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A New Model for Science Teaching

Scientific inquiry is the central nexus of today's science education reform movement. While many times we are encouraged to use inquiry in our teaching, it is as frequently defined so poorly as to make teaching by inquiry very difficult or impossible for those who do not understand how to do so. The current issue of *JPTEO* attempts to fill this void by providing several articles addressing the use of inquiry in the classroom.

The first article, in a series of three related articles, addresses scientific inquiry and its use in introductory physics courses. As such, this article is a generic introduction to the use of inquiry and how it proceeds in general. The second article in this series provides considerable detail about the Levels of Inquiry Model of Science Teaching that was first introduced in 2005 – some six years ago. The Levels of Inquiry Model now incorporates a new learning cycle and an example is given of how this new learning cycle can be fully integrated into each level of inquiry. The third article in this series provides a series of learning sequences – detailed examples of how all the various levels of inquiry can be implemented – and goes on to show how learning sequences can be converted into functional lesson plans. An extensive appendix of these learning sequences is being published separately from this volume of *JPTEO* due to a difference of format and can be found on the Web page associated with this issue.

Experimental inquiry in introductory physics courses

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Physics teacher educators following national science teacher preparation guidelines will both employ and promote the use of experimental inquiry during instruction. In order for in-service physics teachers to use this form of scientific inquiry appropriately, it is important that they possess a basic understanding of the content, nature, and history of science. Indeed, it is imperative for physics teacher educators and their teacher candidates to have a thorough understanding of experimental inquiry so that they come to value it, are more likely to practice it properly, and understand how to help students achieve a higher degree of scientifically literacy.

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 history and nature of science including its nomenclature, intellectual process skills, rules of evidence, postulates, appropriate dispositions, and major misconceptions (Wenning, 2006). Unfortunately, not all teacher candidates learn how to conduct inquiry and not all science teachers use inquiry in an effective fashion. Some in-service science teachers don't employ it at all; others know it but don't know how to teach it.

There are many reasons why established in-service science teachers fail to teach using inquiry (Costensen & Lawson, 1986). Among these reasons is that science teachers themselves often do not possess a holistic understanding of the scientific endeavor. This likely stems from the nature of traditional science teaching at the college and university levels that commonly uses a didactic — teaching-by-telling — approach. Many introductory courses rely on the use of equations to guide instruction at the cost of conceptual understanding. To many students, physics at the introductory level seems to be best characterized by the phrase "the search for the proper equation."

Little attention is given in some teacher education programs to how the processes of scientific inquiry should be taught and acquired. It is often assumed by physicists and physics teacher educators 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. This is most often not the case.

Scientific inquiry processes, if formally addressed at all in the teacher preparation curriculum, are often treated as an amalgam of non-hierarchical activities. Wenning (2005, 2010, 2011) has synthesized a framework for more effective promotion of inquiry processes among students known as the Levels of Inquiry Model of Science Teaching. This article (in conjunction with previously published articles) is designed to help science teachers and teacher educators promote an increasingly more sophisticated understanding of experimental scientific inquiry among their students.

Conducting Scientific Inquiry in the Classroom

Just as in the statement that "not all that glitters is gold," not all science teaching in authentically inquiry oriented even though that might be the intent. Some teachers think that asking students lots of questions constitutes inquiry. Not so. Authentic scientific inquiry has specific characteristics. The reader can see that distinction in the following scenarios and in what follows.

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 starts off asking lots of background questions and then tells his students that light travels in a straight line. He goes on to note that when light 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. He then uses a bright green laser pointer in a darkened room to demonstrate this phenomenon. Finally, he states, "You see, the angle of incidence equals the angle of reflection."

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 and the associated laboratory activities, and both directly and effectively 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 pull one string and hold it in place with a pushpin located near its end. 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 as seen 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 asks, “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 established as a straight line, 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 from the normal. 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 and merely asking students to watch as he confirms what he has said. In Fatima’s case, she is helping students to construct knowledge from their own experiences. 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 Research Council in *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)

The American Association for the Advancement of Science 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. (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 correct — and several specific examples of scientific inquiry are given in the associated texts — these broad characterizations and the associated 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.

Basic Types of Scientific Inquiry

There are many types of scientific inquiry – about as many as there are scientists – but at the most fundamental level these types can be reduced to four: observational, computational, theoretical, and experimental. Still, none of these four can be said to be entirely independent of the others.

Astronomy is an example of what is primarily an observational science. Stars and galaxies cannot be brought into a laboratory for analysis; therefore, variables cannot be manipulated to see the outcome. Scientists apply laws of physics derived from laboratory study to determine the size, temperature, electron density, magnetic field strength, rotation, and other conditions prevailing on the surface. Mathematical processes can be used to model stellar systems from binary stars to star clusters to galaxies.

Scientific modeling based on mathematics (the “queen of sciences” according to Gauss) is a good example of computational scientific inquiry. Models are constructed and modified until they work analogously to real-world systems. Of course, agreement with existing external observations does not necessarily imply that a model is consistent with reality. Only with additional experimental procedures or observations can that conclusion be drawn.

Hypothesis development and testing constitute the major processes of theoretical inquiry. Induction and deduction are part and parcel of what many physicists do today. A study of the history of modern physics shows how the major ideas concerning the structure of the atom were developed and tested.

Experimental sciences allow for the controlled testing of independent variables, changes in dependent variables, and with the use of mathematical processes the analysis of the data. Physics is perhaps the preeminent experimental science as it is among the best suited for teaching experimental procedures in the classroom. Physics provides classroom opportunities for experimental manipulation and visualization and graphing, principle and law production. These are not as readily available in studies of astronomical, chemical, biological, environmental, and earth sciences. The use of experimental inquiry in physics encompasses all forms inquiry in as much as observational, computational, and even theoretical processes can used in the planning, execution, analysis, and explanation of an experiment.

Experimental Inquiry in Introductory Physics

For the purpose of operationally defining experimental scientific inquiry at a level appropriate for introductory physics courses, the author provides an ordered listing of experimental skills necessary for conducting scientific inquiry in Table 1. While the listing in Table 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", 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 physics at the secondary school level is generally not driven by hypothesis/theory development, but that typically data are collected for the purpose of formulating principles, developing empirical laws, or constructing models. Finally, this listing was prepared with the understanding that not all inquiry processes will be experimental in nature. Sometimes reason 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 from scientific inquiry based on experimentation or computation. Astronomers, geologist, biologists, chemists, and physicists all have different approaches to conducting scientific investigations and will use various elements of the listing to different degrees.

