F_b = \rho g V$. Testing of predictions based on this relationship would show it to be of the appropriate form.

Three Types of Inquiry Lab—Based initially on the work of Herron (1971), the author further suggests that inquiry labs can be broken down into three types based upon degree of sophistication and locus of control as shown in Table D-4—guided inquiry, bounded inquiry, and free inquiry. This table displays the shift of question/problem source and procedures as lab types become progressively more sophisticated. Each approach constitutes a stepwise progression of moving from modeling appropriate inquiry practice to fading from the scene. A guided inquiry lab is the next level of inquiry practice beyond the inquiry lesson. The guided inquiry lab, like the bounded inquiry lab to follow, is a transitional form of lab activity leading ultimately to the free inquiry lab approach in which students act with complete independence—even to the point of identifying the research question or problem to be solved. With each successive approach, the teacher provides less structure, and the students become more independent in both thought and action.

Table D-4

Distinguishing Characteristics of Inquiry Labs by Type

Inquiry Lab Type	Questions/Problem Source	Procedures
Guided inquiry	Teacher identifies problem to be researched	Guided by multiple teacher-identified questions; extensive pre-lab orientation
Bounded inquiry	Teacher identifies problem to be researched	Guided by a single teacher-identified question, partial pre-lab orientation
Free inquiry	Students identify problem to be researched	Guided by a single student-identified question; no pre-lab orientation

Guided Inquiry Lab—The guided inquiry lab is characterized by a teacher-identified problem and multiple leading questions that point the way to procedures. A guided inquiry lab might be prefaced by a pre-lab activity or discussion. In guided labs, students are provided with a clear and concise student performance objective. For instance, "Find the relationship between force and acceleration." or "Determine how the magnetic field strength varies as a function of distance from a current-carrying wire." or "Find the relationship between work and energy in this system." or "Gather empirical evidence from a pendulum to determine whether or not energy is conserved in the relationship between gravitational potential energy and kinetic energy." Then, as students progress through the lab, they follow a series of leading questions in order to achieve the goal of the lab.

An extensive pre-lab discussion helps students to understand not only the concepts and objective(s) associated with the lab, but also the scientific processes to be used to attain the specific objective(s). Using the above conservation of energy student performance objective as an example, consider the following line of questioning that might be used in a pre-lab discussion:

a. What approach might we take with a pendulum to determine whether or not energy is conserved in the relationship between gravitational potential energy and kinetic energy?

b. How would we figure out the amounts of kinetic and potential energies at various points within the system?

c. Which points should be chosen and why?

d. What sort of data should we collect at these points?

e. How will we convert the raw data into kinetic energy and potential energy?

f. What would we expect to see if energy is conserved? Not conserved?

g. What factors might affect the outcome of this experiment? Gravity? Friction? Amplitude? Mass?

h. Do we really need to actually control all such variables or are some merely extraneous? How do we know?

i. How might we control confounding variables if such control is necessary?

j. Given the fact that we can not very well control friction (and friction over a distance does change the amount of energy in a system), how close is close enough to say that energy actually is conserved?

While the guided inquiry lab can and must be considered a transitional form between the inquiry lesson and more advance forms of inquiry, it is not sufficient as a complete transitional form. Again, teachers must model more advanced forms of inquiry and then fade, providing and then gradually remove scaffolding, as students become better inquirers after scientific knowledge.

Bounded Inquiry Lab—Students are presented with a clear and concise student performance objective associated with a concept, but they are expected to design and conduct an experiment without the benefit of a detailed pre-lab or written leading questions. They might be required to make simple observations about the relationship between variables, and then asked to perform a dimensional analysis as a means for formulating a logical basis for conducting an experiment. A pre-lab might still be held, but it would focus on non-experimental aspects such as lab safety and use and protection of laboratory equipment. Students are entirely responsible for experimental design, though an instructor might provide assistance as needed in lab; this assistance is more in the form of asking leading questions rather than providing answers to student questions. Note that before a bounded inquiry lab is conducted, students must have had considerable experience with the guided inquiry lab. Without having a model to follow, students

might be confounded in bounded labs by a general lack of direction when told to "do science." This can lead to the frustration and lack of student engagement described in the outset of this article.

Free Inquiry Lab—Both the guided inquiry and bounded inquiry labs will start off with a teacher-identified problem as well as all or part of the experimental design. This contrasts with the free inquiry lab in which students identify a problem to be solved and create the experimental design. Free inquiry labs most likely will be closely associated with a semester-long or capstone science project. They are great outlets for gifted students. More than likely, free inquiry labs will be conducted outside of regular class time, or in a class composed of gifted or otherwise more advanced students.

Hypothetical Inquiry—The most advanced form of inquiry that students are likely to deal with will be hypothesis generation and testing. Hypothetical inquiry needs to be differentiated from making predictions, a distinction many physics teachers fail to understand or to make with their students. A prediction is a statement of what will happen given a set of initial conditions. An example of a prediction is, "When I quickly increase the volume of a gas, it's temperature will drop." The prediction has no explanatory power whatsoever, even though it might be a logical deduction derived from laws or experiences. A hypothesis is a tentative explanation that can be tested thoroughly, and that can serve to direct further investigation. An example of a hypothesis might be that a flashlight fails to work because its batteries are dead. To test this hypothesis, one might replace the supposedly bad batteries with fresh batteries. If that does not work, a new hypothesis is generated. This latter hypothesis might have to do with circuit continuity such as a burned out light bulb or a broken wire. Hypothetical inquiry deals with

providing and testing explanations (usually how, rarely why), to account for certain laws or observations. Hypotheses most certainly are not "educated guesses."

