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TEACHER TRAINING OR EDUCATION: WHICH IS IT?

While teaching my physics pedagogy courses here at ISU, I always make the point to ask, "What is teaching?" I usually get these rather dumbfounded looks stating in effect, "Why would you ask a question with such an obvious answer?" I press the point, however, and before long students are flumixed over the fact that they don't have a good definition for what it is that they propose to do as a chosen career. Is it really any different for those of us working directly in the area of physics teacher candidate preparation? Do we have a good definition of what it is that we do?

Like many of you, I try to keep up to date by reading physics and science education literature. What I frequently stumble across, however, is the regular use of the words "teacher training" and "teacher education." Which is it, and does it make any difference? To me it does, and I want to take this opportunity to share some thoughts about what it is that people such as I do in post-secondary educational institution as it relates to the preparation of secondary-level physics teachers.

When working with my students in Physics 310 - Readings for Teaching High School Physics - I ask them for definitions of teaching so called. While a bit perplexed that I should ask such a question, few are able to give ready answers. I like to point out to them that many things are called teaching, but not all are worthy of the name. For instance, in what way are any of the following processes truly worthy of the name teaching? Instructing? Informing? Brain washing? Training? Conditioning? Educating?

B. Othanel Smith, in a 1987 article, Definitions of teaching, (in M.J. Dunkin (Ed.), *The International Encyclopedia of Teaching and Teacher Education.* Oxford: Pergamon) pointed out that there is a huge distinction between these modes of teaching so called, and that we as teacher educators should distinguish. Without going into the specifics of Smith's article, suffice it to say that training is characterized by Smith as the promotion of rule-obeying behavior among students. Education, on the other hand, can be thought of as preparation of students to make decisions based upon well-reasoned, ethical principles. An educated teacher is the goal of my teaching, not a trained teacher.

It should be obvious to teacher educators that there is no "science" to teaching. You can't give teacher candidates a list of rules from the area of pedagogical knowledge (as opposed to content or pedagogical content knowledge) and say, "Do this, it works," and still expect the future teacher to be covered in any situtation. The fact of the matter, there are very few "best practices" of teaching pedagogy that are authentically so. Yes, we promote "best practices" of teaching, but these are rarely rooted in scientific research and most have been promoted merely on the basis of ideaology. There are at least three notable exceptions to this statement, however, and these have recently been promoted in two related works published by the National Research Council: *How People Learn: Brain, Mind, Experience, and School* (2000) and *How Students Learn: History, Mathematics, and Science in the Classroom* (2005).

These works deal extensively with three pedagogical rules that education research has shown to work to improve learning:

1) Identify, confront, and resolve preconceptions
2) Frameworks
3) Metacognition

So, given the small number of pedagogical rules that are authentically best practice, it is better in light of Smith's definition to say that we are educating teachers rather than training teachers.

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Levels of inquiry: Hierarchies of pedagogical practices and inquiry processes (revised 2/11)

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Little attention is given to how the processes of scientific inquiry should be taught. 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 on appropriate knowledge and skills to their students. This is often not the case due to the nature of university-level instruction which is often didactic. Scientific inquiry processes, if formally addressed at all, are often treated as an amalgam of non-hierarchical activities. There is a critical need to synthesize a framework for more effective promotion of inquiry processes among students at all levels. The author presents a new hierarchy of teaching practices and intellectual processes with examples from buoyancy that can help science teachers, science teacher educators, and curriculum writers promote an increasingly more sophisticated understanding of scientific inquiry among students.

The strength of a concept rests in its ability to organize information. What at first appears to be a disorganized body of knowledge is made comprehensible and useful when a unifying framework is developed. Scientific inquiry is often presented as a jumble of disorganized but interrelated procedures. Teachers and teacher candidates are regularly encouraged to use inquiry processes in demonstrations, lessons, and labs, but there is little organizational pattern provided to relate inquiry to these approaches. This often leaves teachers and teacher candidates with questions about differences between demonstrations, lessons, and labs, and what role inquiry plays in each. For instance, 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 a lesson and a lab activity? The differences between demonstrations and labs seem readily apparent; the real problem resides in defining the transitional phase between a demonstration and a lab – the lesson. Clearly, there must be identifiable differences between all such activities, but science education literature in this area appears to make no clear distinction between them with but a few rare exceptions. (See for instance Colburn, 2000; Staver & Bay, 1987.)

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 assumed that once a teacher candidate learns how to conduct inquiry in the university setting (often a poor assumption given the generally didactic nature of science 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). 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). Again, science education literature appears to be largely devoid of information about how one actually goes about teaching inquiry skills – arguably one of the most central goals of science teaching.

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. After about 15 minutes of lab activity it became obvious to both the student teacher and the university supervisor that the students were floundering. One student called out, "This is a waste of time!" Another vocalized, "We 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 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 there is a difference between a lesson and a lab – that the teacher will mostly control a lesson whereas the lab would be mostly controlled by the student. At this point it became evident 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 inquiry processes if they are to teach science effectively using inquiry.

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. If one is to follow 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 increasingly complex inquiry processes. They will repeatedly model appropriate actions, and then fade from the scene allowing students to implement the modeled inquiry processes.

Basic Hierarchy of Pedagogical Practices – Based on the earlier work of Colburn (2000), Staver and Bay (1987), and Herron (1971), the author here proposes a more extensive continuum to delineate the levels of pedagogical practice and offer some suggestions as to the nature of associated inquiry processes. Table 1 shows the various pedagogical practices mentioned thus far in relation to one another. It should be noted from the table that levels of inquiry differ primarily on two bases: (1) intellectual sophistication, and (2) locus of control. 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. Intellectual sophistication likewise increases continuously from discovery learning through hypothetical inquiry. The thought processes required to control an activity are shifted from the teacher to the student as practices progress toward the right along the continuum. As will be seen, inquiry labs and hypothetical inquiry can be subdivided further.

In the following sections, each of the above practices will be operationally defined; in a corresponding sidebar story, each will be described for ease of reading and as a way of providing additional insights. The author will use a common topic from physics – buoyancy – to describe how different levels of pedagogical practice can be deployed to address this important physical topic and to effectively promote learning of inquiry processes.

SIDEBAR STORY 1: 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.

Discovery Learning – Discovery learning is perhaps the most fundamental form of inquiry-oriented learning. It is based on the "Eureka! I have found it!" approach. The focus of discovery learning is not on finding applications for knowledge but, rather, on constructing knowledge from experiences. As such, discovery learning employs reflection as the key to understanding. The teacher introduces an experience in such a way as to enhance its relevance or meaning, uses a sequence of questions during or after the experience to guide students to a specific conclusion, and questions students to direct discussion that focuses on a problem or apparent contradiction. Employing inductive reasoning, students construct simple relationships or principles from their guided observations. Discovery learning

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 approach.*

is most frequently employed at the elementary school level, but at times it is used even at university level. See sidebar story 1 for an example of discovery learning.

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 appropriate scientific procedures at the most fundamental level, thereby helping students learn implicitly about inquiry processes. See sidebar story 2 for an example of an interactive demonstration.

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 a more complex form of scientific experimentation. The pedagogy is one in which the activity is based upon the teacher remaining in charge by providing guiding, indeed leading, questions. Guidance is given more indirectly using appropriate questioning strategies. The teacher places increasing emphasis on helping students to formulating their own experimental approaches, identifying and controlling variables, and defining the system. The teacher now speaks about 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"

SIDEBAR STORY 2: Example of Interactive Demonstration – 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.

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, for the sake of simplicity, then 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.

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 directed at students asking them to predict which physical factors affect buoyancy which they will later address in an inquiry lesson.

protocol. This approach will more fully help students understand the nature of inquiry processes. This form of inquiry lesson is essential to bridging the gap between interactive demonstration and laboratory experiences. This is so because it is unreasonable to assume that students can use more sophisticated experimental approaches before they are familiar with them. For instance, students must be able to distinguish between independent, dependent, controlled, and extraneous variables before they can develop a meaningful controlled scientific experiment. See sidebar story 3 for an example of an inquiry lesson.

Inquiry Labs – An inquiry lab is the next level of pedagogical 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. See sidebar story 4 for an example of an inquiry lab.

