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Inside This Issue

Recruiting High School Physics Teacher Candidates

Anyone who pays attention to employment trends in secondary-level education knows that there is a large and growing demand for physics teachers. According to the U.S. Department of Education, within the next 10 years fully half of all high school physics teachers are expected to retire or otherwise leave the profession. According to the National Center for Education Information, a recent study shows that 40 percent of all public school teachers plan to leave the profession in the next five years. The trend among high school teachers is most pronounced. That's the highest exit rate since at least 1990.

In many of the larger states such as my own home state of Illinois, as many as 40 to 50 physics teaching positions will go unfilled by "authentically qualified" teachers each year (as opposed to "highly qualified" science teachers who, by some NCLB-related state requirements, might have never even taken a single physics course). This is reason for great concern. The Illinois Section of the American Association of Physics Teachers (ISAAPT) is not ignoring this problem. They are working diligently to do something about it, and are involving other statewide science teacher associations to do something about it as well.

With the support of a $500 grant from the national office of the American Association of Physics Teachers during 2004, the ISAAPT hosted a one-day physics teacher candidate recruitment, preparation, and retention workshop, and commissioned an Ad Hoc Committee to continue the work long term. The Committee has met repeatedly at Section meetings subsequent to the kick-off meeting held during the autumn of 2004. During the joint Illinois and Chicago Section meeting during the autumn of 2005, finishing touches were put on a draft recruitment brochure. The Illinois Section has subsequently created a Web page dealing with teacher recruitment that links to various resources.

The Web page (http://isaapt.org/teach/) provides information about Illinois secondary "science" certification, and contains a listing of all post-secondary institutions through which students can earn teaching certificates. The Web page references a tri-fold brochure designed specifically for high school students that resulted in part from the many contributions by ISAAPT and CSAAPT members during the 2005 joint meeting.

This brochure communicates to readers seven good reasons to become a high school physics teacher, what it takes to become a high school physics teacher, and how to become a high school physics teacher. The brochure lists five criteria that students can reflect upon to determine if indeed they have the "right stuff." Students are informed about eight institutions that are "actively involved" in physics teacher preparation. This listing reflects those eight institutions that participated in a spring 2005 statewide survey of teacher preparation institutions with physics teacher education programs. The brochure is intended for printing by in-service teachers, and distribution to prospective physics teacher candidates. Hundreds of copies have already been distributed to physics teachers across Illinois, and many more will soon be printed for distribution.

During the April 7-8, 2006, meeting of the ISAAPT, a morning workshop will be held to draft an outline that will be provided to in-service teachers to help them understand the need for more physics teacher candidates, their role in the recruitment process, and how to select the most viable teacher candidates. Readers of *JPTEO* with an interest in helping secondary-level physics teachers see the need for candidate recruitment are encouraged to share their ideas by writing the *JPTEO* editor-in-chief using the e-mail address below.

Work is also underway within Illinois to have science teacher associations such as the Illinois Association of Chemistry Teachers (IACT), the Illinois Association of Biology Teachers (IABT), and the Illinois Science Teachers Association (ISTA) to join both the short-term and long-term efforts in recruiting teachers in their respective disciplines and grade levels using the "Illinois Model" (see Repairing the Illinois high school physics teacher pipeline: Recruitment, preparation and retention of high school physics teachers, *Journal of Physics Teacher Education Online, 2*(2), November 2004).

The ISAAPT is, in my judgment, a great example of what can be done to combat the looming problem caused by the pending retirement of a tremendous number of experienced high school physics teachers. Other organizations on a state or national basis can learn something from the Illinois model. All readers with an interest in addressing similar problems in their own state or nation should consider strongly visiting the "Illinois High School Physics Teacher Pipeline" Web page at the following URL:

http://www.phy.ilstu.edu/pipeline/

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REVIEWERS

JPTEO

A framework for teaching the nature of science

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To help students understand the nature of science, good science teachers will infuse considerations for the nature of science throughout their instruction. While such teaching about the nature of science might be limited in scope and duration on any one day, it is generally ongoing, explicit, and in context. Poor science teaching assumes that students will learn about the nature of science implicitly through lecture, problem solving, and cookbook lab experiences. While this assumption is true to a limited extent, using an inquiry approach and teaching directly about the nature of science on a regular basis and in context will be considerably more effective. In order to successfully teach about the nature of science, teachers must be provided with essential understandings, suitable pedagogical practices, and appropriate motivation so they can maximize what their students learn in this important topic area. (Note: Sections III-V on pages 5-6 were slightly updated on 10/17/06; changes are italicized.)