Two Types of Hypothetical Inquiry—Like with inquiry labs, hypothetical inquiry can be differentiated into basic forms—pure and applied—each associated with its own type of pedagogical practices and inquiry processes. Like pure and applied science, pure and applied hypothetical inquiry differ. Pure hypothetical inquiry is research made without any expectation of application to real-world problems; it is conducted solely with the goal of extending our understanding of the laws of nature. Applied hypothetical inquiry is geared toward finding applications of prior knowledge to new problems. The two types of hypothetical inquiry essentially employ the same intellectual processes; they tend to differ on the basis of their goals. They are not otherwise distinguished in the hierarchy of pedagogical practices.

Pure Hypothetical Inquiry—In the current pedagogical spectrum, the most advanced form of inquiry will consist of students developing hypothetical explanations of empirically derived laws and using those hypotheses to explain physical phenomena. Hypothetical inquiry might address such things as why the intensity of light falls off with the inverse square of distance, how conservation of energy accounts for certain kinematic laws, how the laws for addition of resistance in series and parallel circuits can be accounted for by conservation of current and energy, and how Newton's second law can account for Bernoulli's law. In the current set of examples dealing with buoyancy, a teacher could ask students to explain from a physical perspective how the buoyant force originates. By extension, the students might attempt to explain Archimedes' Principle—that the buoyant force is equivalent to the weight of the fluid displaced. Questions such

as these will lead to hypothesis development and testing. Through this form of inquiry students come to see how pure hypothetical reasoning—the worth of which is attested to by successful application—becomes theory.

Example of Pure Hypothetical Inquiry—One example of pure hypothetical inquiry in relation to the current topic, buoyancy, would be to address the source of the buoyant force. The student hypothesizes that buoyancy results from differences in pressure applied over various surface areas (hence forces), say, on the top and bottom of an imaginary cube. With an understanding that pressure increases with depth in a fluid ($P = \rho g d$) and that force equals pressure per unit area multiplied by the area under consideration ($F = PA$), a student can use the imaginary cube to explain the nature of the buoyant force. Calculating pressure on horizontal parallel surfaces at two different depths and taking the difference results in a correct formulation of the buoyant force. This provides support for the correctness of the explanatory hypothesis.

$$F_{top} = P_{top}A = \rho g d_{top} A$$
$$F_{bot} = P_{bot}A = \rho g d_{bot} A$$
$$F_b = F_{bot} - F_{top} = \rho g (d_{bot} - d_{top}) A$$
$$F_b = \rho g V$$

A reformulation of the last equation and proper identification of terms will show why Archimedes' principle works the way it does:

$$F_b = \rho g V = (\rho V) g = m_f g$$

where the subscripted m is the mass of the fluid displaced.

As a result of this form of pure inquiry, the student has deduced from a hypothetical construct the empirical form of the buoyant force law, and can explain Archimedes' law. The student has moved from mere knowledge to understanding. Now, to make certain that students understand the relationship between pure hypothetical inquiry and experimentation (and ultimately theory), they should then be asked to use the hypothesis to explain other real-world phenomena. For instance, how does the hypothesis that buoyant force results from a pressure differential on a body account for such things as floating objects, thermal convection, plate tectonics, and the workings of a Galilean thermometer?

Because this level of inquiry is the most advanced, it is unlikely that many high school students will reach this point along the continuum. Nonetheless, high school physics teachers might want to take the opportunity to have gifted students use this approach to explain empirical laws and apply their hypotheses to other real world phenomena. Alternatively, science teachers might want to use applied hypothetical inquiry in any of its most rudimentary forms—problem-based learning, technological design, failure analysis, and some forms of experimentation—to reach this level.

Applied Hypothetical Inquiry—As a teaching practice, problem-based learning (for instance) is considerably more accessible than pure hypothetical inquiry which has limited application, and that might be used only one or twice per year and then only with gifted students. Consequently, problem-based learning (PBL) is a commonly employed teaching practice in science classrooms. As a hypothetical inquiry process, PBL places all students in active roles as real-world problem solvers. Students must build a case for a hypothesis formulated on the basis of facts surrounding a situation, and they must argue

logically in support of their hypothesis. The problems students address are generally complex in nature, often have no clear answers, and are based upon compelling problems. This process appeals to the human desire for problem resolution, and sets up a context for learning. During PBL the teacher works as a cognitive coach, modeling and fading, facilitating student clarification of the problem, and generally supporting the student learning process with cycles sometimes described as "facts/hypotheses/learning issues."

Example of Applied Hypothetical Inquiry—Dianna Roth, a physics teacher at Lanphier High School in Springfield, Illinois, annually employs a PBL titled "When Lightning Strikes" (Roth, 2003). This PBL is based on an actual event that took place in her community many years ago. This PBL deals with a scenario wherein a young female student is mysteriously killed while pitching a softball game. Roth's high school physics class assembles on the bleachers of the school's baseball field. The problem statement is then read aloud as follows, followed by the task statement:

> A Springfield girl's softball team is playing when threatening clouds begin to build on the horizon. The officials at the game believe they can finish before a storm occurs. As the pitcher winds up, a large lightning bolt strikes the earth in far left field. As the lightning "crack" is heard, the pitcher takes a step forward to pitch and slumps to the ground, dead.
>
> What electrical phenomena are related to and/or caused the young pitcher's death? Each person should write a persuasive argument that provides support for their conclusions regarding the cause of death. Include all evidence; ideas, facts, scale diagram, calculations, experimental electrical field mapping data. One oral report is required per group. Be prepared to answer questions individually. In addition, be sure to include all physics concepts, related terms, and diagrams that support your argument in both your written and oral reports.