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

SIDEBAR STORY 3: 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.

Cookbook labs:	Inquiry labs:
are driven with step-by-step instructions requiring minimum intellectual engagement of 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.
commonly 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 laws 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.*

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.

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. 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

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.*

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 experienced by the student teacher in the situation 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.

SIDEBAR STORY 4: Example of a Guided Inquiry 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 previous 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?

Hypothetical Inquiry – The most advanced form of inquiry that students are likely to deal with will be hypothesis generation and testing. Hypothetical inquiry needs to be differentiated from making predictions, a distinction many physics teachers fail to understand or to make with their students. A prediction is a statement of what will happen given a set of initial conditions. An example of a prediction is, "When I quickly increase the volume of a gas, it's temperature will drop." The prediction has no explanatory power whatsoever, even though it might be a logical deduction derived from laws or experiences. A hypothesis is a tentative explanation that can be tested thoroughly, and that can serve to direct further investigation. An example of a hypothesis might be that a flashlight fails to work because its batteries are dead. To test this hypothesis, one might replace the supposedly bad batteries with fresh batteries. If that 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 or a broken wire. Hypothetical inquiry deals with providing and testing explanations (usually how, rarely why), to account for certain laws or observations. Hypotheses most certainly are not "educated guesses."

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

Pure Hypothetical Inquiry – In the current pedagogical spectrum, the most advanced form of inquiry will consist of students developing hypothetical explanations of empirically derived laws and using those hypotheses to explain physical phenomena. Hypothetical inquiry might address such things as why the intensity of light falls off with the inverse square of distance, how conservation of energy accounts for certain kinematic laws, how the laws for addition of resistance in series and parallel circuits can be accounted for by conservation of current and energy, and how Newton's second law can account for Bernoulli's principle. 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 –

SIDEBAR STORY 5: 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 origin 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.

the worth of which is attested to by successful application – becomes theory. See sidebar story 5 for an example of pure hypothetical inquiry.

Applied Hypothetical Inquiry – Hypothetico-deductive reasoning can be fruitfully employed to account for certain observations or to make predictions. For instance, this approach can be used to develop concepts dealing with Archimedes' principle, the relationship of density to floating and sinking, and other related phenomena. Used this way, applied hypothetical inquiry can still overlap to a considerable extent with pure hypothetical inquiry. See sidebar story 6 for several examples of applied hypothetical inquiry.

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.

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.

SIDEBAR STORY 6: Examples of Applied Hypothetical Inquiry – After students have developed an understanding of the law of buoyancy, this knowledge can be applied to new situations as part of the process of hypothetico-deductive reasoning. For instance, students can be asked to determine the relationship between the buoyant force and the weight of the water displaced by the immersed object. The students will find and should be able to account for the fact that the buoyant force is equal to the weight of the fluid displaced by the immersed object. This is nothing more than Archimedes' principle.

Students also can apply their knowledge of the law of buoyancy to new situations in an effort to account for various observations such as the following: A beaker filled with water is placed on a balance. If an object that sinks is completely immersed in the water and suspended without allowing it to touch the bottom, how will the weight of the beaker with water-be affected? If the object is allowed to settle to the bottom, how will the weight of the system be affected?

Other questions about buoyancy can be introduced, and students allowed to work out explanations or make predictions. For example, a demonstration is conducted with objects that have densities greater or less than water. They are immersed in water and it is found that those objects that have a density less than water float and those objects with a density greater than water sink. Why do objects float or sink based based on their density in comparison to the water? Students should be able to use the law of buoyancy to explain why.

What fraction of a fresh water iceberg is visible above the surface of a sea of salt water? A knowledge of the relative densities of the ice and water and the buoyant force being a function of the volume of water displaced by the ice should help solve the problem and for a prediction to be made.

Why does a Cartesian diver sink or rise when the pressure on the water increases and decreases respectively? Again, using the law of buoyancy and the principle of sinking or floating as a function of the densities of object and fluid can lead to the proper solution of this problem.

Application to Teacher Preparation, Instructional Practice, 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 near the beginning of this article. The student teacher had moved from a series of low sophistication, teacher-centered inquiry activities – basically a series of interactive demonstrations – to a bounded lab activity that had a student-centered locus of control and a relatively high degree of sophistication. He moved the from a situation in which the students were strongly dependent upon the teacher providing guidance to one with little to no guidance without first providing appropriate bridging activities. 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 before being confronted with a relatively sophisticated bounded inquiry lab; neither had attention been paid to the continuum of intellectual process skills so important to developing scientific inquiry. This was due in large part to the failure of the student teacher to understand the underlying hierarchies of pedagogical practices and inquiry processes. It was also the fault of this teacher candidate's educators to recognize and make known to him the underlying 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 have been infused throughout the physics teacher education curriculum at Illinois State University. When working with teacher candidates, the relationship between the practices of demonstration, lesson and lab and their associated intellectual processes is now being made explicit. Teacher candidates are developing a growing understanding of what it means to bridge the gap between teacher-centered activities and student-centered demonstrations, 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 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 teaching practice. Instructional development

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.*

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.*

and curricular decision-making will likewise benefit from an understanding and application of the continuum of pedagogical practices and inquiry processes. Failure to include due consideration for the continuum at any level will in all likelihood result in a pedagogy that will be less effective both in theory and practice. Failure to do so will leave teacher candidates, and perhaps their future students, with an incomplete understanding of how to effectively teach science as both product *and* process.

The author wishes to thank Mr. Luke Luginbuhl for drawing the initial distinction between inquiry lesson and inquiry lab that served as the basis for this article. He was a 2004 graduate of the Physics Teacher Education program at Illinois State University. He now teaches physics at Havana High School in Havana, Illinois. He was not the student teacher mentioned in this article.

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JPTEO

Instruction on motion in North Carolina: Does it align with national standards on paper and in practice?

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National organizations such as the AAAS (American Association for the Advancement of Science) and The National Research Council have developed standards or benchmarks for what should be taught in science classrooms. This study examines if the North Carolina Standard Course of Study developed by the North Carolina Department of Public Instruction aligns with these standards both on paper and in practice. The topic of motion was chosen to be the vehicle to examine the synergy between these documents. Ideally, all of these documents would be written to help foster conceptual change in students as they progress through school.Teachers no longer enjoy the autonomy of picking the topics that they teach in the classroom. By the time material is presented to students in today's classroom it has been filtered through national organizations, state level agencies, district level guidelines, and lastly, everyday teacher time constraints. In an ideal world, these different levels of control over the curriculum work together to produce the conceptual change in students that is necessary for the proper understanding of a topic. Unfortunately we do not live in this world. Through the examination of the topic of motion in North Carolina this paper will discuss what is necessary to produce conceptual change. It will also survey the full range of the curriculum in North Carolina to see if the conceptual changes dictated by national organizations for one particular topic -motion -are being addressed.

Conceptual Development - Students do not enter the classroom as blank slates. This includes early elementary students, whose prior knowledge on physics topics such as motion may or may not be correct. Early instruction about motion does not always improve upon these preconceived ideas. In fact, a study in the UK found that pre-school students with no instruction were better able to predict the path of an object coming out of a curve than school aged children (Pine, Messer, & St. John, 2001). In the same study, teachers surveyed about their interest in students' preconceptions responded that they wanted to know the students' ideas and either enrich what was correct or reconstruct what was not correct.

How then can students achieve the proper conceptual change needed to understand physics topics that may be counter to their prior knowledge? One suggestion is that for proper conceptual development to occur, the new concepts that are presented to the students must be intelligible and plausible, yet disharmonious with their previous conceptions

(Georghiades, 2000). In a review of the literature, Maria (2000), looking at conceptual development through the lens of a social constructivist, suggests that conversation with peers and teacher-led discussions that confront alternative conceptions directly are particularly important in fostering conceptual change.

Science is a difficult domain in which to foster conceptual change because students of all levels will cling to their prior knowledge (Guzzetti, 2000). One method of guiding students to reformulate their misconceptions is through the use of refutational texts. Although refutational texts have been shown to have the best long-term effect on conceptual change, such texts in themselves, however, are not enough (Guzzetti, 2000; Maria, 2000). Improvement is possible by pairing these texts with classroom discussion. This classroom discussion needs to be teacher moderated because in cooperative groups students can convince each other that an alternative explanation is actually the correct concept (Guzzetti, 2000).