Table 1. *Framework providing an ordered listing of scientific inquiry skills inherent in introductory-level scientific inquiry. This framework is intended to be suggestive, not definitive.*

- Identify a problem to be investigated.
- If appropriate:
    - use induction to formulate a hypothesis or model incorporating logic and evidence.
    - use deduction to generate a prediction from the hypothesis or model.
    - design experimental procedures to test the prediction.
- Conduct a scientific experiment, observation, or simulation to gather data, test a hypothesis or substantiate a 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 principle using induction or a law based on evidence that uses graphical methods or other mathematic model
- 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.

Characterizing Experimental Inquiry

Even with the framework for characterizing experimental scientific inquiry given in Table 1, some student teachers and in-service teachers might still not have a fully developed understanding of how scientific inquiry is done or taught. 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 (Reif, 2008). 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 funneling type of questioning (Wood, 1998) does not constitute authentic inquiry. Scientific inquiry is NOT a teacher asking lots of questions, and neither is having students solve "puzzle problems" at the end of a textbook chapter, looking up vocabulary definitions, or completing worksheets. Neither is inquiry 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-oriented instruction. Among these are the following:

- *Misconception: Inquiry-oriented instruction 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 amounts 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 address 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.

- *Misconception: 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 allows students to identify questions, and develop and follow their own procedures to answer those questions. Teachers need to be aware of the fact that much of the inquiry process occurs both before "doing" a lab, as well as after. The actual hands-on components aren't always the most important parts.

- *Misconception: 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.

- *Misconception: 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 experimental inquiry is one of the backbones 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 science instruction. Every teacher educator, every teacher candidate, and every in-service teacher should be fully cognizant 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: *Through inquiry-oriented instruction,*

1. *students learn about science as both process and product*. Understanding science consists of more than just knowing facts or being able to find and solve the proper equations. 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, calculations, and critical thinking. Properly constructed inquiry-oriented laboratory activities will include some opportunities for designing investigations that 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. *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. Students do not enter the classroom with minds that are *tabulae rasae* — blank slates — 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 either replacing or modifying and refining their current understanding. In an inquiry-oriented classroom, the quality of classroom discourse is dramatically improved with the use of such things as whiteboards and Socratic dialogues (Wenning, 2005; Wenning, Holbrook & Stankevitz, 2006). Teachers conducting Socratic dialogues come to understand what students know, and can identify, confront, and resolve preconceptions that limit students' understanding.

3. *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 – passing a test.

4. *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 science classroom. Directly experiencing natural phenomena and discussing results helps students understand that science is the work of a community of real people, and that "genius" in science 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. Science might be thought of as a process of developing knowledge by consensus. Disagreements must be worked out between students. The teacher is not viewed as the ultimate "authority" in a true inquiry-oriented classroom.

5. *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 indoctrinating them to become uncritical consumers of information, or we can help them learn the nature and values of science thereby gaining a scientific worldview. Do we not want to graduate students who are rational and skeptical inquirers rather than intellectual plebiscites? Of course we do, and inquiry-oriented instruction is one way to achieve it. Using such instructional practices, student learn comes 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. *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 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.

7. *students can come together in cooperative groups to develop the mental operations and habits of mind that are essential to developing strong content knowledge, appropriate scientific dispositions, and an understanding of both the nature of science and scientific knowledge.* 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. 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.

8. students can receive the motivation they need to learn science and pursue science-related careers. Actively learning science content through first-hand experiences is much more interesting for students when compared to passively accepting it as "received wisdom". Inquiry-oriented instruction can serve as an important motivational tool for getting students to consider careers in the sciences and help to maintain classroom discipline. Students who experience the joy and wonder of creativity and discovery are more likely to pay attention in class and become scientists (or science buffs) than perhaps through any other process.

Teacher educators, teacher candidates, and in-service teachers need to realize that scientific inquiry is suitable for use and as subject matter for study at all grade levels. 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 using inquiry-oriented instruction. 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 in comparison to soaking it up on their own through "osmosis" (Wenning, 2006).

Approaches to Experimental Inquiry

As a study of the history of science shows, there are many approaches to 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 or models 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 <u>observation experiment</u> 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 <u>testing experiment</u> 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 <u>application experiment</u> 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 experiencing various levels of inquiry.

Levels of Inquiry Model of Science Teaching

The Levels of Inquiry Model of Science Teaching (Wenning, 2005, 2010, 2011) provides a framework for inquiry-oriented instruction in the introductory science classroom. It is summarized very briefly here. The author refers readers to the above articles for detailed information and examples exhibiting the use of this model.

Levels of inquiry is an inquiry spectrum consisting of discovery learning, interactive demonstrations, inquiry lessons, inquiry labs (guided, bounded, and free), and hypothetical inquiry (pure and applied). These are arranged in increasing order of intellectual sophistication with the locus of control shifting from teacher to student. Each level of inquiry is associated with intellectual and scientific process skills. Each of the levels in the inquiry spectrum is associated with a 5-stage Levels of Inquiry Model for Science Teaching learning cycle consisting of student-centered activities: observation, manipulation, generalization, verification, and application. Instructional plans based on the inquiry spectrum are known as learning sequences, numerous examples of which are provided by Wenning & Khan (2011).

Conclusion

Science teachers cannot teach what they do not know. This is true both in relation to the content and processes of science. Inquiry is among the most essential of components in the "tool kit" of science teachers. Without a deep understanding of inquiry, its types and approaches, teachers are left handicapped when it comes to teaching using reformed approaches called for in the current science education reform movement. Without an understanding of inquiry and methods for teaching using inquiry-oriented approaches, it is highly unlikely that many, if not most, students enrolled in introductory physics courses will have much of a chance to become scientifically literate in this critically important area.

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The Levels of Inquiry Model of Science Teaching

(Shaded sections added January 2012; refer to Wenning (2010) for explications of real-world applications component of the Inquiry Spectrum.)

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The Levels of Inquiry Model of Science Teaching is reviewed and explicated. The Model's levels – discovery learning, interactive demonstrations, inquiry lessons, inquiry labs, and hypothetical inquiry – are integrated with a new 5-stage learning cycle to produce a refined model for science teaching. By systematically addressing levels of inquiry with the use of the associated learning cycle, students develop a wider range of intellectual and scientific process skills. Syntaxes are presented to explain how best to implement learning sequences that promise to lead to a more comprehensive form of scientific literacy. An example of a learning sequence that incorporates the new learning cycle is provided.

Models of Science Teaching

Models of teaching provide a basis upon which coherent instructional practices can be based. Instructional models help practitioners understand the importance of and relationships between various activities associated with teaching. Instructional models also provide the framework for interactions between teacher and students. For instance, in a teacher-centered instructional model the focus is placed more on the teacher transmitting information, whereas in a student-centered instructional model the focus is placed more on students constructing knowledge from experiences.

The goal of an instructional model is to help students learn. Any such model should be based upon supportable theories of learning. While more than 20 models of teaching were described by Joyce & Weil (1986), a small subset of these models seem most suitable to science instruction. Among these are constructivist, sociocultural, inquiry, and direct/interactive models. These models stem from ideas proffered by educational theorists such as Dewey, Brunner, Piaget, Vygotsky, and others.