Subsequent to the initial overview, students are provided with information as requested. Information sources are such things as a newspaper report, a police report, EMT summary report, park manager's accident report, coroner's report, and radar

summary. After a review of the facts of the case, the students are asked to hypothesize as to the cause of the pitcher's death in light of these facts. Students collect additional information using libraries, Internet resources, interviews, and laboratory experiments in the physics classroom.

Complete Hierarchy of Pedagogical Practices—Table D-5 provides a more complete hierarchy of inquiry-oriented science teaching practices that includes distinctions between laboratory types and types of hypothetical inquiry. The continuum is now shown as a tuning-fork diagram with a long handle and two short tines. In addition to a progression of intellectual sophistication and locus of control, there are also other progressions along the continuum such as a shifting emphasis from concrete observation to abstract reasoning, from inductive processes to deductive processes, and from observation to explanation. In order to address these more fully, it is important to describe a hierarchy of inquiry processes associated with the continuum.

Table D-5

A More Complete Hierarchy of Inquiry-Oriented Science Teaching Practices Including Distinctions Between Laboratory Types, and Pure and Applied Inquiry

Discovery Learning	Interactive Demonstration	Inquiry Lesson	Guided Inquiry Lab	Bounded Inquiry Lab	Free Inquiry Lab	Pure Hypothetical Inquiry / Applied Hypothetical Inquiry
Low	← Intellectual Sophistication →					High
Teacher	← Locus of Control →					Student

Hierarchy of Inquiry Processes—As has been stated, the degree of intellectual sophistication increases the further to the right along the continuum an inquiry practice is located. A question may now be logically asked, "What is the precise nature of this increasing intellectual sophistication?" Sophistication has to do with the type of the intellectual science process skills required to complete a specified level of inquiry-oriented activity. Some science educators (notably, Ostlund, 1992; Lawson, 1995; Rezba et al., 2003) have distinguished two hierarchies of such intellectual process skills based on elementary/middle school and middle/high school education. The National Research Council (NRC, 2000) in its publication *Inquiry and the National Science Education Standards* identifies three sets of fundamental abilities of inquiry based on grade levels 1-4, 5-8, and 9-12. Regardless of these distinctions, people continue to use and develop all levels of intellectual process skills throughout their lives. Because most of the science reform movement literature has focused on less sophisticated inquiry skills, it seems that more advanced process skills are being overlooked. Clearly, if students are to be more critical thinkers, they probably should possess *advanced inquiry skills*. Advanced inquiry skills are those intellectual processes that might be said to represent the end-goal of science education (scientific literacy). A hierarchy of inquiry processes can be found in Table D-6. The listings are intended to be suggestive, not definitive.

Table D-6

Relative Degree of Sophistication of Various Inquiry-Oriented Intellectual Processes

Rudimentary Skills	Basic Skills	Integrated Skills	Advanced Skills
Observing	Identifying variables	Identifying problems to investigate	Solving complex real-world problems
Collecting and recording data	Constructing a table of data	Designing and conducting scientific investigations	Synthesizing complex hypothetical explanations
Drawing conclusions	Constructing a graph	Using technology and math during investigations	Establishing empirical laws on the basis of evidence and logic
Communicating	Describing relationships between variables	Generating principles through the process of induction	Analyzing and evaluating scientific arguments
Classifying results	Acquiring and processing data	Communicating and defending a scientific argument	Constructing logical proofs
Measuring metrically	Analyzing investigations		Generating predictions through the process of deduction
Estimating	Defining variables operationally		Hypothetical inquiry
Decision making 1	Designing investigations		
Explaining	Experimenting		
Predicting	Hypothesizing		
	Decision making 2		
	Developing models		
	Controlling variables		
Low	← Intellectual Sophistication →		High

Note. These listings are intended to be suggestive, not definitive.

Cooperative Learning and Scientific Inquiry

The importance of cooperative learning cannot be overstated in helping students develop the abilities of scientific inquiry—either in the laboratory working on an experiment or in a classroom working on an Internet-based research project. Working actively in small groups, students develop the mental operations and habits of mind that are essential to developing strong content knowledge, intellectual and procedural skills, appropriate scientific dispositions, and an understanding of both the nature of science and scientific knowledge. Cooperative learning also contributes significantly to advancing a more comprehensive form of scientific literacy.

Students working in cooperative groups can attack and solve more complex laboratory and real-world problems than they could do individually. Cooperative work frequently results in more and better solutions to such problems. Communities of learners commonly demonstrate a deeper understanding of the problem being addressed, how to solve it, and the meaning and significance of the solution. Learning communities provide students with the opportunity to "talk science" in a comfortable setting, share their understanding without needless criticism, and clarify their thinking through peer communication without embarrassment. Each student can practice problem-solving and critical-thinking skills in a relatively safe environment until they become individually more proficient. Chapter X—*Cooperative Learning*—will deal more extensively with how to develop and nurture a community of science learners.

Assessing Inquiry Abilities as Part of Scientific Literacy

Achieving scientific literacy is commonly referred to as the main goal of science teaching (AAAS, 1989, 1993; NRC, 1996; NSTA 2003). Scientific literacy is multi-dimensional, and comes in a variety of types and degrees (Shen, 1975; Shamos, 1995; NRC, 1996). The *National Science Education Standards* (NRC, 1996) have defined a relatively comprehensive form of scientific literacy that teachers should attempt to achieve with their students. The *Standards* indicate that scientifically literate individuals will possess an understanding of six major elements of scientific literacy: (a) science as inquiry, (b) science content, (c) science and technology, (d) science in personal and social perspectives, (e) history and nature of science, and (6) unifying concepts and processes.