Cross and Pitkethy (1991) put this research to the test in Australia. They used a six-week course with many varied activities to try and change the conceptions of first graders in Australia with respect to the idea of speed. After the completion of the unit the students demonstrated significant improvement on an observational test of comparing the speed of cars by the students. These results suggest that the concepts of speed and motion can be effectively taught to children even at a young age.

Standards- Science education standards are attempts to show what conceptual development should be fostered in all students through all grade levels. The standards movement began in 1989 when the National Council of Teachers of Mathematics (NCTM) came out with their *Curriculum and Evaluation Standards for School Mathematics* (The National Council of Teachers of Mathematics, 2000).

In science, the original set of standards manifested itself as the Benchmarks for Scientific Literacy produced by the Association of Americans for the Advancement of Science as part of their Project 2061. "Project 2061 is the long-term initiative of the American Association for the Advancement of Science working to reform K-12 science, mathematics, and technology education nationwide" (Benchmarks On-Line, 2002). This document set standards for what concepts should be understood by students at the end of grades 2, 5, 8, and 12 in order to become scientifically literate adults.

More recently a set of Science Education Standards produced by the National Research Council has also examined what concepts students should understand at grade levels k-4, 5-8, and 9-12. Besides setting standards for what students should master, this document also explains what content area knowledge teachers should have and what teachers should learn from their professional development (National Science Education Standards, 1996).

The Problem - These national documents are typically used by states as a starting point for setting their own curriculum guides for science. Individual school districts and teachers then take the last step and craft the state curriculum guides, which are based on national standards, into daily curriculum guides and lesson plans. With this framework in mind, this paper will examine one topic in the area of physical science, motion, tracing its theoretical coverage versus actual coverage by teachers in the state of North Carolina. The impetus for this study lies in the fact that when students enter institutions of higher learning they should understand certain topics and concepts, yet university instructors consistently report that students do not possess this knowledge. This paper will describe where there are breakdowns in the coverage of the topic of motion and how these might affect student learning.

Method- This study begins with a review of the major standards in science education. This will include a comparison and contrast of the Benchmarks for Scientific Literacy by AAAS, from here on referred to simply as the Benchmarks, the Science Education Standards by the National Research Council, and the North Carolina Standard Course of Study by the Department of Public Instruction of North Carolina (NC SCOC).

Teachers from a large metropolitan school district in North Carolina were interviewed about how they taught the topic of motion in their classroom. One teacher each in grade or course where motion is covered, kindergarten, first grade, eighth grade, physical science and physics, was contacted to try to understand how this topic was actually being addressed. Teachers were chosen because they were either known by the researcher or recommended by others in science education. All of these interviews were conducted in person, except one, which was completed via email.

After reviewing the expectations set forth by the NC SCOC and topics actually taught by teachers in the classroom, the last step was to contact university professors. University professors at a major research university in North Carolina that taught freshman level physics for either physics majors or non-majors were interviewed via email about their perceptions of their students' abilities with regards to motion.

Motion- The 'Standards' Motion is a fundamental topic in physics. It is addressed as early as kindergarten and is taught in varying degrees throughout all levels of school. The idea of motion of objects is treated throughout the Benchmarks, the Science Education Standards, and the NC SCOC. In Appendix 1, the standards, or outcomes, for each of these three bodies are compared at similar grade levels.

It would appear by studying these standards that a student from North Carolina who completed physical science and physics at their high school would receive a more rigorous understanding of motion than is suggested by either the Benchmarks or the Science Education Standards. This is not, however, a fair comparison. The Benchmarks and Science Education Standards are expectations for every student, and certainly not every student in North Carolina completes a physics course. Graduation requirements in North Carolina state that a student must take at least one course in the physical sciences. Typically, this means a student must take either physical science, or chemistry, or physics. Table 1 shows the number of students in each of these courses over the past five years (The North Carolina Statistical Profile, 2003).

Because this is aggregate high school data it is impossible to tell from these statistics how many students in the graduating class of 2002, statistical report of 2003, had completed a physical science or physics course. These numbers do indicate that at least some students are taking more than the one course in the physical sciences that is required as the sum enrollment in these three classes is greater than 25% each year. The numbers also indicate that a large portion of North Carolina students satisfy their physical science requirement with chemistry and therefore obtain no more than an eighth grade education in physics, and in particular motion. Just to note, the sharp decrease in the number of students enrolled in physical science beginning with the 2001 report coincides with the addition of an earth/environmental science requirement.

Year of Report	Total High School Student Population	Physics Population (%)	Physical Science Population (%)	Chemistry Population (%)	Principles of Technology (%)
2003	325,000*	12,000 (3.7)	51,000 (16)	47,000 (14)	2000 (.62)
2002	358,000	13,000 (3.6)	44,000 (13)	48,000 (13)	2000 (.56)
2001	351,000	12,000 (3.4)	43,000 (12)	46,000 (13)	3000 (.85)
2000	344,000	13,000 (3.7)	73,000 (21)	47,000 (14)	3000 (.87)
1999	313,000	13,000 (4.2)	77,000 (25)	46,000 (15)	3000 (.96)

Table 1 - *Students taking classes dealing with motion in North Carolina All numbers are rounded to the nearest thousand.*

The three groups of curriculum standards are most similar at the lowest grade levels. In fact, the NC SCOC seems to have nearly copied some of the Benchmarks verbatim for this stage. The Science Education Standards cannot be directly compared because their first tier of standards extends to 4th grade instead of first grade as the NC SCOC, or second grade as do the Benchmarks.

North Carolina does not treat the topic of motion again until 8th grade, leaving a seven-year window for students to construct and reinforce their own ideas. The primary concepts that seems to be omitted from the NC SCOC at this level is the idea that a force will produce a change in motion, speed or direction, and that the size of the force and the degree of the change are proportional. Teaching these concepts during elementary school may prevent a common misconception still retained by college students- that force is proportional to velocity instead of acceleration (Halloun & Hestenes, 1985a).

Continuing to higher-grade levels, the divergence among the three sets increases. By the end of 8th grade, the Benchmarks only introduce one new concept, that forces may cause motion that is curved. The Benchmarks also reinforce the key concept of force being proportional to the change in an object's motion. The Science Education Standards and the NC SCOC are more similar in that they both suggest that students learn to describe, measure, and graph motion. The Science Education Standards also point to the same concept as the Benchmarks that force and change in motion are proportional. The NC SCOC more specifically suggests describing motion in terms of Newton's Laws of motion. The NC SCOC introduces at this level the idea that all motion is relative, something not addressed at all in the Science Education Standards and not until high school in the Benchmarks.

As mentioned earlier, a high school student who takes physical science and physics receives a more extensive treatment of the idea of motion than would the typical 'every student' envisioned by the Benchmarks or the Science Education Standards. As shown by the table, however, such a student is in the minority. A student could instead select only chemistry as their physical science course and receive less formal instruction about motion than suggested by the Benchmarks or Science Education Standards.

Motion- What is Covered:

K-1- The kindergarten and first grade teachers that were interviewed for this project were honest about the fact that motion is not of primary importance to them. They were both aware of what the NC SCOC said about the topic. One teacher even suggested she could "go get her notebook" when asked about the NC SCOC. They both felt that what the NC SCOC suggested for motion was adequate for their grade level. When asked about what preconceived ideas their students might have, they both thought that their students had very few ideas about motion besides that they move and other things can move.

In this kindergarten class, science was covered once a week for 45 minutes at a time. Motion was a two-week unit in this classroom. In this first grade science was covered every other day for 45 minutes for two weeks and then rotated out for two weeks. The first grade teacher could not specify how much time was spent on motion because all science topics were integrated together.

Both teachers reported that their students understood what they tried to teach about motion. They thought that the students did not leave with any misconceptions about motion. Science and motion are not tested by the state at this level or any level in elementary school.