Based upon the works of these theorists, as well as on the efforts of science education researchers, many science teachers and science teacher educators today will agree that there are emerging themes that all science teaching models should incorporate. Hassard and Dias (2005) identified five such themes. According to Hassard & Dias, science instruction should be active, experiential, constructivist, address prior knowledge, and include cooperative and collaborative work. Learning sequences based upon the Levels of Inquiry model of science teaching incorporates these themes, and even more.

A Levels of Inquiry Redux

Earlier works by Wenning (2005a, 2010) introduced the Levels of Inquiry Model for science teaching and later explicated the associated learning sequences. The author pointed out that by systematically addressing the various Levels of Inquiry – discovery learning, interactive demonstrations, inquiry lessons, inquiry labs, and hypothetical inquiry (collectively known as the inquiry spectrum) – teachers would help students develop a wider range of intellectual and scientific process skills. Now included in the inquiry spectrum is real-world applications with its two variants – solving end-of-chapter textbook problems and solving authentic problems. When the general inquiry spectrum is translated into day-to-day classroom lessons, a learning sequence results.

To more fully appreciate what the inquiry spectrum does for both teacher and students, it is imperative to examine the primary pedagogical purposes of each of the levels of scientific inquiry. They are outlined in Table 1.

Level of Inquiry	Primary Pedagogical Purpose
Discovery Learning	Students develop concepts on the basis of first-hand experiences (a focus on active engagement to construct knowledge).
Interactive Demonstration	Students are engaged in explanation and prediction-making that allows teacher to elicit, identify, confront, and resolve alternative conceptions (addressing prior knowledge).
Inquiry Lesson	Students identify scientific principles and/or relationships (cooperative work used to construct more detailed knowledge).
Inquiry Laboratory	Students establish empirical laws based on measurement of variables (collaborative work used to construct more detailed knowledge).
Real-world Applications	Students solve problems related to authentic situations while working individually or in cooperative and collaborative groups using problem-based & project-based approaches.
Hypothetical Inquiry	Students generate explanations for observed phenomena (experience a more realistic form of science).

Table 1. *Focus of each of the model's six levels of inquiry. This table is suggestive, not definitive.*

The Levels of Inquiry Model of Science Teaching is based in part on John Dewey's turn-of-the-twentieth-century call for experiential learning. Dewey's call for the use of experiential learning and inquiry practice was directed toward enhancing the general scientific literacy of school children. He argued that teaching theory should be more closely associated with desired outcomes (1904), and that the best way to get students to become more scientifically aware and informed is through the processes of experiential learning – having students learn science by mimicking the work of scientists. Six years later, Dewey (1910, p. 25) noted, "Science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject-matter." Dewey envisioned learning driven by a series of rudimentary learning cycles (modern parlance) in which students would receive an impulse, make an observation, derive a conclusion from that observation, and make a judgment as to its worth. The students would then complete another such cycle of learning triggered by a new impulse. By completing a series of such cycles, students would build up knowledge on the basis of experience. (See Figure 1.)

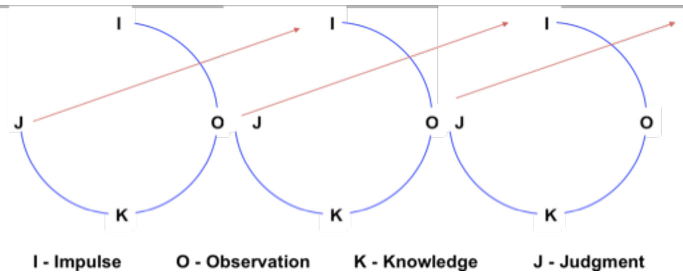

Figure 1. *John Dewey's 1904 Model of Experiential Learning*

While Dewey's was a thought-provoking idea, it was never widely adopted. From a modern perspective, the problem with Dewey's model of experiential learning is that it is essentially "horizontal." While it does utilize a very rudimentary form of learning cycle, the model did not directly call for development of progressively more sophisticated scientific and intellectual process skills that we want to inculcate among students today in this vastly more advanced technological age. The Levels of Inquiry Model of Science Teaching takes these factors into account and uses a more sophisticated form of learning cycle that more closely mirrors the work of professional scientists. This newer 5-phase learning cycle and its relationship to the inquiry spectrum is shown in Figure 2.

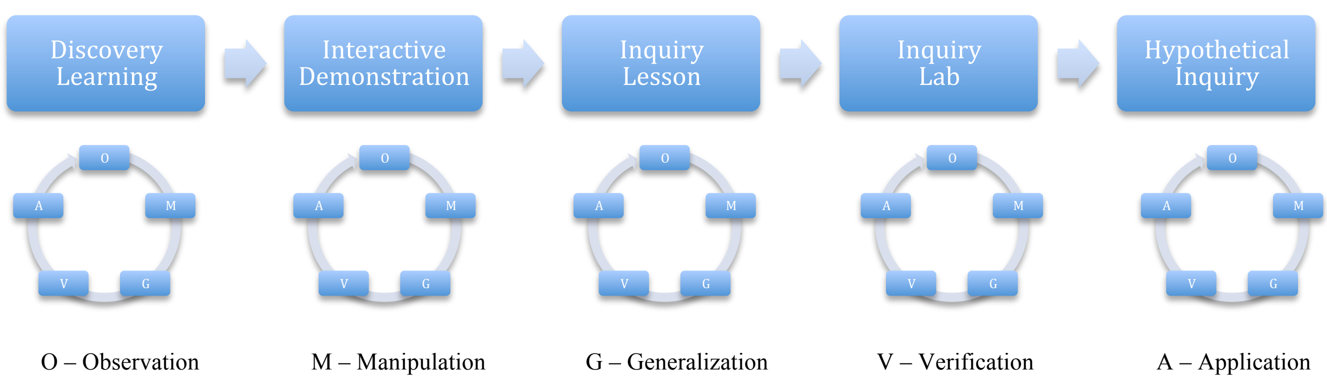

Figure 2. *Levels of Inquiry Model of Science Teaching*

The Inquiry Spectrum's Relationship to Learning Cycles

Many different learning cycles have been proffered since Robert Karplus introduced his learning cycle in 1962. The number of learning cycles has proliferated substantially since that time, each with its own emphasis and viewpoint on teaching. Table 2 gives a number of learning cycles that have been applied to science teaching more recently.