If the main goal of science teaching is to achieve scientific literacy, it would seem reasonable that assessment instruments would exist for measuring progress toward that goal. Not a single comprehensive scientific literacy assessment instrument is known to the author; indeed no single test of scientific literacy could exist that would be of reasonable length and complexity for use in the school classroom. Only a battery of independent tests geared toward the task of assessing scientific literacy in its many dimensions could provide meaningful information about scientific literacy. Such a battery of test could provide critical information to assess gaps in student knowledge and skills, guide instructional practice, hold schools accountable for achieving specific goals, and determine program and teacher effectiveness.

Science as inquiry plays an important role in achieving scientific literacy among students. This chapter has provided a framework for teaching and assessing the abilities

of scientific inquiry, and the author has made available a 35-item standardized assessment instrument known as the *Scientific Inquiry Literacy Test* (Wenning, 2007) that can be used by teachers. Details about this and other assessment strategies that support the development of scientific literacy is provided in Chapter Y of this book—*Science Assessment*.

Application to Teacher Preparation, Teaching, and Curricular Development—Given these hierarchical distinctions for the construction of scientific knowledge, it should now be clear what the student teacher's problem was in the example cited at the beginning of this section. The student teacher had personally moved from a series of low sophistication, teacher-centered inquiry activities—basically a series of interactive demonstrations—to a bounded lab activity that had no structure and a relatively high degree of sophistication without providing appropriate bridging activities for students. The only prior experiences the high school students had had in a lab setting prior to the arrival of the student teacher were traditional cookbook labs. These had left the students uninformed about important inquiry processes. The students, not having learned to "walk before they were asked to run," understandably had problems with the more advanced nature of the lab imposed upon them. The source of the student teacher's problem was that inquiry lessons and guided inquiry labs had not been a regular part of the students' physics curriculum; neither had attention been paid to the continuum of intellectual process skills so important to scientific inquiry.

Science teachers will greatly improve their practice by incorporating an understanding of levels of inquiry, and their students will directly benefit from a more effective form of instruction. Instructional development and curricular decision-making

will likewise benefit from an understanding of the continuum of pedagogical practices and inquiry processes. Failure to include due consideration for the continuum will in all likelihood result in a pedagogy that will be less effective. Not doing so will leave students with an incomplete understanding of the nature of science as both product *and* process.

Failure of Science Teachers to Employ Inquiry

With strong arguments for and evidence in favor of employing the inquiry approach, why do not some new and established science teachers use inquiry-oriented teaching methods? The National Research Council in *Inquiry and the National Science Education Standards* (NRC, 2000a) propounded an implementation model that suggests what it takes for science instructors to be able to teach using inquiry practices. The NRC has in effect suggested that the reason for teachers failing to implement inquiry-oriented instruction has to do primarily with the lack of adequate preparation. The NRC (p. 87) argued, "For students to understand inquiry and use it to learn science, their teachers need to be well-versed in inquiry and inquiry-based methods. Yet most teachers have not had opportunities to learn science through inquiry or to conduct scientific inquiries themselves. Nor do many teachers have the understanding and skills they need to use inquiry thoughtfully and appropriately in their classrooms." The NRC implementation model further posits that four factors account for teachers' understanding of scientific inquiry: (a) having learned science through inquiry, (b) having learned to teach science through inquiry, (c) having been lifelong inquirers, and (d) having followed a professional development plan that has inquiry-based instruction as its focus. Understanding of scientific inquiry is then positively correlated with implementation of inquiry-based

instruction. The supposed NRC implementation model is shown diagrammatically in Figure 1.

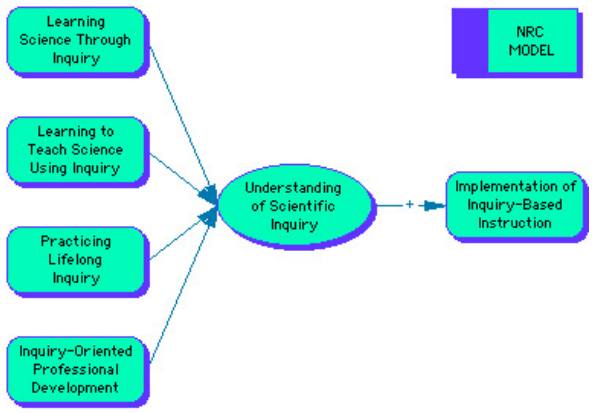

Figure 1. The implementation model of the NRC. This model suggests that teachers' understanding of scientific inquiry, as well as those educational experiences that lead to this understanding, are positively correlated with implementation of inquiry-based instruction.

Even though understanding of scientific inquiry is a prerequisite for implementing inquiry-based instruction in the classroom, it is not the only factor that influences its implementation. The NRC model is deficient to the extent that it fails to account for the human condition and the social context of teaching. As Kennedy (1991, p. 11) noted, "Although it is all too easy to do, let us not lose sight that causal laws in the social sciences refer to people." Unfortunately, this is what the NRC model appears to do; it makes the same mistake as the science education reformers did in the 1960s. The NRC model fails to take into account confounding variables - those factors that tend to be negatively correlated with the implementation of inquiry-based instruction.

Costenson and Lawson (1986), during interviews with teachers dedicated primarily to the lecture mode of instruction, identified 10 major confounding factors to

explain why these teachers failed to include inquiry practices in their teaching. While Costenson's and Lawson's 1986 work is now over two decades old and refers to biology teaching, these points are broadly applicable to all science teaching today. The following list encapsulates the major impediments teachers cited as the reasons they failed to regularly employ inquiry-oriented practice in their classrooms:

- *Time and energy*—It is difficult and time consuming to produce high quality inquiry lessons; it is difficult to sustain the high level of energy required to use active learning.