Eighth Grade- Again, the eighth grade teacher was familiar with what the NC SCOS had to say about motion for her grade level, especially that the student would have, "an understanding of motion and forces." She deemed that these were adequate for this grade level.

She perceived her students to have the misconception that equated speed only with fast moving objects. To address this misconception she explained how she did labs and activities to help the students better describe motion, both fast and slow, and begin to understand acceleration. She reported that despite her efforts, she felt that most students still left her class with the misconception of equating speed with fast moving objects.

Some of her other learning objectives about motion include being able to calculate speed and velocity in the correct SI units and being able to graph motion in the form of distance time graphs. She also requires students to describe friction and to identify factors that determine the friction between two surfaces. Motion is not directly tested by the state at the end of eighth grade.

Physical Science- The physical science teacher that was interviewed for this project taught in a high school where physical science was offered primarily as a junior level course. Students were required to take a physical science course for graduation; choosing from physical science, chemistry, or physics. For most students, this class marked the end of their study in the physical sciences.

This teacher was again aware of the coverage of motion in the NC SCOC. She felt that this was adequate for the topic of motion because "with everything else we have to teach with the SCOCÖwe have both chemistry and physics."

According to this teacher, the students entered this physical science class with ideas about motion, but very poor verbalization skills. Her students lacked much of the terminology and standard descriptors for motion. One of her main goals was that the students leave knowing how to properly describe motion and use correct terminology. She spent three to four weeks covering motion in her class. She felt that the students mastered these objectives well.

The students in the physical science course are given a state-mandated end of course exam, commonly called the EOC. This test is compiled with many others as part of a school's ABC report card by the state. This teacher reported the students who received high grades in physical science also received high EOC test scores.

Physics- The physics teacher for this project was also aware of what was expected concerning motion by the NC SCOC. He felt that the standards were adequate but that there were a few things that should be taken out of the NC SCOC.

When asked about the students' preconceived ideas he had very specific ideas. He believed that students held the belief that motion meant force. He also observed that students used velocity and acceleration nearly interchangeably.

His objectives for covering motion included students being able to represent motion in several different ways. He wanted them to properly graph motion, to understand motion diagrams or "strobe photography", and to accurately describe motion with words. He also wanted students to correctly identify how force and acceleration are related to the motion of an object. He devoted about a month and a half at the beginning of the school year to covering motion.

He believed that most of his students adequately mastered his objectives about motion at the end of the unit. He observed that their biggest area of misconception upon completion of the motion unit was about the concept of positive and negative velocity and distinguishing between the two.

The Physics course also has a state-mandated EOC. This teacher's students had typically performed well on the EOC. He also perceived that seniors who were in the process of finishing up school tended to not do as well on the EOC because of lack of motivation.

Conceptual Understanding at the University Level - Three university physics professors participated in the email survey regarding their perceptions of their physics students. These replies indicated that they notice the students arriving on campus with misconceptions about velocity, acceleration, and force and its relationship to motion. They reported the misconceptions were the same regardless if the students were from what they believed were high schools with strong physics programs or had not had physics at all prior to college. They indicated that they spent anywhere from two to six weeks covering Newtonian motion concepts in their class and sensed some, but certainly not all, of the students' misconceptions were corrected by the end of instruction.

These results mirror very closely the results of 478 surveys and 22 interviews that were carried out in a study by Halloun and Hestenes (1985a) at Arizona State University. This extensive survey of students enrolled in university physics courses showed that only 17% of the students held a belief about motion that could be characterized as mainly Newtonian. The rest either held to impetus theory, 65%, or Aristotelian beliefs, 18%. Echoing the North Carolina physical science and physics teachers in this study, Halloun and Hestenes found that students had a very difficult time describing motion. The students had interchangeable definitions for distance, speed, velocity, and acceleration. The survey also found that it was common for students to reply that a force, external or internal, was required to maintain motion. This force often was described as having to be in contact with the object, and sometimes attributed only to being provided by living things.

Halloun and Hestenes (1985b) followed this survey with additional research that gave pre- and post-tests in mechanics to students at four levels; high school physics, high school honors physics, college physics (non-calculus based), and university physics (calculus based). They found high school students had so many misconceptions their pre-test scores were barely above the level of guessing on the multiple-choice test. They focused their study on students in the university physics sections. These students were in four sections of physics taught by four different professors with very different instructional styles. The gain scores for these four groups were not significantly different from each other. The gain scores were also smaller than hoped for in all the university sections. This suggests that the misconceptions were held tightly by these students regardless of the method of instruction they received in an attempt to instill the correct conceptions.

Conclusions- There are several reasons why students in North Carolina carry misconceptions about motion with them all the way to college. One reason is the extreme gap in elementary school in covering the topic of motion. While the Benchmarks and Science Education Standards all suggest motion be covered throughout elementary school, with the NC SCOS the topic is addressed in kindergarten and first grade and then not again until eighth grade.

Another reason is that if a subject or concept is not directly tested, it is often not taught as thoroughly. The End of Grade or End of Course testing in North Carolina is very high stakes as it is used to determine if an individual student is promoted, as a measure of the schools overall performance and as the deciding factor for annual monetary bonuses to the teachers of up to $1500. Students in North Carolina are currently not tested on the concept of motion until the physical science or physics end of course exams. A student could, however, escape any testing about motion in high school by taking only a chemistry course to fulfill the physical science graduation requirement.

Discussion- By comparing the answers from the professors at a North Carolina university and the results of Halloun and Hestenes (1985b), North Carolina appears to be producing college bound students with similar misconceptions about motion as other places in this country. The teachers interviewed for this study realized that students came into their classes, and left their classes, with misconceptions. They addressed these to the best of their ability in the time that they had available to devote to the topic. It is neither feasible nor realistic for teachers to complete a six-week intensive course on motion with first graders to induce the conceptual change demonstrated by Cross and Pitkethly (1991) in Australia. Another factor that these teachers may have against them as they try to determine if their students have achieved any conceptual change is that students will pretend to have achieved conceptual change as a result of social pressure to please their peers or their teacher (Maria, 2000).

The topic of motion probably lends itself to as many, if not more, misconceptions as any topic as students have been observing things move their whole life. Bringing conceptual change to these students is not an easy task. Varied, focused, hands-on activities as well as refutational readings and discussions can all be used to help form proper conceptions about motion. In North Carolina, implementing this change is hindered by the very large gap in grade levels between intended instruction on motion as set forth by the NC SCOC.

To assure that North Carolina students learn about motion, as set forth by the Benchmarks and Science Education Standards, several changes would be desirable. First, motion would be addressed in the curriculum at least one more time between first and eighth grade. Second, teachers would be provided with the additional training and materials needed to change students misconceptions. Third, motion would receive more emphasis on End of Grade exams in elementary and middle school. Fourth, all students would be required to take a sequence of high school science courses that assure that all students cover the basic learning goals supported by the national standards.

Coincidentally, during the authoring of this paper the North Carolina Department of Public Instruction (NC DPI) recognized the same gap in the coverage of motion in the upper elementary grades. To address this, the NC SCOS has been adjusted to include in fifth grade (*Proposed Revisions for 2003-2004 Science SCS*, 2003):

o The learner will conduct investigations and use appropriate technologies to build an understanding of forces and motion in technological designs.

o Objectives:
- Determine the motion of an object by following and measuring its position over time.
- Evaluate how pushing or pulling forces can change the position and motion of an object.
- Explain how energy is needed to make machines move.
- Determine that an unbalanced force is needed to move an object or change its direction.
- Determine factors that affect motion including; force, friction, inertia and momentum.
- Build a model to solve a mechanical design problem
- Determine how people use simple machines to solve problems.

North Carolina is also currently developing, in accordance with the No Child Left Behind Act, a fifth and eighth grade science test. These tests will be field tested for the next two years and be in place for the 2006-2007 school year. Depending on the content of these exams, they should help to increase the coverage of motion by teachers in the upper elementary and middle school grades.

The construction of a state standard course of study that meets the National Science Standards is a negotiation process. For instance, the North Carolina high school science course requirement is the result of a compromise of several disciplinary points of view. We have shown how in one subject area – the study of motion - that student conceptual development can have gaps and omissions in the best of compromises.