Learning cycles are essential elements of science instruction because they help teachers sequence learning activities. They can provide structure for lesson planning and delivery. By using learning cycles as guides, teachers can more easily plan instruction that mimics the way that scientists tend to work. By integrating a learning cycle into each components of the inquiry spectrum, students can gain a much more comprehensive understanding of all the intellectual and scientific process skills that are inherent in each of the levels of inquiry. Indeed, the Levels of Inquiry Model of Science Teaching is a series of learning cycles operating within the context of a larger cycle that encompasses different levels of inquiry. The over arching levels of inquiry cycle will be initiated each time new subject matter is introduced.

The various levels of inquiry – discovery learning, interactive demonstrations, inquiry lessons, inquiry labs, and hypothetical inquiry – are more fully explicated with the use of a learning cycle. A new 5-stage learning cycle introduced with this article provides additional structure to each level of the inquiry spectrum. By moving through the various stages of a learning cycle and levels of the inquiry spectrum, a student more fully comprehends science as both process and product, and gains a much deeper understanding of the scientific enterprise. *This new 5-stage learning cycle constitutes the basic syntax for each level in the Levels of Inquiry Model of Science Teaching.*

3-Stage Karplus	4-Stage Art of Teaching Science	4-Stage Dykstra	5-Stage Bybee	7-Stage Eisenkraft	5-Stage Levels of Inquiry
Exploration Invention Discovery	Invitation Exploration Explanation Taking Action	Elicitation Comparison Resolution Application	Engage Explore Explain Elaborate Evaluate	Elicit Engage Explore Explain Elaborate Evaluate Extend	Observation Manipulation Generalization Verification Application

Table 2. *Learning cycles applied in science teaching; modified from Gallagher (2006)*

The 5-Stage Levels of Inquiry Learning Cycle

The new 5-stage Levels of Inquiry learning cycle originated from some 15 years of teaching experience within the Illinois State University physics teacher education program. While not substantially different from any of the learning cycles identified in Table 2, this 5-stage learning cycle places a consistent and stronger emphasis on the action of students rather than on the actions of the teacher, and – in the author's opinion – perhaps more simply and more closely mimics the overall processes of rudimentary physical science. The five stages of the Levels of Inquiry learning cycle are as follows:

- *Observation* – Students observe a phenomenon that engages their interest and elicits their response. Students describe in detail what they are seeing. They talk about analogies and other examples of the phenomenon. A leading question is established that is worthy of investigating.
- *Manipulation* – Students suggest and debate ideas that might be investigated and develop approaches that might be used to study the phenomenon. They make plans for collecting qualitative and quantitative data and then execute those plans.
- *Generalization* – Students construct new principles or laws for phenomena as needed. Students provide a plausible explanation of the phenomenon.
- *Verification* – Students make predictions and conduct testing using the general law derived from the previous stage.
- *Application* – Students set forth their independently derived and agreed-upon conclusions. The conclusions are then applied to additional situations as warranted.

Throughout this 5-stage process, students continuously communicate ideas, approaches, processes, data, and results – including difficulties and tribulations. They share in successes and redress failures. They operate as members of both small and whole group communities to develop, confirm, and apply findings derived at each level of inquiry.

General Syntaxes of the Various Levels of Inquiry

While the 5-stage learning cycle constitutes the basic syntax of teaching within the inquiry spectrum, it is very broad and subject to modification when utilized. Several examples are now provided that represent (if not with perfect precision) how learning cycles are implemented within the Levels of Inquiry Model. In the strictest sense of the term "syntax", there are no specific steps that must always be followed. In a more pragmatic sense, general syntaxes will flow from but not slavishly adhere to the 5-stage learning cycle.

The reader should keep in mind that teaching is more of an art form than a science. There is no established set of rules that educators can point to and say, "Do this; it will work every time." The educational process is complex and there are as many ways of teaching as there are teachers. Nonetheless, the Levels of Inquiry Model of Science Teaching suggests certain general practices and approaches that are described here as syntaxes.

As students move from guided to bounded to free inquiry labs and then on to hypothetical inquiry, the locus of control shifts from the teacher to the students. As students – perhaps working individually – move through the forms of hypothetical inquiry, their work becomes intensely individualistic and even private. As a result, syntactic steps are not presented for either more advanced labs and hypothetical inquiry because it is now primarily up to students to design and conduct their own lab activities and provide and work out their own hypothetical explanations. These processes necessarily will be idiosyncratic in nature and cannot therefore be supplied.

How subject matter is introduced to students will depend strongly on the nature of that subject matter. In some subject matter various aspects of the 5-stage learning cycle will be emphasized and others deemphasized, or perhaps skipped altogether. For instance, helping students to discover concepts related to motion (a very concrete activity) will likely be considerably different from learning about the concepts related to relativity (a much more abstract form of student learning). Nonetheless, it is still possible to provide useful generalities.

Discovery Learning

Discovery learning entails developing conceptual understanding on the basis of experience. Descriptions of the phenomenon (answers to "what" and "how" questions) are elicited. Explanations of the phenomenon (answers to "why" questions) are not elicited. However, if unsolicited explanations do arise, they should be set aside for future investigation. The following general steps can be used to develop concepts at this level of the inquiry spectrum:

1. The teacher introduces students to one or more interesting physical examples of a phenomenon to be studied. Students are attracted to and intrigued by the display of the phenomenon.
2. The teacher asks students to describe (not explain) what they are seeing, and to relate commonalities they are seeing between the various examples.
3. The teacher encourages students to identify, and describe other analogous physical situations where the phenomenon also might be observed.
4. The teacher encourages students, now working in small groups, to interact with various examples of the phenomenon, encouraging them to change variables and see what the effect is on the phenomenon.
5. The teacher asks students to discuss ideas, identify relationships, draw conclusions, and develop insights as to what is happening – what accounts for the phenomenon being observed.
6. As appropriate, the teacher provides names for the concepts so developed.

Interactive Demonstration

Sokoloff & Thornton (2004) provide an 8-step approach for conducting interactive lecture demonstrations, the first seven of which are generally consistent with the interactive demonstration component of the inquiry spectrum as well as the model's 5-stage learning cycle. Paraphrasing their first seven steps and replacing their eighth, provides the following general syntax for the inquiry spectrum's interactive demonstrations:

1. The teacher introduces a demonstration describing the mechanical process that will be followed to exhibit the desired phenomenon. This is done entirely without explanation or a statement of outcome.
2. The teacher asks students to think about what will happen and why it will happen when the demonstration takes place, and to state their individual predictions and explanations in writing.
3. The students are engaged in small group discussions with their one or two nearest neighbors, the purpose of which is to share their predictions and explanations in the hope that they will self correct in the light of alternative predications and explanations.
4. The teacher elicits from the students a common prediction and explanation using a consensus-building process.
5. The students record, each on their own record sheet, the group's final prediction and explanation.
6. The teacher carries out the demonstration in an obvious fashion with results being clearly evident. The demonstration is repeated as necessary until the outcome is clear.
7. The teacher asks the students to compare the results of the demonstration with both sets of predictions. The teacher identifies any alternative conceptions that have been elicited.
8. If authentic alternative conceptions are identified (as opposed merely to student learning difficulties), the teacher confronts and resolves the alternative conceptions, and reinforces new learning using the Elicit-Confront-Identify-Resolve-Reinforce (ECIRR) approach for dealing more effectively with alternative conceptions (Wenning, 2008).