- *Too slow*—Inquiry takes more time than teaching by telling; the school curriculum requires coverage of broader spectrum of content than is possible with inquiry.

- *Reading too difficult*—Students have difficulty translating textbook knowledge into active inquiry.

- *Risk too high*—The school administration does not support inquiry practice due to a lack of sufficient content coverage; the teacher might be perceived as not doing his or her job.

- *Tracking*—Classrooms filled with lower-performing students do not contain the right type of population needed to conduct inquiry effectively.

- *Student immaturity*—Students are too immature and waste time in unstructured settings; they do not benefit from inquiry-oriented teaching.

- *Teaching habits*—Established expository teaching habits are hard change after long periods of use; teachers do not have knowledge and skills required for inquiry teaching.

- *Sequential text*—The textbook constitutes the curriculum; chapters are not skipped because too much important material is included in each.

- *Discomfort*—It is uncomfortable not to be in control of the lesson; being uncertain of the outcomes that might result from inquiry-oriented teaching is disturbing.

- *Too expensive*—Inquiry requires active engagement, and many classrooms are not equipped with sufficient teaching materials suitable for hands-on learning.

None of these 10 teacher-identified confounding variables is included in the NRC model. In addition, other important considerations are missing—such things as the explosive growth of textbook contents, the quality of student teaching experiences, the lack of teacher mentoring, the unintended consequences of high-stakes testing and No Child Left Behind legislation attended by calls to return to "direct instruction" (Cavanagh, 2004). All play a crucial role in determining whether or not inquiry is implemented in the classroom.

A New Model for Implementing Inquiry-Based Instruction

The NRC model for implementing inquiry-based instruction, while appearing logical, does not address factors that confound the implementation of inquiry-based instruction. This model, therefore, cannot serve as the basis for the "powerful teacher education process" called for by Darling-Hammond. If a more complete implementation model is provided, curriculum planners, instructional developers, teacher educators, professional development providers, in-service teachers, and teacher candidates can be given a better understanding of the relationship between pertinent educational factors associated with the implementation of inquiry-based instruction. In educating/reeducating teachers, efforts can be made to galvanize them to resist confounding factors. The author has proposed a hypothetical model to explain more completely and accurately the observed disconnect between teacher preparation/professional development and teacher performance (Wenning, 2005). This new model replaces the four positively correlated factors of the NRC model with three somewhat different factors essential for the implementation of inquiry-based instruction: knowledge, skills, and disposition. In

addition, educational experiences (e.g., student teaching and professional development) are also incorporated. Finally, the new model groups the 10 negative factors identified by Costenson and Lawson into four major (if somewhat overlapping) groups that are all negatively correlated with implementation of inquiry-based instruction: personal teaching concerns, concerns about students, instructional and curricular concerns, and didactic teaching philosophy. The new model is depicted in Figure 2.

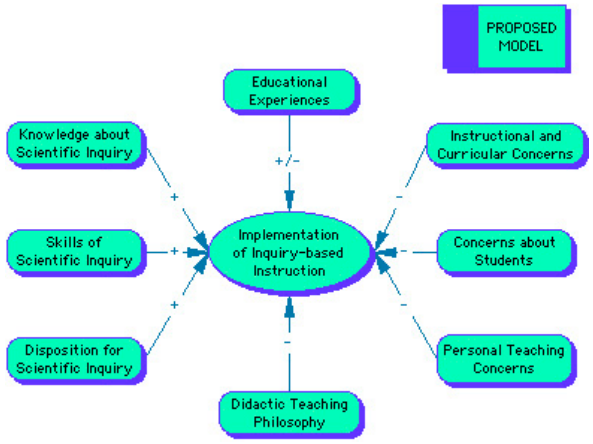

Figure 2. The proposed model including confounding variables to more fully explain the degree to which science teachers implement inquiry-based instruction in their classrooms. This model suggests that teachers' understanding of scientific inquiry is not the only factor that affects the implementation of inquiry-based instruction.

Experience has shown that there is a significant relationship between the dependent variable in this model (implementation of inquiry-based instruction) and the multiple independent variables (understanding of science inquiry in three different dimensions, didactic teaching philosophy, personal teaching concerns, concerns about students, instructional and curricular concerns, and educational experiences). Other

contributory factors might also negatively or positively influence the degree to which inquiry-based instruction is implemented. These factors could be grouped together in the model and appear as "specification error." They are, however, not included in Figure 2. According to this new model, when positive correlates exceed the negative correlates, inquiry teaching takes place. When the opposite occurs, little if any inquiry teaching occurs. This more complete implementation model, then, appears to explain the failure of teacher preparation programs to graduate teachers who will regularly implement inquiry as part of their teaching practice.

Failure to employ a real-world model for promoting and implementing inquiry-based instruction will impede any solution to the improvement-of-practice problem. As history has shown, the difference between educational practices that are influenced by a well-thought-out model and those that are not can be profound in both their implementation and effects. The difference will be to the extent that an educational process is conducted blindly under the control of unexamined traditions or take into account personal, social and political factors.

School-based Resistance to Inquiry

Inquiry-oriented science teachers sometimes experience resistance to inquiry from students and their parents, school administrators and even science-teaching peers. This often stems from misunderstandings of the nature of scientific inquiry and the benefits that accrue to the students who practice it. Classroom climate setting can be a very important factor in overcoming school-based resistance to inquiry.

