Levels of inquiry: Hierarchies of pedagogical practices and inquiry processes

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There is little attention given to how the processes of scientific inquiry should be taught. Inquiry is often treated as an amalgam of non-hierarchical activities. It is apparently assumed that once teacher candidates graduate from institutions of higher learning they understand how to conduct scientific inquiry and can effectively pass this knowledge on to their students. This is often not the case due to the nature of university-level instruction that is often didactic. There is a critical need to synthesize a framework for more effective promotion of scientific inquiry skills among students at all levels. The author presents a hierarchy of teaching practices and intellectual processes with examples from physics that can help science teachers, science teacher educators, and curriculum writers promote an increasingly more sophisticated understanding of inquiry among their students.

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 the differences between demonstrations, lessons, and labs, and what role inquiry plays in each. For instance, couldn't 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 an 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.)

Student inquiry has been defined in the *National Science Education Standards* (NAS, 1995, p. 23) as "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." (It is to this definition that the author refers when he mentions "inquiry-oriented" activities.) The *Standards* do define the abilities necessary for students to conduct scientific inquiry: "identify questions and concepts that guide scientific investigations, design and conduct scientific investigations, use technology and mathematics to improve investigations and communications, formulate and revise scientific explanations using logic and evidence, recognize and analyze alterative explanations and models, [and] communicate and defend a scientific argument" (pp. 175-176). Nonetheless, the *Standards* provide precious little guidance about how inquiry processes are to be taught. It evidently is presumed 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 instruction) 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). Because inquiry processes are the "coin of the realm" for science teachers, pertinent activities in relation to pedagogical practices must be clearly delineated. Science teacher educators should be interested in not only inculcating an understanding of inquiry in teacher candidates, they should also want to make sure that teacher candidates are able to actually teach in a way that their future students will come to know and understand the nature of scientific inquiry.

Merely speaking with teacher candidates about random inquiry processes will not help them teach in such a way that will systematically 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 of "doing science." After about 15 minutes of lab activity it became painfully clear 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 don't 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 painfully clear to the teacher educator that this student teacher needed to know more about how to teach students to "do science." This article originated as a result of discussions held during a subsequent seminar with several student teachers. One of the student teachers (not the one in the example) pointed out rather succinctly that the difference between a lesson and a lab is that a lesson will be controlled by the teacher whereas the lab would be controlled by the student; that there is indeed some sort of hierarchy among pedagogical practices. At this point it became clear to the author that 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 scientific effectively using and promoting inquiry.

The literature of scientific literacy is replete with calls for teachers to use inquiry as a regular part of teaching practice. Unfortunately, this doesn't 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. The expected approach is that the teacher will repeatedly model appropriate actions, and then fade from the scene allowing students to implement the modeled strategies. If one is to follow this conventional wisdom, teachers who attempt to teach inquiry processes should progress through a series of successively more sophisticated levels of pedagogical practice, each having associated with it specific 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.

Basic Hierarchy of Pedagogical Practices – Based on the earlier work of Colburn (2000) and Staver and Bay (1987), 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 1 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 from one another primarily on two bases: (1) intellectual sophistication, and (2) locus of control. That 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 experiment. The thought processes required to control an experiment are always present but are shifted from the teacher to the student as practices progress toward the right along the continuum. As well be seen, inquiry labs and hypothetical inquiry can be subdivided further.

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

Table 1. *A basic hierarchy of inquiry-oriented science teaching practices. The degree of intellectual sophistication and locus of control are different with each level of pedagogical approach.*

As teachers move from the most basic form of pedagogical practice – discovery learning – to the most advanced form of inquiry practice – hypothetical inquiry – they should progress through intermediate levels of inquiry such as interactive demonstrations, inquiry lessons, and inquiry labs. In the following sections, each practice will be defined and operationally described. The author will use a common topic from physics – 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.

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 meaning or 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.

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've seen, does the buoyant force depends 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 isn't 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 2.

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 much more consistent with authentic scientific practice; show the work of science to be recursive and self-correcting.

Table 2. *Some major differences between traditional cookbook and authentic inquiry-oriented lab activities.*

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 (ρ) 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 ρ. 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 ρ) 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 ρ 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 $F_b = \rho g V$. Additional testing of this relationship would show it to be of the appropriate form.

Hypothetical Inquiry – The most advanced form of inquiry that high school students are likely to deal with will be hypothesis generation and testing. Hypothetical inquiry needs to be differentiated from making predictions, a distinction many high school 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 decrease the volume of a gas, it's temperature will rise." 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 doesn't work, a new hypothesis is generated. This latter hypothesis might have to do with circuit continuity such as a burned out light bulb. 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."

Basic Hierarchy of Pedagogical Practices – There is a continuum, then, of levels of inquiry that ranges from discovery learning as the simplest form to hypothetical inquiry as the most complex. In Table 2 the various levels of inquiry described thus far are shown in relation to one another. It should be noted from the table, and more importantly from what has been said up to this point, that levels of inquiry differ from one another primarily on two bases: (1) intellectual sophistication, and (2) locus of control. That the locus of control shifts from the teacher to the student moving from left to right along the continuum should be clear. 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 experiment. The thought processes required to control an experiment are always present but are shifted from the teacher to the student as practices progress toward the right along the continuum. Inquiry labs can be subdivided further by the degree of intellectual sophistication and shifting locus of control. Similarly, hypothetical inquiry can be subdivided into different types of pedagogical practice. Attention is now turned to fully delineating three types of progressively more sophisticated inquiry labs

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

Table 2. *A basic hierarchy of inquiry-oriented science teaching practices. The degree of intellectual sophistication and locus of control are different with each level of pedagogical approach.*

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 3 – 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.

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

Table 3. *Distinguishing characteristics of inquiry labs by type.*

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’t 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.

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 essentially the same type but different form of inquiry; they are not otherwise distinguished in the hierarchy of pedagogical practices.

Pure Hypothetical Inquiry – Perhaps 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 high school 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 which constructs 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 as needed using libraries, Internet resources, interviews, and laboratory experiments in the physics classroom.

Complete Hierarchy of Pedagogical Practices – Table 4 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.

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**

Table 4. *A more complete hierarchy of inquiry-oriented science teaching practices including distinctions between laboratory types, and pure and applied inquiry.*

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 5. The listings are intended to be suggestive, not definitive.

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**

Table 5. *Relative degree of sophistication of various inquiry-oriented intellectual processes. These listings are intended to be suggestive, not definitive.*

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 article. 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. This was due in large part to the failure of the teacher educator to recognize and make known to his teacher candidate the hierarchies of pedagogical practices and inquiry processes.

That deficiency in the preparation of physics teacher candidates at Illinois State University has now been remediated. The insights gleaned from the development of this paper are being slowly infused throughout the physics teacher education curriculum. When working with students, the relationship between such practices as lesson and lab and their associated procedures is now being made clear. Teacher candidates are developing a growing understanding of what it means to bridge the gap between teacher-centered activities and student-centered inquiry lessons and labs. Eventually all teacher candidates at Illinois State University will read and discuss this paper as part of a senior-level methods course. It is believe that this will redound to their benefit and their students for years to come.

There is a lesson here, too, for science teacher educators, in-service teachers, and curriculum developers. In-service 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. To 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.

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