Inquiry Lesson

The inquiry lesson employs a think-aloud protocol in which the teacher encourages students to act like scientists in a more formal experimental setting where efforts are now taken to define a system, and both control and manipulate a single independent variable to see its effect on the single dependent variable. The following general procedures should be used:

1. The teacher identifies the phenomenon to be studied, including the goal of the investigation. The teacher clearly enunciates the guiding question for the investigation to follow.
2. The teacher encourages students to identify the system to be studied, including all pertinent variables. Students are asked to distinguish between pertinent and extraneous variables.
3. The teacher encourages students to identify those independent variables that might have an effect on the dependent variable.
4. The teacher asks students to devise and explain a series of controlled experiments to determine qualitatively any effects of the independent variables on the dependent variable. The teacher uses a think-aloud protocol to

explain what is happening experimentally and why it is being done in the fashion demonstrated.

5. The students, under the watchful eye of the teacher, conducted a series of controlled experiments to determine qualitatively if any of the independent variables has an affect on the dependent variable under controlled conditions.
6. The students, with the assistance of the teacher, state simple principles that describe all relationships observed between the input and output variables.
7. The teacher, with the aid of the students, clearly identifies those independent variables that need to be further studied in relation to the dependent variable in a follow-up inquiry lab that will be used to identify more precise relationships between variables.

Inquiry Labs, Real-world Applications, and Hypothetical Inquiry

Because students become more and more knowledgeable about the processes of science as they repeatedly progress through the inquiry spectrum employing the associated 5-stage learning cycle, they become more and more independent in both thought and action despite the fact that the intellectual sophistication of the tasks before them increases with each level. Because this is so, it is less incumbent upon the teacher to provide students with a script for action. While this might be necessary to so during the early part of a course, it becomes much less necessary – and perhaps an anathema as students see it – as the school year progresses. As a result, the locus of control shifts from the teacher to the students and the need for a general syntax – even the advisability of such syntax – becomes questionable. Nonetheless, the teacher should still proctor student work and be prepared to respond to questions when the students are confounded. Students should be reminded to follow in general the five-stage learning cycle associated with the Levels of Inquiry Model that tends to be characteristic of the work of scientists. Teachers generally should avoid directly answering student questions; rather, they should gently coax them to answer their own questions with the use of leading questions, and provide hints as necessary.

Learning sequence example from optics

An example is now provided showing how levels and inquiry and learning cycles can be integrated to produce a learning sequence dealing with lenses. The general idea for the lesson was derived from the Modeling Method of Instruction, and assumes that students understand shadow formation and that light propagates in straight lines. The main goal of the learning sequence is to have students construct an understanding of how a refracting telescope works.

Discovery Learning (using lenses as hand magnifiers)

- *Observation* – Students are given two convex lenses, one thick compared to the edge (short focal length) and one thin compared to the edge (long focal length). At the teacher's direction, students describe the differences in shape and any other things they can determine about the lenses – what they do, how they perform and so on. Students write their findings on whiteboards that include such things as ability to provide erect and inverted images
- *Manipulation* – Students are asked to determine if there is any relationship between the "thickness" of the lenses and the size of images (magnification) they view through them if held the same distance from a printed page. Or, they might be asked to determine the relationship between the distance of an object from the lens and the lens' ability to product erect or inverted images.
- *Generalization* – Students generate one or more rules for convex lenses such as, "Thick lenses produce larger images than do thin lenses when held at the same distance from a piece of newsprint." or "There is a specific distance for each lens where the image shifts from erect to inverted. The distance appears to be related to the thickness of each lens."
- *Verification* – Because scientific conclusions are the purview of the scientific community and not the individual or even a small group within the community, these findings are again shared with the whole group so that the conclusions can be checked and verified.
- *Application* – Once the community of learners has verified the findings of individuals and groups, students apply what they have learned to new situations. For example, students complete a worksheet or answer a series of "what if" questions from the teacher that apply the knowledge to specific situations.

Interactive Demonstration (using a lens to project)

- *Observation* – Students observe as the teacher uses a large convex lens to project an image of a bright outdoor scene onto a screen within the darkened classroom. With the instructor's use of leading questions, the students note such things as the focal distance and that the image is inverted and in color.
- *Manipulation* – The teacher, referring to this set up, suggest a number of experiments to determine what controllable factors influence the production of the image. For example, the teacher suggests the change in lens thickness (using another lens) to see how it affects the focal distance. Students make predictions and then the demonstration is carried out. They might suggest changing the effective size of the lens by masking its edge to see what effects diameter have on the image production. Again, students make predictions before the demonstration is carried out. The teach might ask what would happen if a hand – held far from the lens and the very close to the lens – was used to cast shadows on the lens to see effect on the image produced. The students again predict and their forecasts checked with another set of demonstrations.

- *Generalization* – Based on their experiences with the demonstrations, students draw conclusions and document their findings in writing.
- *Verification* – Students then receive two index cards from the teacher – one with a pinhole in the center and the other without a pinhole. They are asked to hold the index card with the pinhole nearer the window and place the second index card in the shadow of the first. They can then study the new image and compare with the results from the lensed projection.
- *Application* – The teacher asks the students to determine whether or not a pinhole acts like a convex lens and visa versa. If so, to what extent? How are pinholes and convex lenses different?

Inquiry Lesson (understanding image projection)

- *Observation* – Students watch as the teacher explains how to use a pinhole projector to produce the image of a light bulb on a screen. (A small box with a pinhole in one end and a cut out with a wax paper screen on the other does well. The box is cut in half allowing the two sections to slide in and out of one another allowing the distance between the pinhole and screen vary.)
- *Manipulation* – During this phase, students are asked to describe which pertinent and controllable factors might influence the shape, size, orientation, and overall appearance of the projected image. Only one of the many possibilities are actually implemented during this phase without making precise measurements, reserving the other possibilities for study during a follow-up laboratory activity.
- *Generalization* – Modeling scientific inquiry, students are asked to generalize the findings from the prior phase using appropriate terminology.
- *Verification* – The students are now given pinhole projectors and light bulbs of their own and asked to verify individually or in small groups the single finding of the whole group.
- *Application* – The students are informed that they will now use variations of the approach just used to conduct a qualitative study of the other components of the pinhole camera system.