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Appendix 1- Comparison of the Major Standards and the NC SCOS

Benchmarks for Scientific Literacy by Project 2061 of AAAS	**Science Education Content Standards by The National Research Council**	**North Carolina Standard Course of Study by the Department of Public Instruction**
By the end of grade 2: • Things move in many different ways, such as straight, zigzag, round and round, back and forth, and fast and slow. • The way to change how something is moving is to give it a push or a pull.	As a result of activities in grades k-4, all students should develop an understanding of: • The position of an object can be described by locating it relative to another object of the background. • An object's motion can be described by tracing and measuring its position over time. • The position and motion of objects can be changed by pushing or pulling. The size of the change is related to the strength of the push or pull.	Kindergarten: • Describe motion when an object, a person, an animal, or anything else goes from one place to another. First Grade: • Observe the way in which things move; straight, zigzag, round and round, back and forth, fast and slow. • Describe motion of objects by tracing and measuring movement over time. • Observe that movement can be affected by pushing or pulling. • Observe that objects can move steadily or change direction.
By the end of grade 5: • Changes in speed or direction of motion are caused by forces. The greater the force is, the greater the change in motion will be. The more massive an object is, the less effect a given force will have. • How fast things move differs greatly. Some things are so slow that their journey takes a long time; others move too fast for people to even see them.	Nothing at comparable grade level.	Nothing at comparable grade level.
By the end of grade 8: • An unbalanced force acting on an object changes its speed or direction of motion, or both. If the force acts toward a single center, the object's path may curve into an orbit around the center.	As a result of activities in grades 5-8, all students should develop an understanding of: • The motion of an object can be described by its position, direction of motion, and speed. The motion can be measured and represented on a graph. • An object that is not being subjected to a force will continue to move at a constant speed and in a straight line. • If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.	Eighth Grade: • Develop an understanding that an object's motion is always judged relative to some other object or point. • Describe and measure quantities that characterize moving objects and their interactions within a system: time, distance, mass, force, velocity, center of mass. • Apply Newton's Laws of Motion to the way the world works: inertia, acceleration, gravitation, action/reaction.

Appendix 1 continued - Comparison of the Major Standards and the NC SCOS

By the end of grade 12: • The change in motion of an object is proportional to the applied force and inversely proportional to the mass. • All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion. • Whenever one thing exerts a force on another, an equal amount of force is exerted back on it.	As a result of activities in grades 9-12, all students should develop an understanding of: • Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship F=ma, which is independent of the nature of the force. Whenever on object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object. • Gravitation is a universal force that each mass exerts on any other mass. The strength of the gravitational attractive force between two masses is proportional to the masses and inversely proportional to the square of the distance between them.	Physical Science: • Analyze uniform and accelerated motion: Uniform motion is motion at a constant speed in a straight line (constant velocity), the rate of change in velocity is acceleration. • Analyze forces and their relationship to motion, Newton's Three Laws of Motion. Physics: • Analyze velocity as a rate of change of position: average velocity, instantaneous velocity. • Compare and contrast as scalar and vector quantities: speed and velocity. • Analyze graphs to describe instantaneous velocity as motion at a point in time. • Analyze acceleration as rate of change in velocity. • Analyze graphically and mathematically the relationships among position, velocity, acceleration, and time. • Evaluate the measurement of two-dimensional motion (projectile and circular) in a defined frame of reference. • Assess the two-dimensional motion of objects by using their component vectors. • Assess the independence of the horizontal and vertical vector components of projectile motion. • Analyze and evaluate uniform circular motion. • Determine that an object will continue in its state of motion unless acted upon by a net outside force (Newton's 1st Law of Motion, The Law of Inertia). • Assess, measure, and calculate the relationship among the force acting on a body, the mass of the body, and the nature of the acceleration produced (Newton's 2nd Law of Motion). • Analyze and mathematically describe forces as interactions between bodies (Newton's 3rd Law of Motion).

Use of J. Bruner's learning theory in a physical experimental activity

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In the present study, laboratory performance of a group of university students was examined. The students were in the final year at the Physics Teaching Department, had passed most of the theoretical subjects in their programme, had normal cognitive levels, and were expected to gain scientific and mental skills. The participants were asked to find the electron charge by means of electrolysis of water, using J. Bruner's induction (open-ended experiment) method. They were divided into four groups at random. While group works were continuing, the participants' cognitive, sensorial and psychomotor skills were investigated.

INTRODUCTION

In physical sciences, dissolution occurring by the effect of electric current is called electrolysis. Electrolysis of acid, base and salt solutions are conducted by using various voltmeters in the laboratory. When water is electrolyzed with a Hoffmann type voltmeter, two volumes of hydrogen and one volume of oxygen are obtained. Acid, base and salt solutions conduct electricity; therefore, they are called electrolytes. When acid, base and salt are dissolved in water, their molecules are decomposed into the atoms or atomic groups of which they are formed. These electrical components are called ions.

In physics and/or chemistry education, teaching methods and learning strategies are of great importance, as well as the theoretical knowledge. J. Bruner is one of the prominent figures who expended great effort to teach how to learn. His teaching methods are still most popular [1]. According to his inductive experiment method, students are first encouraged to have their scientific experiences in the laboratories, and then they are asked to discuss and evluate these experiences within the classroom. Conducting an experiment is to check a hypothesis by controlling the dependent variables and examining their effects on independent variables [2]. In order to reveal a cause-and-effect relationship, the hypotheses are confirmed or rejected after defining variables experimentally. The use of logical cause-and-effect relationships is necessary to perform an experiment successfuly. [3]. J. Bruner, whose learning theory is taken as the basis for this study, has two important contributions in science. The first one is "learning through exploring" and the second one is "teaching concepts. " J. Bruner considered learning as an active process, and suggested students' full participation in learning activities. This approach depends on thinking, testing and finding out. In this process, students develop a high self-confidence as they attain new knowledge by themselves. When students conduct experiments in laboratories, they acquire problem-solving and research skills, and have positive attitudes towards science [4], [1]. In addition, they are encouraged to become scientists as they try to examine previous scientific studies, and they will learn that they can obtain new knowledge in a sequence, and that current theories and models can change. This learning approach is suitable for the students having low, moderate and high scientific process skills [5]. The following methods can be used by a science teacher considering the scientific skills of those students:

1. The teacher explains a problem and some possible solutions to the students and asks them to solve the problem. This method is suitable for the students who have low cognition levels and who could not improve their scientific process skills in previous studies.
2. The teacher explains a problem and asks for solutions from students who have moderate cognition levels or scientific process skills.
3. The teacher explains neither a problem nor any solutions; students identify problems and find out some solutions. The teacher has only an evaluator role, so he/she gives some feedback to students when they complete their tasks. This method can be applied with the students who have high cognition levels.

In the present study the aim is to examine students' competence in designing and practising open-ended experiments, and to investigate the effectiveness of a constructivist teaching method on practising problem-solving activities, such as finding the electron charge 'e' by means of electrolysis of water. The second method in the above list is found to be suitable for the subjects of the study because of the socio-economic conditions of the present context.

MATERIAL AND METHOD

Materials: For experimental activities, some materials were provided for the students such as the following: a Hoffmann-type voltmeter, pure water, H_2SO_4 (sulphuric acid); a scaled pot, a 0-20 volt DC low-current power supply, digital voltmeter, amp meter, barometer (Fortin barometer), thermometer, an adjustable ruler, time counter and technical measurement tools.

The participants: The participants of the study consisted of 35 students in the 5th class in the Department of Physics Teaching divided into four groups.

Method: The students were asked to find the electron charge by means of the electrolysis of water based on the open-ended experiment method of J. Bruner. Each group made its experiment plan. Then all the groups exchanged, examined and evaluated their original plans. The plan that all the groups designed together was shown on the OHP. This plan was used in the experimental activity. Some directive questions were asked during this time. For instance, were there any bubbles left under the voltmeter taps? What have you observed? Is it necessary to know the Avogadro hypothesis? Does the water level in the open-ended pipe of the voltmeter remain stable? Why? How can you distinguish hydrogen and oxygen gas accumulated inside the pipes? Why is the table of saturated vapour pressure given? Is it necessary to know the thermodynamics laws, such as general gas laws, in order to find the mass and volume of hydrogen under normal conditions. Do you need to know the Faraday laws?