Student Resistance

Inquiry-oriented teachers sometimes experience several types of student resistance to inquiry with varying degrees and commonalities. Some students resist inquiry if they perceive it as a threat to them achieving high grades. Good students, but especially borderline "A" students who have done well under the more traditional "teaching by telling" mode of instruction, tend to find learning more challenging in a classroom where there is strong reliance on inquiry. Some students who have succeeded well under the old system of didactic instruction now feel threatened by a constructivist approach. Such an approach requires them to do more than merely memorize and replicate information on tests, and conduct number crunching with formulas and calculators. Some students express a strong sense of frustration of not "knowing the right answer" and having to arrive at the correct answer on their own using the inquiry approach. They sometimes indicate that they would like more lecture and reliance on a textbook than is common to constructivist approaches. They want teachers to "have the final word" or to have the instructor speak "with one voice." It is not unusual to hear students say something to the effect, "I would rather be told what I need to know" or "I don't know what I need to know." In the long term, these concerns can lead to student disengagement characterized by passivity, calculator gaming, doing other homework in place of participating in class, or working only on those projects which are perceived to be of value in the course grade while letting others do the non-scored work. Some students will wait for others to begin work, and only then follow other students' leads. Students sometimes will not take notes unless the teacher is speaking; the value of other students' commentary is deemed questionable if not worthless. Students sometimes undermine a lesson by shouting out the

answer if they know it by another means. At other times they strongly resist participating in discussion or Socratic dialogues for fear of being wrong. Much of this resistance slowly dissipates as students become more comfortable with inquiry practices, but at the outset the introduction of inquiry practice does lead to some difficulties for both students and teachers.

Parental Resistance

The degree of parental resistance is, in most cases, significantly less than that originating with students. Parental resistance typically originates from students complaining to their parents. The complaints can be varied, but parents become concerned and vocal when they perceive that their children's education is "threatened" by non-traditional approaches. Some parents are concerned about adequate subject matter coverage and wonder how inquiry approaches will affect future success in school, college, or university life. How will the slower pace of inquiry impact student learning, and how will this affect standardized test scores such as the ACT exam? They do not understand why an inquiry-oriented teacher is not always teaching directly from a textbook, or perhaps not using a textbook at all. Because instruction is classroom intensive and student- and assessment-centered (learning from empirical observations and Socratic dialogues for instance), parents become frustrated upon not knowing how to help their children with homework. Tutors are sometimes hired to provide additional assistance. Parents, based on their own experiences with science, will sometimes wonder, "Why aren't you teaching them as much science as I learned in high school?" or "Why are you watering down the curriculum?" Parents who want to vent might write "nasty e-mails" to teachers or do an end-run around a teacher and go directly to the school administration with a complaint.

Fortunately, after adequately addressing parental concerns, resistance from this quarter appears to rapidly diminish.

Administrator Resistance

A school administrators' (departmental chairperson, school principal, or superintendent) resistance to inquiry might stem from complaints by students and/or parents. Additional questions might arise from concerns about high stakes testing such as that associated with No Child Left Behind legislation. Other forms of resistance might originate from the fact that inquiry teaching does not align well with assessment instruments designed for use with didactic teaching styles. Fortunately, little resistance will be encountered when school administrators are brought onboard early, and have been provided substantial information about inquiry-oriented teaching goals, processes, and benefits. When they are periodically updated with information about teacher experiences, and have been provided additional background information in a timely fashion, this helps them to cope with concerns expressed by parents and students.

Peer Resistance

More traditional science teachers sometimes are concerned about not covering enough subject matter due to the "slowness" of inquiry. They are sometimes concerned about the methods of inquiry due to a failure to understand the philosophy, pedagogy, and benefits associated with inquiry-oriented instruction. Because student attitudes about science and an instructor can be strongly affected by the degree of active involvement, some peer teachers are concerned about "popularity contests." This can result in strong student preferences for one subject over another or one teacher over another. Teaching

peers sometimes fear being "forced" to use an inquiry approach with which they are unfamiliar or uncomfortable.

Peer resistance also might result in a school where the science classes follow as standard curriculum with specific lessons, labs, and tests taking place department wide on particular days. Perhaps the best way to deal with this problem is to address it head-on with fellow teachers. Accommodations might be made for the necessarily slower pace of inquiry-oriented teaching.

Student, parental, administrator, and peer teacher resistance to the use of inquiry-oriented instruction in the science classroom potentially can have deleterious if not debilitating consequences for teachers of inquiry. A teacher's commitment to the approach can be reduced when confronted with mild and periodic forms of resistance, or at least make him or her question what he or she is doing. Being confronted with significant and on-going resistance can result in the new inquiry teacher returning to the older form of direct instruction. Unless all persons with a stake in the process of learning via inquiry are provided with a broad understanding of the reasons for its implementation, the use in inquiry-oriented instruction in the science classroom will be threatened. There are steps, both proactive and reactive, with which teachers using inquiry-oriented instruction should be familiar. A teacher can either work proactively to prevent resistance to inquiry, or can work reactively to respond to resistance after it originates. In the author's opinion, the former approach is to be preferred. It is easier to change people's attitudes if they have no preconceived notions about inquiry procedures; they are willing to listen, and might be positively supportive of a new teaching approach if they understand it and can foresee the benefits of its use. It is much more difficult to change minds after people develop

prejudices; prejudice is a strong impediment to educational change. With these points in mind, how then does one work with students, parents, administrators, and peer teachers to minimize, if not altogether eliminate, resistance to inquiry instruction? The approach consists of properly using climate setting to establish a receptive atmosphere in the classroom, school, and community.