As a physics teacher educator since 1994, I have seen many physics teacher candidates at Illinois State University come into my classrooms as juniors with a limited understanding of the nature of science. They generally have a good understanding of the content of physics, but only a vague understanding of what science is about and how it proceeds. When questioned about various nature-of-science topics, they frequently are unable to assemble more than one or two cogent sentences in response. This is not surprising when textbook-driven instruction gives the conclusions of scientific work and merely explains the concepts. Much introductory science teaching leaves out of the discussion the processes – the context and motivations, the twist and turns, the mistakes and dead ends, the assumptions and decisions – explaining how scientists arrived at their conclusions.

If students have taken several years of didactic physics content courses, it is understandable why they have such a limited knowledge of the nature of science. Given a traditional textbook approach, how can we expect science teacher candidates to impart a suitable understanding of the nature of science to their own students? Logically speaking, we can't. Teachers cannot effectively teach what they do not know and understand.

While there have been volumes written about the nature of science and its relationship to science literacy, very little information is provided about how to actually teach students so that they can develop the expected understanding of the nature of science. After several years of classroom experience and reflection, I feel that my colleagues and I are now in a position to help our physics teacher candidates learn what they need to know about the nature of science, and how to both value and teach it.

It would be presumptuous of any author if he thought that he could fully describe and explain everything a teacher candidate should know about the nature of science in a short essay. Only a book-length manuscript would be sufficient for this purpose. Nonetheless, it is my goal here to outline how we prepare our physics teacher candidates at Illinois State University to effectively educate their own students about the nature of science at the high school level.

To What Does "Nature of Science" Refer?

The concept of "nature of science" is complex and multifaceted. It involves aspects of philosophy, sociology, and the history of science (McComas, Clough, & Almazroa, 1998). It is surrounded by numerous issues (Alters, 1997; Labinger & Collins, 2001; Laudan, 1990), and is rather complex as the review of any relatively recent philosophy of science book will show (e.g., Bakker & Clark, 1988; Klee, 1997).

Authors variously define what constitutes the nature of science (NOS), and what students should know in order to be "NOS literate." For instance, Aldridge et al. (1997) see the processes of scientific inquiry and the certainty of scientific knowledge as being central to understanding NOS. Lederman (1992, p. 498) states, "Typically, NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development." Lederman et al. (2002) define NOS in part by referring to understandings about the nature of scientific knowledge. These understandings deal with science's empirical nature, its creative and imaginative nature, its theory-laden nature, its social and cultural embeddedness, and its tentative nature. They also express concern about understandings relating to "the myth of The Scientific Method."

Project 2061's *Science for All Americans* (AAAS, 1989) and *Benchmarks for Science Literacy* (AAAS, 1993) both regard understandings about scientific world view, scientific inquiry, and the scientific enterprise as being central to a comprehension of NOS. According to the Project 2061 authors, a scientific world view consists of beliefs that the world is understandable, that scientific ideas are subject to change, that scientific ideas are durable, an that science cannot provide complete answers to all questions.

In addition, individuals will understand the processes of inquiry and know that science demands evidence, is a blend of logic and imagination, and explains and predicts, but is not authoritarian. Those who are NOS literate will also be knowledgeable about the scientific enterprise. They will understand that science is a complex social activity, that science is organized into content disciplines and is conducted at various institutions, that there are generally accepted principles in the conduct of science, and that scientists participate in public affairs both as specialists and as citizens. They attempt to avoid bias.

The National Research Council in *National Science Education Standards* (NRC, 1996) sees scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures as being central to understanding the nature of science.

These characterizations of what constitutes the nature of science are incomplete. Many more things could be added to these characterizations such as an understanding that science is self-correcting, that scientists assume a naturalistic world view, that science most often advances as a result of incremental change which is just as important as if not more important than genius, and that the primary roles of science consist of explanation and prediction.