Guided Inquiry Lab (finding qualitative relationships among variables using controlled experiments)

- *Observation* – The teacher, reviewing the inquiry lesson, asks students to conduct controlled experiments with the pinhole projector and light source such that there is only one independent variable and one dependent variable. The teacher gets students to define pertinent variables such as d_o (distance of the objective from the pinhole), d_i (distance of the image from the pinhole), h_o (height of the light bulb filament), and h_i (height of the filament image) prior to beginning the next phase.
- *Manipulation* – Students, conducting controlled qualitative experiments (no measuring instruments permitted), change one variable at a time while holding two constant and allowing the fourth the vary to see the consequences of changes in the first.
- *Generalization* – Students, making a series of observations while changing the independent variable over a wide range, write their findings in words (no mathematic equations) on a whiteboard or other surface that can readily be shared with the entire group.
- *Verification* – By communicating results, students find that other study groups have drawn the same conclusions from evidence. If there are any conflicts additional data are collected until such time as it is clear that nature does act uniformly and that differences that arise are likely the result of human error. This helps students to understand the nature of science (Wenning, 2006).
- *Application* – The students complete a worksheet that includes multiple examples of ray tracings that explain why the image is fuzzier when using a large pinhole, why images are inverted in relation to the object, why the image is larger if the screen is made more distant from the pinhole and visa versa, why the image gets smaller for a fixed pinhole-screen distance if the distance between the lamp and the pinhole gets smaller and visa verse, how changing the orientation or size of the light bulb affects the image, why multiple pinholes produce multiple images and so on.

Bounded Inquiry Lab (finding relationships among quantifiable variables using controlled experiments)

- *Observation* – In a follow-up discussion, students discover that other students observed the same basic relationships (e.g., as d_i increases, h_i increases under the condition of fixed system parameters).
- *Manipulation* – The teacher jigsaws the larger problem into smaller components (e.g. two groups conduct a controlled study of the relationship between d_i and h_i, another two groups study the relationship between d_o and h_i, etc.)
- *Generalization* – Students collect pertinent data and generate mathematical relationships using graphical analysis.
- *Verification* – Students share their mathematical findings (e.g., $d_i \propto h_i$, $d_i \propto 1/h_o$, do $\propto h_i$, and $d_o \propto 1/h_o$) with other groups, and confirm findings as appropriate.
- *Application* – Students combine the small group findings to produce a general relationship between quantifiable variables (e.g., $h_i/h_o = d_i/d_o$). Students are encouraged to find a definition of magnification, M. They should easily be able to produce the following relationship: $M = h_i/h_o$.

(continued next page)

Real-world Applications (developing a working definition of magnification)

- *Observation* – Students are provided with an optical bench and a set of three of lenses consisting of one long, one intermediate, and one short focal length lens. They are then asked to "invent" a telescope that produces a maximum magnification of a distant object.
- *Manipulation* – Students – already knowing what a telescope looks like – switch out various lenses to serve as objective and eyepiece. They conclude that the maximum magnification is achieved when the longest focal length lens is used as an objective and the shortest focal length lens is used as an eyepiece.
- *Generalization* – Students enunciate a rule to the effect that magnification, M, is proportional to the focal length of the objective, F, and inversely proportional to the focal length of the eyepiece, f.
- *Verification* – Students exchange various combinations of lenses for objective and eyepiece and verify if the rule they have proposed, $M \propto F/f$, is likely to be correct.
- *Application* – Students determine the focal lengths of all lenses by projecting images of very distant objects onto a sheet of paper and measuring the distance between the lens and the paper. From these data, they calculate the magnifications of various combinations of lenses.

Applied Hypothetical Inquiry (explain how a refracting telescope works)

- *Observation* – Students observe as the teacher uses two lenses in combination to produce images as with a refracting telescope. Student attention is drawn to the fact that the image is inverted despite the fact that light from the object pass through two lenses.
- *Manipulation* – Students are given one long and one short focal length convex lens and told to "invent" their own telescope.
- *Generalization* – Students attempt to explain the role of the lenses to both project a real image (using the long focal length objective lens) and to examine that image with the use of a short focal length hand magnifier (eyepiece).
- *Verification* – Students verify that a real image is indeed produced between the objective and the eyepiece by inserting an index card in the focal plane of the objective lens.
- *Application* – Students use their knowledge of how a refracting lenses work to provide an explanation of how a refracting telescope works something to the effect that, "An objective lens produces a real image on a plane and an eyepiece is used beyond that focal plane to both to view and magnify the resulting image."

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Pure Hypothetical Inquiry (accounting for the nature of the magnification relationship)

- *Observation* – Students look through a telescope set up on an optical bench that consists only of an objective lens and an eyepiece lens. The telescope is focused on a very distant object. The teacher introduces a sheet of paper into the focal plan of the objective where the students clearly see that a real image is formed.
- *Manipulation* – Students are informed of the focal lengths of both lenses and ask to determine the relationship between these focal lengths and the separation between the lenses when a very distant object is clearly focused. They conclude that the separation is $F + f$, the sum of the focal lengths of the objective and eyepiece lenses.
- *Generalization* – Students draw a ray diagram for the distant object, objective lens, eyepiece, and eye. Between the objective and the eyepiece, they denote the position of the objective's image plan and draw an inverted real image produced by the objective such as an arrow. From this construct and by comparing the true angular size of the object with the apparent size of the object as seen through the eyepiece, students determine that the magnification of the system is simply a ratio of the focal lengths of the objective and eyepiece, F/f.
- *Verification* – Students can confirm the above relationship by comparing it with outcomes from the pinhole projection activity in which $M = h_i/h_o = d_i/d_o$
- *Application* – Students compare the results of magnification from the formula, $M = F/f$, and the ratio of true and apparent angular sizes of the object.

Implementing the Levels of Inquiry Model

Creating effective learning sequences can be a daunting and time consuming task, as the author's experiences have shown. Perhaps that is because many of us as teachers don't have many experiences explicitly developing detailed, progressive, and increasingly sophisticated lessons for our students. If learning sequences based on the Levels of Inquiry Model of Science Teaching are to be generated, perhaps they should be the effort of work groups such as used with the lesson study process (Stigler & Hiebert, 1999). This approach has been used with considerable success in the Physics Teacher Education program at Illinois State University (Wenning & Khan, 2011).

Clearly, the time required to prepare and teach a learning sequence using the Levels of Inquiry Model of Science Teaching is considerable. This is only one of the many reasons that some science teachers fail to include inquiry practices in their instruction (Costenson & Lawson, 1986). Other reasons include time and energy, too slow, reading too difficult, risk too high, tracking, student immaturity, teaching habits, sequential text, discomfort, too expensive, and lack of teaching materials suitable for hands-on learning. These problems, either perceived or real, and how to address them have been dealt with earlier by

Wenning (2005b). In-service teachers should be aware of the fact that as students move repeatedly through the various levels of inquiry and the associated learning cycles, the whole process of developing these kinds of learning activities becomes second nature to the teacher.