The students made some tables to record the data they obtained during the experiment. To increase the reliability of the results, they repeated the experiments and conducted controlled experiments by changing the variables. They started to anlayse the data after completing experimental manipulations. Following this, each group presented their reports and discussed the results with the whole class.

FINDINGS AND DISCUSSION

The following findings were obtained while the students were engaged with experimental activities:

1. None of the students could find the electron charge individually.
2. None of eighteen students could write the anode and cathode reactions.
3. Fourteen students made technical errors when they first prepared the experimental assembly (i.e., they did not release the whole gas under the taps, or they started the electric current when the taps were open).
4. 75% of the students attempted to find the electron charge by taking the Faraday laws into account and using the equation related to the amount of the gas accumulated at the cathode. However, they did not succeed.
5. Nearly 50% of the students did not comprehend Avagadro's hypothesis.
6. All of the students confirmed that hydrogen's volume at the cathode was twice as large as oxygen's volume at the anode, and that water was made of two hydrogen and one oxygen atoms.
7. Twenty-four students appeared to understand that the hydrogen pressure on the electrolyte's surface in cathode pipe is $P= P_a + h/13.6 – P_b$. Eight students found the pressure as 76cmHg. Only 20 students could find the pressure correctly, but most of them could not think of the relationship between pressure, temperature, and gas volumes, and relate it with general gas laws.

This can be interpreted as that some of the students still maintained traditional laboratory approaches (i.e., plain description, demonstration method and closed ended experiments etc.). This may also indicate that some of the students could not improve their scientific process skills since they could not try to solve a problem through thinking, exploring and trying solutions.

At the end of classroom discussions, the following steps were suggested:

1. A small amount of H_2SO_4 should be added to into water because water is insulating.

2. An acids is ionised in water according to

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{-2}$$

3. When a current is allowed to pass,

$$SO_4^{-2} + H_2O \rightarrow SO_4^{-2} + \frac{1}{2}O_2$$

reaction occurs at the anode and

$$2H^+ + 2e^- \rightarrow H_2$$

reaction occurs at the cathode.

4. Hydrogen accumulates at the cathode and oxygen at the anode. The hydrogen volume is twice as large as the oxygen volume. Hydrogen can be recognised by its blue flames.
5. H_2 gas at the cathode can be read on pipes, temperature can be measured by a thermometer, air pressure with a barometer, time with a chronometer and electric current force with a voltmeter.
6. H_2 gas pressure on the electrolyte can be found using $P= P_a + h/13.6- P_b$ equation
7. H volume (V), pressure (P) and temperature (T) are changed into normal conditions according to common gas laws. V_0 is found under T = 273.150°C and P_0=76cmHg (for mercury) via $PV/T=P_0V_0/ T_0$
8. Normally, 1 molgram of any gas contains N_0 molecules.
9. Hydrogen molecules (having V_0 volume) receive the same amount of electrons as their atoms to be neutralised. (If 1 molgram Hydrogen contains $N_0= 6.02x10^{23}$ molecules and 1 mole of H_2 has a volume of 22.4L, then the number of H_2 atoms and molecules can be found easily).
10. There are $N_0= 6.02x10^{23}$ molecules in 22,400cm^3 H, and there are $X = V_0N_0/ 22,400$ molecules and 2X atoms in V_0 H.
11. Electron charge can be found using 2X.e=i.t ---> e=i.t/2X----> $e=11200.i.t/ V_0N_0$ equations.

CONCLUSION AND SUGGESTIONS

- At the end-of-class discussions, the electron charge is found as $q_e=1.60076304x10^{-19}$C. This result matches highly with those are reported in literature.

- The more students learn, the more consciously they examine the events and facts, and the more effectively they defend their findings.
- Students should be motivated well and attention should be paid on using physics learning theories in both theoretical and practical studies.
- Feedback should be given to students in all the stages of their activities. Thus, they will find out their learning levels by self-evaluation.
- This learning approach, which is based on thinking, trying, and finding, is an indisputable student-oriented method and should be used in science lessons at secondary schools. We believe that this approach can help students to gain a scientific thinking discipline and to have a good basis for their higher education.

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Using virtual laboratories and online instruction to enhance physics education

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Teaching introductory and survey physics courses has never been an easy task, especially given the great breadth of material to be covered. Although it is universally accepted that a laboratory or demonstration is the best way to convey the more complex concepts, equipment constraints and complicated laboratory setups often constrain the variety and quality of laboratories available to physics educators at all levels of physics education. This paper introduces physics educators to the use and adoption of Java- and Shockwave-based applets in order to create virtual, online physics laboratories for their students. Details of course preparation, including applet acquisition, customization, and laboratory development, will be discussed. These techniques have been used to successfully form a Laboratory course which augments the more conventional lectures in a Concepts of Physics course at Devry University in Pomona, California. The laboratories have been instructor-led but are sufficiently self-contained to become part of a virtual classroom offering.

1. INTRODUCTION

Physics is filled with beauty and mystery. Sadly, very few people besides physicists appreciate these deeper aspects of the world we inhabit. More often than not, the budding curiosity of a non-scientist is killed, tragically, in a physics classroom of all places. The sheer breadth of complex material covered in any physics survey course bludgeons and confuses all but the most dedicated students. This has always been the dilemma faced by physics educators: how to communicate the content, impart the knowledge, and, all the while, keep the fascination of physics alive.

It is almost universally accepted that the best way to convey these ideas is through a laboratory or a demonstration, where students can see physics in action and truly appreciate the natural world around them. Every physics educator knows that even the most disinterested student is completely enthralled when you explain the mystery behind the objects and phenomena that populate their world. Thus, in the Concepts of Physics course offered by the General Education department at Devry University, Pomona, we offer both a lecture and a companion laboratory. This is a breadth course that is required of all undergraduates. For most students, this is possibly their only opportunity to learn basic physics before graduation. Students in these courses generally do not have a strong background in math and science and will not continue on with science subjects; more details about the pre-requisites can be found in the syllabus for the course available on the course homepage [8]. Concept clarity and increasing our students' motivation is our main goal. Due to the breadth of the content covered, these courses have traditionally been a challenge to teach and, therefore, innovative teaching methods have been employed to accommodate different learning styles [4].

Funded by a Faculty Technology Grant from Devry University, our approach was to use modern, computer-hosted tools to visually demonstrate many of the concepts covered in the lectures. In this study, we discuss a prototype we have used in Physics 214 at Devry University, Pomona to provide an option to the more traditional "hands-on" laboratory experiments, which are usually done in a group format and have been a traditional part of most introductory physics courses. We have employed these labs over the course of three semesters, with multiple sections held in each term; student feedback was very positive and this has led to a proposal to expand the prototype to develop a full semester-length "On-line Physics Laboratory" course consisting of ten laboratory experiments. Our approach is readily exportable to other university and non-university campuses and can easily be hosted on existing computer facilities with negligible additional cost.

While the initial application was to Physics 214, this same approach can readily be applied to Calculus-based physics and also to other science classes such as Chemistry and Astronomy, which may be subsequently added to the curriculum. It opens up the possibility of effective remote teaching of subjects that had previously been thought to require on-campus participation. Further extension to a fully interactive environment is envisioned. We have, in fact, produced a prototype of an interactive experiment and the strength of this format is easily seen. Indeed, such advanced information technologies can be used to create so-called "virtual" classrooms, which incorporate "blended" or "hybrid" learning; a large body of research indicates that such techniques are proving to be very effective methods of promoting student learning [2][6][10].

2. MOTIVATION

A course such as Physics 214 in the General Education department at Devry University consists of three hours of lecture and two hours of laboratory each week. It is aimed at non-engineering majors with limited science/math skills. Usually, there are 10-11 such lab periods per semester devoted to experiments that complement the concepts taught in class. In General Education, we are limited by the available number of equipment to two groups per class. For an average size class, this would range from 7-12 students in each group using only one set of equipment — too many to provide an optimal learning experience for each student. Traditional wisdom tells us that two to three students is optimal for such labs. In addition, at least at Devry, Pomona, the labs are held in the lecture classrooms in lieu of a dedicated lab space. An online laboratory can thus significantly improve the quality of the learning process and, in fact, has received very positive student review at the Pomona campus.