Classroom Climate Setting

Whole Group Climate Setting

Classroom climate setting refers to creating the correct intellectual atmosphere under which inquiry-oriented instruction will be conducted. Successful climate setting addresses two critical components—the role of the teacher and the role of the student (Roth, 2003). Because inquiry-oriented teaching is conducted under what is for some students a very different classroom atmosphere, climate setting needs to be part of every inquiry-oriented teacher's management plan. In climate setting teachers help students understand the difference between the traditional didactic instruction and inquiry-oriented instruction. For instance, students need to understand that the authentic role of the teacher is to prepare situations through which students can learn. Students must understand that learning is their responsibility, and that teaching does not necessarily translate into learning. The teacher explains that he or she will set up a problem, anticipate student needs, and provide access to needed resources. The teacher will play the role of mentor, and students will work cooperatively to solve the problem presented. Teachers must stress that the roles of teachers and students change. Teachers are no longer to be seen as purveyors of information; rather, they are to be seen as facilitators of student learning. Students are no longer to be seen as empty receptacles to be filled by teachers; rather, they

are to be seen as active inquirers. Students no longer rely on teachers and textbooks for their learning. They must take responsibility for their own learning, and construct knowledge from personal experiences. If effect, they must learn science by becoming scientists.

Teachers should make clear to their students that teachers might ask questions even if they know the answer; that they might ask "why?" two or three times in a row, that they will ask students to explain and justify their conclusions on the basis of evidence. Teachers must point out that questioning an idea does not mean that it is wrong. Students need to understand that their role is to speak up, ask questions, confront apparent fallacies, and ask questions when they do not understand. They must see the educational process as the construction of knowledge in which ideas derived from experience are clearly stated and clearly evaluated. They need to know that no idea is "stupid," and that the only poor question is the question that is not asked. Students must have an understanding of this changing climate, and these differences should be pointed out early and often. Initiating climate setting should be done at the very outset of a course. It should be done on a daily basis thereafter until the classroom atmosphere is clearly and strongly established as one that supports and sustains inquiry. Such a classroom climate setting process might seem overly repetitive, but experience has shown that it is extremely important for successful inquiry-based instruction. Done this way, problems can be avoided to the greatest possible extent.

The climate setting process might be thought of as "renegotiating" the classroom atmosphere. Teachers who employ inquiry-based instruction need to be fully cognizant of the fact that students can interpret classroom activities in variety of ways, some of which can be antagonistic to inquiry. In the first column of Table D-7 the reader will find

a number of specific inquiry-oriented activities. In the next two columns the reader will find how students could interpret these activities. The second column relates to a more traditional interpretation, and the third column refers to the intended interpretations most suitable to the inquiry-oriented classroom. Teachers can use these distinctions to help their students understand the value of what it is that they do when they employ inquiry-oriented pedagogical practices.

Table D-7

Renegotiating the Classroom Atmosphere by Providing Alternative Interpretations of Classroom Activities

Specific inquiry-oriented teacher activities	Traditional interpretations of teacher activities	Inquiry-oriented interpretations of teacher activities
teacher asks questions of students	teacher's questions imply evaluation, monitoring, and efforts to control students	teacher seeks clarification and elaboration of students' ideas
teacher focuses on questions rather than answers	teacher does not understand the content of this course	teacher is interested in having us understand how scientists know what they know
teacher deflects "simple" questions to other students or answers one question with another	teacher does not know the answer, or the teacher is too lazy to answer the question.	teacher wants us to learn how to think for ourselves, and/or learn from others
teacher engages a single student in an extended discussion while most of the class waits	teacher believes that the student must misunderstand or has the wrong idea; this attention is unfair to the rest of the students	teacher appears to believe the student has something uniquely valuable to share and is provid-ing an opportunity for other students to learn from someone other than the teacher
teacher makes very selective use of or deemphasizes use of textbook	teacher is a "big shot," and wants to show us what he or she knows	teacher wants us to learn from nature, not authorities
teacher engages students in active and extended scientific inquiry	teacher wants the students to do all the work while (s)he merely wanders around the lab; does not care if we learn	teacher wants students to under-stand the methods of scientific experimentation, and how we come to know
teacher provides opportuni-ties for scientific discussion and debate among students	teacher does not care what we learn or if we are confused	teacher wants us to see that science is a social compact, that knowledge is empirical and depends upon a consensus among scientist
teacher works to make student understanding visible through student presentations and student answers to questions	teacher wants students to feel inferior, stupid, or incapable	teacher wants to know what we think we know so that errors can be identified, confronted, and resolved

(table continues)

Specific inquiry-oriented	Traditional interpretations	Inquiry-oriented interpretations

teacher activities	of teacher activities	of teacher activities
teacher spends time on conceptual development at the expense of back-of-the-chapter exercises	teacher does not have a good understanding of the phenomenon under study and wants to hide ignorance of exercise-working skills	teacher really wants us to understand the concepts of science, not just mathematical number crunching employing formulas
teacher focuses on depth of understanding rather than breadth of coverage	teacher does not want students to know that (s)he has limited knowledge of the subject matter	teacher wants students to understand the content, processes, and nature of science by studying fewer topics in depth

Note. Many of the above characteristic activities come from *National Science Education Standards,* 1996.