There are additional sources of resistance to inquiry that comes from sources such as peer teachers, school administrators, parents, and even the students themselves. The author has addressed how teachers can effectively deal with these types of resistance through the processes of climate change (Wenning, 2005c).

Granted, no teacher who is concerned with breadth of coverage as well as depth of instruction will want to use learning sequences exclusively. That is acceptable and understandable. However, to use more didactic approaches (e.g., direct instruction) to the near exclusion of inquiry-oriented teaching is troubling, as teaching by telling is known not to be terribly effective for developing long-term understanding. Equation-based teaching often leaves students with precious little conceptual understanding that can be readily applied to real world experiences.

Levels of inquiry, the inquiry spectrum, learning sequences, and classification of their associated skills will continue to be refined as more learning sequences are developed. Such is the development of an educational model.

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Levels of Inquiry Model of Science Teaching: Learning sequences to lesson plans

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This article presents a framework for lesson planning using the Levels of Inquiry Model of Science Teaching. The model's inquiry spectrum consists of discovery learning, interactive demonstrations, inquiry lessons, inquiry labs, and hypothetical inquiry. Each level of this inquiry spectrum is associated with a 5-stage learning cycle consisting of observation, manipulation, generalization, verification and application This article provides several examples of learning sequences showing how to plan lessons for each level of inquiry. The article has implications for classroom teachers, teacher educators and researchers who are directly involve in the teaching and learning process dealing with the construction of pedagogical content knowledge in the areas of introductory physics.

The Levels of Inquiry Model of Science Teaching (Wenning, 2005, 2010, and 2011) is an approach to instruction that systematically promotes the development of intellectual and scientific process skills by addressing inquiry in a systematic and comprehensive fashion. When taught using the Levels of Inquiry approach, students have the opportunity to make observations, formulate predictions, collect and analyze data, develop scientific principles, synthesize laws, and make and test hypotheses to generate explanations. The leading author's various articles dealing with Levels of Inquiry provide a framework for inquiry-oriented instruction by way of its inquiry spectrum. No longer is inquiry-oriented teaching to be seen as an amalgam of convoluted and disconnected processes. Rather, it is to be treated systematically as a series of hierarchical approaches each with affiliated process skills.

Wenning (2005) presented a hierarchy of inquiry-oriented teaching approaches that included the following levels: discovery learning, interactive demonstrations, inquiry lessons, inquiry labs, and hypothetical inquiry. Discovery learning helps students develop concepts on the basis of teacher-directed experiences. Interactive demonstrations help teachers elicit, identify, confront, and resolve alternative conceptions. Inquiry lessons guide students to identify scientific principles and/or relationships. Inquiry labs allow students to establish empirical laws based on measurement of variables. Hypothetical inquiry permits students to derive explanations for observed phenomena. The inquiry spectrum constitutes a progressive level of intellectual sophistication and changing locus of control that shifts from the teacher to the student.

Wenning (2010) associated the inquiry spectrum with learning sequences for the first time. Learning sequences are specific cases of the application of the inquiry spectrum. Learning sequences help to ensure that students develop a wider range of intellectual process skills than are promoted in a typical introductory physics course that uses more limited modes of instruction. Wenning notes that it is imperative for teacher educators, teacher candidates, and in-service teachers to have a thorough understanding of the full spectrum of inquiry-oriented approaches to teaching so that they can more easily help teacher candidates and students achieve a higher degree of scientifically literacy. To give a more practical understanding of the inquiry spectrum framework and associated learning sequences, contextualized examples were provided.

Wenning (2011) provided more information about the Levels of Inquiry Model of Science Teaching by associating the inquiry spectrum with a new 5-stage learning cycle that incorporates observation, manipulation, generalization, verification, and application. Each of these stages focuses attention on student activities and provides a more practical example of the nature of typical scientific approaches in the study of the world.

The present authors now provide a number of sample learning sequences that address a wide range of topics generally addressed in an introductory physics course. The purpose of these learning sequences is to give the reader a clearer understanding of inquiry approaches and present a framework for how to develop day-to-day classroom lesson plans.

The following examples (see Appendix) do not adhere slavishly to the 5-stage learning cycle of Levels of Inquiry Model of Science Teaching. Such details constitutes the fine structure of lesson planning and are left to the reader who might use these learning sequences to teach science content and process.

Sometimes there are options for conducting one or more level of inquiry activities within a learning sequence. These are indicated by the presence of thin horizontal lines splitting various boxes in the table. Either or both approaches can be used depending upon time, material, and interest of the students.

Several references are made in the following appendix to the Illinois State University Physics Department's *Student Laboratory Handbook.* This online resource consists of 25 one- to three-page articles written by Wenning between 2004 and 2011 and refined over time. The *SLH,* as it is known locally, is used to provide background readings for students enrolled in introductory physics courses, and serves as reference material in the department's Physics Teacher Education program (http://www.phy.ilstu.edu/pte/). Resources within the *SLH* deal with graphical analysis, mathematical methods, experimental procedures, and laboratory equipment. It is freely available online at the following URL: http://www.phy.ilstu.edu/slh/.

Learning Sequences to Lesson Plans

Table 1 shows a learning sequence dealing with pinhole projection and image formation. A series of lessons explicating the use of the learning cycle and based in part on this learning sequence was presented earlier in Wenning (2011) Additional comments are provided here for the development of lesson plans in general.

Teachers should be cognizant of the fact that the lesson sequence frameworks should be integrated with the 5-stage Levels of Inquiry Model of Science Teaching learning cycle to produce the associated lesson plans.

As a lesson plan is developed for a single class period, all teachers needs to be aware of the fact that sometimes one, two, three, or even more of the levels of inquiry can be addressed in the same lesson. Some of the concepts addressed in the various levels of inquiry don't take that long to address. Discovery learning and interactive demonstrations in many cases won't take longer than about 10-15 minutes each.

Every in-service teacher will likely have his or her framework for writing a lesson plan. This generally is not the case for teacher candidates. In the Illinois State University physics teacher education program teacher candidate develop idealized (read "lengthy") lesson plans that include a larger number of elements than is typical for in-service teachers. (The distinction between "idealized" and "pragmatic" is made clear to the students and helps alleviate some of the stress associated with future teaching.) This extended framework helps teacher candidates understand the critical components that should be part of every lesson plan, but that are often not explicitly stated in pragmatic lesson plans used by in-service teachers. Items A through L below constitute the framework for the ISU idealized lesson plan. It explains each of the elements that teacher candidates must include in their idealized lesson plans.