In addition, the main benefit of the online approach is to bypass most of the equipment constraints that plague a traditional physics laboratory. Most labs are constrained by the type and variety of equipment, equipment budgets, maintenance costs, experimental errors, and frustration from all of these issues. Using the applet-based virtual labs, each student can have a personalized learning experience. They can work at their own pace and the equipment issues that usually sidetrack students and take away from the physical concepts being explored are eliminated. Of course, this can be viewed as a disadvantage for the science majors or the advanced students, as a lot of learning happens when things go wrong. But, for the most part, virtual labs minimize experimental errors that can stump and, even worse, frustrate non-science majors, all the while making learning difficult concepts fun, as evidenced by the student feedback below.

3. REQUIREMENTS

3.1 Applets

The applets that form the core of the computer-based laboratory experience for students use standard Java and Shockwave as their main programming medium. An applet is essentially an application that runs within a regular browser window (e.g., Internet Explorer, Mozilla, Firebird, etc.). These mini-applications provide total interactivity, combined with full multimedia and graphics that allow students to easily visualize difficult concepts. Incorporation of Java and Shockwave applets present the ideal way to:

* Allow each student to have an interactive, hands-on experience in a lab that explores various physical principles, from basic to advanced
* Allow each student to have a personalized learning experience (e.g., instead of large groups watching a demo)
* Eliminate equipment issues that usually sidetrack students and take away from the physical concepts they're trying to explore
* Minimize experimental errors that can stump and, even worse, frustrate non-science majors
* See "physics in action": online learning resources not only help make learning difficult concepts easier but also more fun for students

These applets are accessible from any computer that has a browser and an internet connection (even a simple dial-up connection will suffice). For those labs that lack an internet connection, it is possible to package the applets themselves, along with the associated lab, onto a CD and distribute these to the students.

3.2 Hardware

On the server side, however, we utilize cutting-edge Open Source Freeware to present this innovative product. Using an Apache web server, combined with a MySQL database powered backend, we incorporate PHP/Perl and the latest HTML technologies (e.g., CSS) to serve up the Java and Shockwave interactive applets. Our labs can be hosted on any computer connected to the Internet; as most universities already have some Internet-ready computers, such labs require no additional investment in hardware. Of course, as alluded to earlier, these servers are only necessary if the presentation is to be over the Internet, as opposed to on CD.

The labs are self-explanatory and their use by instructors requires no training before it can be used in a student environment. Of course, the laboratory instructors should always try a "dry run" to get familiar with the lab concepts and the applets. In our experience, the ideal setup is as listed below in Table 1, with the web server being any Pentium III or higher web server with at least 256 MB RAM.

	Item
Hardware	Web Server (pre-existing)
	Red Hat Linux 9.0
	HTML/CSS v4.0 (as per latest W3C compliance)
	PHP 4.1.2
	Perl 5.6.0
Software	MySQL 3.23

Table 1: *Hardware/Software Requirements*

Since all of the server software associated with this project is free Open Source software (and the web server is presumably already available at any university), the main costs associated with development of the labs are programmer-time in setting up the hardware and software and instructor time in customizing the labs for each specific course. Finally, client computers (one per student) can be any Internet-connected computer with a Java- and Shockwave-enabled browser (either Mozilla, Firebird, or Internet Explorer).

3.3 Acquiring and customizing the applets

Our experience with our prototype indicates these facilities can be readily integrated with other users. The course itself makes use of existing software (applets) which are available at no cost from the web as most authors of applets allow free use for non-commercial applications by educational colleagues. Note: there may be some licensing issues with the use of some applets and such use must be authorized by the authors of the applets. We have compiled an extensive list of resources on the web where such applets are readily available in [7]. However, given the speed with which the Web changes, most of these links are likely to become outdated soon. Thus, search engines like Google or meta search engines like Dogpile or even directories like Yahoo! are likely to provide the most up-to-date applets. For those interested in writing their own applets from scratch, there is no better reference than [3]. However, it should be pointed out that those willing to get their hands dirty can use the Java reverse-engineering tool javad, which is standard in the Sun Java SDK distribution, to customize and modify the freely available Java applets from the web. As with their original acquisition, however, authors' permission should always be sought before any alteration or publication. There is no comparable reverse-engineering tool for customizing Shockwave applets.

4. DESCRIPTION

The experiments themselves consist of more than the applet; in fact, the majority of the work involved in creating a successful virtual lab is constructing a proper experiment around the applet. Most of the labs we created for the applets below had extensive experiments built around them. A user's guide for the experiments is available at [5]. Instead of having groups of 7-12 students, each lab experiment can be performed by individual students on computers which are connected to the Internet and which run a standard suite of software, as described in Section 3. Pre-existing computer labs at most universities should suffice for these purposes and these facilities will readily allow hosting of the proposed physics labs.

Our approach is visually-based, with graphics to allow the student to see and understand the principles that underlie the procedural text that he/she is following. This is particularly good to demonstrate how a change in one parameter directly affects another parameter. Students can proceed at their own pace and can even access the labs at home or out of regular laboratory hours if they need to achieve better understanding. This is a useful feature since our Physics 214 students usually come from diverse backgrounds and exhibit quite a range of expertise. By putting forth both basic and more challenging questions, our labs provide a challenge and an optimum learning experience to each skill set. This comes very close to our ultimate goal here at Devry University of providing an optimal learning environment for a diverse student group.

The proposed labs make use of selected Java and Shockwave Applets available from the web. Our communications with the authors of these Applets indicate that their use by third parties is allowed provided acknowledgement is given; however, caution must be taken as the situation is different for each author and each applet. We have identified over 25 such applets covering physics principles that are appropriate to our course, with most of them listed in [7]. An even wider range is available for other subjects such as Astronomy, Mathematics, and Electronics.

The laboratory package proposed here can be extended by providing a fully interactive version, such that the student is asked to perform actions and then respond to subsequent questions. Immediate feedback as to their correctness would then be given and, if incorrect, the student is asked to try again. The power of this feature can be seen by viewing the prototype webpage at [5].

5. FIVE SAMPLE LABS

5.1 Measurement and use of the Vernier Caliper

The idea of this lab is to use simple measuring tools (a ruler and a Vernier caliper) to measure dimensions of objects in both the English and the Metric units and show that they are equivalent. This exercise requires some unit conversion.

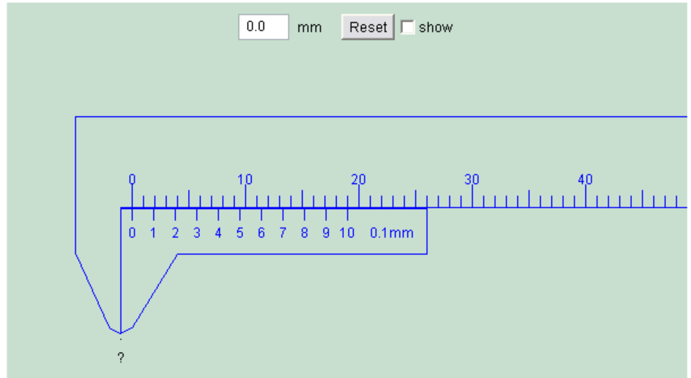

Figure 1: *Vernier Caliper Applet*

5.2 Fluid Behaviour & Density

These experiments are aimed at: a) the determination of the density of an irregularly shaped object from the volume of fluid displaced when it is immersed in a fluid and it's mass when measured on a balance and b) the demonstration of the principles governing fluid behaviour.