Small Group Climate Setting

Successful group-level climate setting does not assume that students possess the requisite social skills to work cooperatively. Because cooperative approaches to education tend to be very interactive and depend strongly on teamwork, teachers must clearly state expectations for student interactions. They must not assume that students will have a good understanding of what it means to work cooperatively. Teachers must assist students in gaining an understanding of the social aspects of cooperative group work. They must assist students to clarify tasks and procedures, and to work together equitably and fairly to attain a common goal. The teacher must help students understand that the solution of a presented problem belongs to them, not the teacher. Below are several team-level participation rules adapted from Roth (2003) for student-on-student interaction within teams. Each team member will:

- be present and ready to work, contribute to the project, and do the work assigned
- communicate accurately and unambiguously, fully expressing ideas

- substantiate claims using evidence
- pass judgments on the value of ideas and not individuals
- ask questions when an idea or fact is presented that they do not believe or understand

In addition, teachers might want use the reflective group processing approach promoted by Johnson, Johnson & Holubek (1988) to help students understand what works and does not work from a student interaction perspective.

Individual Climate Setting

Perhaps one of the most overlooked components of education in traditional and inquiry-oriented classrooms alike is the role of metacognition and its relationship to student self-regulation. Metacognition—knowing what one knows and does not know—is characterized by a student's ability to self-monitor levels of understanding. Self-regulation deals with a student modifying behavior in an effort to learn without direct teacher intervention. Metacognitive and self-regulatory practices aid significantly in student learning in science (NRC, 1999, 2005). Because successful inquiry practice in the classroom depends strongly upon individual student's abilities in these areas, teachers who promote metacognitive and self-regulatory practices are less likely to encounter resistance to inquiry-oriented instruction. While conducting individualized climate setting can be done with a whole class of students, the focus should be on individual cognition and accountability. Other individualized climate setting practices consist of promoting appropriate academic skills—from note taking to test taking. A teacher can help improve students' academic performance by making them more cognizant of the general procedures of "studenting." For students to be the best possible

students they can be, teachers must have a comprehensive understanding of what it means to be both teacher and student. From the teaching perspective, a teacher should be certain to clarify objectives, motivate students, supply models, sequence subject matter appropriately, guide initial student trials, manage practice effectively, provide for recall, help students apply knowledge to new situations, and provide for self-assessment (Rhodes, 1992). The topics of metacognition and student self-regulation are addressed elsewhere, and readers are referred to key resources such as How People Learn (NRC, 1999), and How Students Learn (NRC, 2005).

Working with Non-Students

The inquiry-oriented teacher will at times be disappointed, and at other times dismayed, to learn that parents, administrators, and teaching peers are resistant to inquiry practices. Climate setting can play a critical role when dealing with these individuals as well. It is preferred that climate setting be done in a proactive way, but sometimes—depending upon circumstances—only reactive climate setting can take place depending on the circumstances. Unfortunately, it is not at all unusual to find that parents, administrator, and peer teachers will concern themselves with pedagogical practices only after a "problem" is perceived.

Non-Students Generally

Proponents of inquiry-oriented instruction generally should be prepared to point out the fact that inquiry approaches are being integrated into post-secondary instruction. College and university faculty members are more interested in students who know how to think than in students who know lots of facts. As Vesenka et al. (2000) point out, there

is a growing recognition among higher education faculty that inquiry-oriented instruction improves the level of performance in the areas of critical thinking and problem solving. As a result, more and more colleges and universities are turning to this mode of instruction. This paradigm shift in post-secondary instruction has been well documented on physics education research group web sites such as those at the University of Washington (McDermott, 2005), State University of New York-Buffalo (MacIsaac, 2005), University of Maryland (Redish, 2005), and the University of Maine (Wittmann & Thomson, 2005) among others. It is important to understand that high school students who have been educated through the use of inquiry practices will be better prepared as college and university thinkers than will students who have merely memorized lot of facts and have learned how to do "plug and chug" problem solving.

Parents

It is good to communicate with parents about the inquiry-oriented teaching approaches to be used with their children. Open houses at the start of the school year are particularly valuable for allowing teachers to frankly address potential concerns related to inquiry. For instance, parents legitimately might wonder how the inquiry approach—while moving much more slowly than direct instruction—will adequately prepare students to successfully complete standardized tests. The point can be made that many standardized tests such as the ACT exam are not content tests; rather, they are tests that stress critical thinking skills and the ability to read and interpret graphs. Less structured open house nights might allow for involving parents in a short paradigm lab activity in which they can experience the fun of inquiry. Teachers might also want to post to their websites information that frankly addresses their concerns and "making the case for inquiry."

Administrators and Peer Teachers

Every administrator and peer science teacher should be aware—or made aware of—the many substantive arguments in favor of inquiry so that they can understand or respond to criticisms of inquiry-oriented approaches. In order to prevent, offset, deflect, or defeat complains about inquiry stemming from those both inside and outside the classroom, practitioners of inquiry must be able to make the case for inquiry.

Critical Need for Sustained Climate Setting

Forms of inquiry-oriented instruction such as the Modeling Method, cooperative learning, and problem-based learning, are all subject to various types, degrees, and frequencies of resistance from students, parents, administrators, and teaching colleagues who do not understand the value of inquiry. Teachers employing these methods, therefore, have a critical need to understand the value of inquiry, and an ability to conduct climate.

Climate setting is used to offset resistance to inquiry. The importance and procedures of climate setting and classroom, school, and community atmosphere cannot be over stated. Unless enough time and attention are focused on this aspect of inquiry teaching, resistance can mount. Teachers are encouraged to regularly perform climate setting to help students and others understand how and why inquiry-oriented instruction is different from traditional didactic instruction.

Encountering resistance is relatively common among teachers who employ inquiry-oriented instruction. Fortunately, resistance typically is neither frequent nor strident. What resistance to inquiry exists eventually dissipates as students, parents,

administrators, and peer teachers gain an understanding of the value of the inquiry-oriented approaches employed. The importance of climate setting and atmosphere cannot be over emphasized in minimizing resistance to inquiry-oriented science instruction.

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