Pinhole Projection	**Discovery Learning:** Students are introduced to the concept of pinhole projection with the use of two index cards and a clear light bulb with a large filament. The first index card with the pinhole is held closer to lamp; the second index card is held in the shadow of the first. Students see image produced on second index card. They discover inversion, distinction between image and object, and note that distance of the object (d_o) and distance of the image (d_i) (both measured from the pinhole) have an effect on image height (h_i). The object height (h_o) is fixed. Students image brightly lit objects outside the classroom window or overhead lamps in similar fashion. Students note both inversion of image and color.	**Interactive Demonstration:** The instructor explains to students the use of a pinhole camera – two boxes sliding in and out of one another with a pinhole in one end (aluminum foil) and a projection screen (white vellum or wax paper) on the other. Students are asked to predict what would happen to h_i if d_i and d_o were varied. Students are further asked to explain what would happen if the size of the pinhole and the number of the pinholes were increased. Students are given pinhole cameras and asked to interact with them in any meaningful fashion using artificial light sources. Students complete a worksheet attempting to explain the various observed phenomena. Image inversion and increasing/decreasing size also explained.	**Inquiry Lesson:** Students conduct controlled activities with the assistance of the instructor to find simple qualitative relationship between d_i and h_i when d_o and h_o are fixed. (No measuring devices are permitted at this stage of the activity.) Students conduct another controlled activity to derive a qualitative relationship between d_o and h_i when d_i and h_o are held constant. Students write conceptual relationships such as "When d_i increases, h_i increases if all else is held constant." Students are asked to how they might conduct a controlled experiment to determine the mathematical relationship(s) between the associated variables.	**Inquiry Lab:** Students are engaged in conducting controlled experiments using a meter stick and ruler a means for quantifying data. The lab activity is "jig sawed" so that several simple relationship from the inquiry lesson can be evaluated. For instance, one group will find the relationship between d_o and h_i when d_i is held constant. Another group will find the relationship between d_i and h_i when d_o is held constant. The first group will find an inverse relationship; the second group will find a proportional relationship. Drawing these relationships together, and looking at the system parameter of h_o, students find with the assistance of the teacher that: $magnification = \frac{h_i}{h_o} = \frac{d_i}{d_o}$. (A negative sign can be introduced as appropriate if the distances are considered vector quantities.)
	Hypothetical inquiry: Students use their knowledge of geometry (similar triangles) to derive the relationship $\frac{h_i}{h_o} = \frac{d_i}{d_o}$ noting that magnification is merely a definition.			

Table 1. *A sample learning sequence addressed more fully by Wenning (2011).*

Idealized Lesson Plan Framework

A. *Guiding Question(s):* The goal of the science lesson should be inquiry oriented. Students' attention should be focused on answering one or two key questions based on empirical evidence. State these questions. Remember that a teacher simply asking lots of questions does not constitute an inquiry-oriented lesson.

B. *Student Performance Objective(s):* What, more specifically, are the students expected to know and be able to do at the end of the lesson? You can only assess these objectives through observable performances. Include assessments for content knowledge, intellectual skills, and dispositions as appropriate. Students must be made aware of day-to-day objectives.

C. *Science Content and Standards:* List here the order of science content as it will be taught as well as the corresponding Illinois Learning Standard(s). Please cite similar to the following: 13A1c for ILS objectives and "Working in Groups" for ILS Applications of Learning.

D. *Alternative Conceptions:* List here any alternative conceptions (preconceptions that students might bring to this subject matter and misconceptions that they might develop during class) as a result of studying the content of this lesson. Be certain to cite your reference(s).

E. *Instructional Approach(es):* Indicate which active learning strategies you will employ in this inquiry-oriented lesson such think/pair/share, problem/project based learning, concept mapping, interactive demonstrations, simulations, microcomputer-based labs, whiteboarding with Socratic dialogues, case study, discussion, student summaries, etc. Good inquiry-oriented lessons also will include activities from each of the three following categories: individualized, small group, and whole group.

F. *Introduction:* Link the current lesson with any previous lesson that is somehow related. The anticipatory set is included to ensure that the students are ready for this lesson as the next lesson in a series of lessons. These introductory activities focus student attention, provide for review or a very brief practice on previous objectives, and develop readiness for the current lesson. This is a good time to develop fundamental concepts and to elicit and address students' alternative conceptions.

G. *Instructional Activities and Accommodations:* List instructional activities to help all students (including those with disabilities) accomplish the stated objectives. Include estimated times for each activity and how you will address special needs. Students should be actively engaged in the construction of knowledge on the basis of empirical evidence. Be certain to see the Inquiry Lesson Scoring Rubric for pertinent teacher and student behaviors as they relate to inquiry-oriented lessons.

H. *Checking for Understanding:* How will you as teacher determine if the student performance objective(s) for the day's lesson has been achieved? How will you assess the objectives in an informal though meaningful manner? Recall that performance assessment must be observable and ideally will extend to all students.

I. *Extensions:* Explain how you will teach explicitly about the nature of science, its unifying concepts, the philosophy of science, issues of science and technology and/or the processes of science during your lesson if appropriate.

J. *Homework:* What projects or homework activities will you assign to your students to help them internalize and better understand the intended learning of this lesson?

K. *Materials and Safety:* What materials will you need to teach your lesson? Do any of your materials represent a safety hazard? If so, what precautions will you take to minimize hazards and otherwise protect your students?

L. *Backup Plan:* No lesson plan should be written without considering the possibility that students will complete their tasks faster than expected. Every lesson plan should, therefore, include meaningful back up activities. The backup plan should not consist of having students work on an assignment intended for homework.

A *lesson plan* scoring rubric based on the above criteria is currently in use at Illinois State University. It can be used for self-assessment and is available for download at: http://www.phy.ilstu.edu/pte/311content/lessonstudy/lesson_plan_scoring_rubric.pdf.

A parallel *inquiry lesson* scoring rubric is also available from the ISU Physics Teacher Education web site http://www.phy.ilstu.edu/pte/311content/inquiry/Inquirylessonscoringrubric.pdf. This rubric provides addition guidance for developing and teaching of an inquiry-oriented lesson. In this latter rubric the teacher is expected to:

- promote student thinking and critical questioning,
- engender debate and discussion among students,
- focus on one or two major questions as the guide to inquiry,
- provide a variety of levels and paths of investigation,
- serve a mentor and guide, giving as little direction as possible,
- promote an active quest for new information and ideas,
- maintain a classroom atmosphere conducive to the inquiry process, and
- place emphasis on "How do I know the material of this course?"

Khan (2009) provides a number of excellent examples of inquiry-oriented lessons based on thermodynamics that include hypothetical inquiry and can serve as the basis of lesson development.

Conclusion

The Levels of Inquiry Model of Science Teaching provides an instructional framework that helps to ensure that students develop a broader range in intellectual and scientific process skills. Teachers help to ensure this learning by moving students through the 5-stage learning cycle associated with each of the levels of inquiry. The reader is referred now to the Appendix of this article in which numerous examples of learning sequences are provided.

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