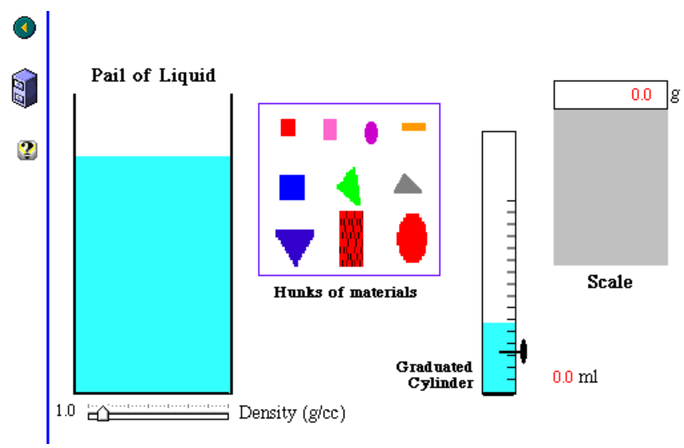

Figure 2: *Density Shockwave Applet*

5.3 Temperature and Heat

To determine the temperature of a liquid in degrees Fahrenheit and Centigrade and to use the data to confirm the general relationship between the two scales. Also, to determine the specific heat of a metal object by measuring the amount of heat transferred from that metal object to another, cooler body (of water). But the main purpose of this lab is to elucidate the scientific method at work. The idea is to make a guess (your hypothesis) based on some underlying reasoning. Then, you perform an experiment to confirm or deny that hypothesis and, based on the results, modify your guess (your hypothesis), if necessary.

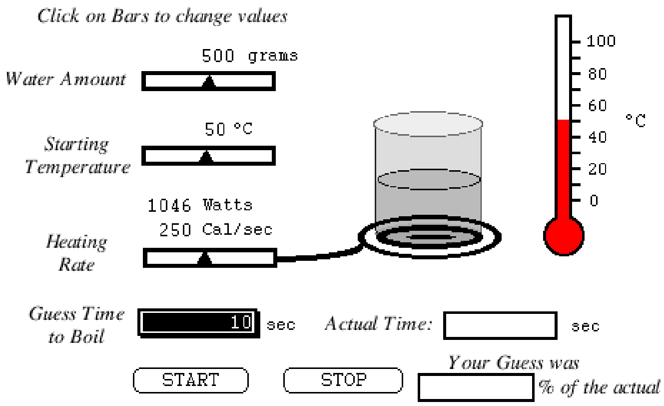

Figure 3: *Boiling Water Applet*

5.4 Centripetal Force & Motion

If an object moves in a circular path there must be a Centripetal Force acting on it. This experiment determines this Centripetal Force and compares it with the balancing force of gravity on a hanging object.

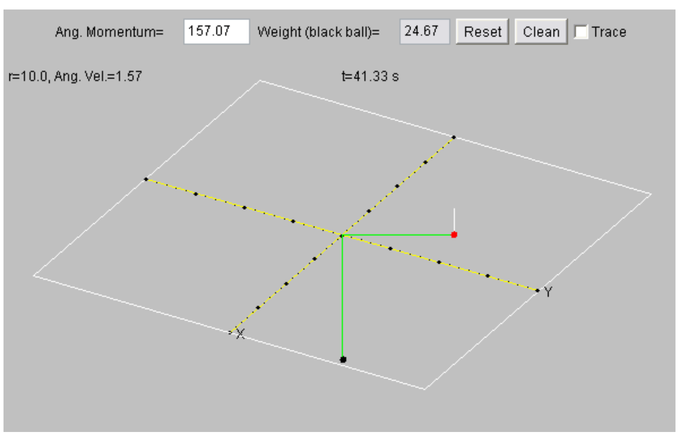

Figure 4: *Centripetal Motion Applet*

5.5 Buoyancy

These experiments are aimed at: a) the determination of the density of an irregularly shaped object from the volume of fluid displaced when it is immersed in a fluid and it's mass when measured on a balance and b) the demonstration of the principles governing fluid behaviour.

6. OUTCOME, ASSESSMENT & IMPACT

A physics lab aims at convincingly demonstrating concepts. This means that the result obtained should agree sufficiently well with the predicted result to convince the student that, in fact, the concept is true. This agreement is often not good enough, perhaps because of equipment or technique and the student is left wondering why there is such a discrepancy. With the computer-based physics lab, results are programmed to achieve the agree-

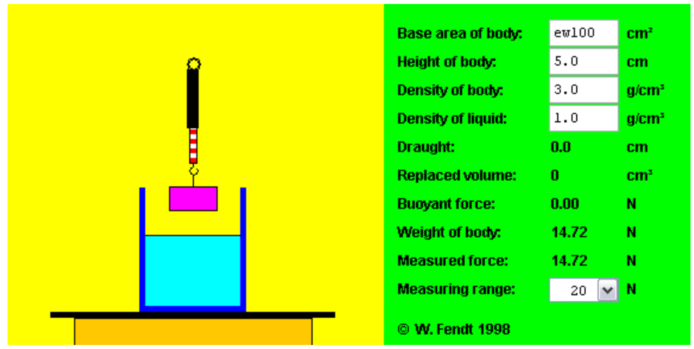

Figure 5: *Buoyancy Java Applet*

ment that would result from a careful, first-class experiment. The result is a strong positive reinforcement of the relationships between the variables.

We see this project very much supporting the learner-based concept of education, which opens up the possibility to offer such science-based courses to those students who do not have the opportunity to attend a regular university environment. As long as learners have access to the Web, they can avail themselves of the on-line, instructor-independent physics labs.

The assessment of our prototype has been done by students from the Fall 2002 classes. Some of the comments are cited below. After running the demonstration, and following the lab exercise, it shouldn't surprise us to find student feedback like:

"... the computer was a good tool for accuracy"
"Most of them were fun.. great teaching tools"
"I enjoyed sitting at home on the weekend, a cup of coffee in my hand, and playing with them online"

Although the vast majority of students were enamored with the online approach, a few did lament the loss of a true "hands-on" approach where they could touch and feel the equipment and actually experience errors. Thus, while most students do like the computer-based physics labs, the true test of its benefit is to determine if the learning process has been improved. We propose to do that by introducing, as part of the testing process (quizzes and exams), more probing questions concerning the content of the labs than is now the case to determine specifically if the lab concepts have been grasped. In addition, we will include an interactive quiz at the end of each laboratory project to give immediate feedback and to point the student back to the appropriate area that they missed. The results of such a quiz will provide valuable instructor feedback to allow strengthening of the procedure. As a result of these processes, we will continually optimize the content of the labs.

It has immediate application to the remote learner who is able to access the Internet from his/her computer and is therefore very compatible with one of the growing trends in education [11]. This represents, in our opinion, a significant benefit by replacing the traditional science lab (requiring investment in equipment and facilities space) with a very cost-efficient, effective, and competitive alternative.

While the initial application is to the laboratory associated with the Concepts of Physics university course, this approach can be readily extended to non-university courses, also. Our initial motivation has been to generate and stimulate an interest in science for students in non-science majors. However, we see a more widespread benefit of the approach in allowing students to improve their analysis capabilities by using an environment with immediate on-line feedback (instructor-independent; i.e., replacing the lab instructor) to see how their "textbook" learning is applied to real events. This results in a person who is better qualified to make an immediate contribution when he graduates which, in turn, reflects on the quality of his school.

To many students, the traditional "hands-on laboratory" does not seem to reflect "modern technology". By using computer-based labs, this perception is eliminated and replaced with a learning experience which is perceived to be in step with today's technology. In fact, most on-line experiments could be combined with several traditional, "hands-on" experiments to make up a complete course.

7. CONCLUSION

This paper has described a physics laboratory course that was initially developed to augment the General Education, Physics 214 lectures at Devry University, Pomona. A prototype has received very positive student response. The concept allows subjects such as physics to be taught to students at remote locations or locally in lieu of equipment constraints. We believe this approach has application to other courses, both in a university and a non-university setting and to other subjects, such as Astronomy and Mathematics. There will continue to be a debate over the benefit of a traditional "hands-on" laboratory versus a computer-based laboratory for science subjects. We believe, however, in classes aimed primarily at providing a well-balanced, university-level experience to the student, that a computer-based laboratory is a unique and valuable asset in the arsenal of tools that the instructor should use. Finally, the authors would like to thank Dr. A. Cherif, Dr. C. Koop, Dr. D. Overbye, Dr. B. Aron, and Dr. N. LaChance for their support in the Faculty Technology Grant program at Devry University.

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