In order to achieve the goal of having students become broadly NOS literate, we must first identify essential understandings about NOS, and provide an implementation model, practical advice, and motivation for implementing appropriate NOS literacy practices in the classroom.

Essential Understandings about NOS

Statements about what it means to be NOS literate are inadequate for planning purposes to the extent that they do not provide a detailed definition. Teaching in the Illinois State University PTE program is predicated on a nominal definition of what it means to be NOS literate. Individuals with a broad understanding of the nature of science will possess knowledge of the content and history of at least one science discipline, plus knowledge of associated scientific nomenclature, intellectual process skills, rules of scientific evidence, postulates of science, scientific dispositions, and major misconceptions about NOS.

While this definition appears rather comprehensive, it takes an admittedly simple if not simplistic view of NOS. Nonetheless, judgment about what constitutes an adequate understanding of the nature of science must be based on the practicalities of teacher preparation. While it would be ideal if every teacher candidate would take a course dealing with the nature of science or the history of science, it too infrequently happens due to the lack of such courses or as a result of the prodigious number of graduation requirements placed on science education majors. As a consequence, we use a pragmatic operational definition tempered by the requirement that we must be able to address the various components of the definition in our physics content and teaching methods courses. It should be noted that a reasonably comprehensive understanding of physics content knowledge is not addressed, but is assumed.

I. Scientific Nomenclature

A common language is essential to accurately communicate ideas (Hirsch, 1987). We believe that this is true in relation to NOS. As such, we have identified twenty-four terms that we feel are most closely associated with both experimental and epistemological concepts. We believe these terms represent the minimal vocabulary and concepts with which every teacher candidate, teacher, and their students should be familiar.

The experimental terms are regularly employed in inquiry-oriented laboratory activities associated with introductory calculus-based physics courses that students take at Illinois State University. All experimental terms are fully explained in our regularly referenced *Student Laboratory Handbook* (see http://www.phy.ilstu.edu/slh/). Epistemological terms and concepts are addressed in considerable detail in two of our six required physics teaching methods courses: Physics 310 – Readings for Teaching High School Physics and Physics 312 – Physics Teaching from the Historical Perspective (for hyperlinks to all courses described in this article, visit http://www.phy.ilstu.edu/pte/). The terms that serve as the basis for our NOS-related course work appear in Table 1.

assumption	hypothesis	proof
belief	induction	pseudoscience
control	knowledge	system
deduction	law	science
empirical	model	scientific
evidence	parameter	theory
explanation	prediction	truth
fact	principle	variable

Table 1. *Essential scientific nomenclature: Twenty-four fundamental terms and concepts with which science teachers and their students should be familiar.*

II. Intellectual Process Skills

We believe that students cannot have a comprehensive understanding of the nature of science if they do not have first-hand experiences with the empirical methods of science. We have adopted a list of essential observational and experimental skills that will be learned when science is taught using inquiry-oriented teaching and laboratory methods. A listing of the some of the key intellectual process skills addressed in our inquiry-oriented labs is provided in Table 2.

- Generating principles through induction
- Explaining and predicting
- Observing and recording data
- Identifying and controlling variables
- Constructing a graph to find relationships
- Designing and conducting scientific investigations
- Using technology and math during investigations
- Drawing conclusions from evidence

Table 2. *Some of the many intellectual process skills addressed in ISU's inquiry-oriented labs in introductory physics.*

Based on the skills in Table 2, the Physics Department recently has undertaken the task of replacing its traditional cookbook labs with inquiry-oriented labs that strongly focus attention on important intellectual process skills used by scientists.

III. Rules of Scientific Evidence

The rules of scientific evidence have been a topic of considerable attention for notable scientists and philosophers ever since the "Enlightenment" of the 17th century (e.g., Pascal, Leibniz, Galileo, Newton, Bacon, Berkeley, Hume, Hobbes, Locke, and Kant to name but a few). Nonetheless, to the best of the author's knowledge, the rules of scientific evidence have never been codified in an easily accessible way. There is a need for such if treatment of this subject matter is ever to be addressed systematically through teaching. What follows is a simple compilation of such. There is no claim of completeness, and no claim that every scientist or philosopher of science would agree with all these statements. Readers are cautioned that characterizations are at best tentative. No form of hierarchy is to be inferred on the basis of order. This list is a point of departure for those who would like to talk about rules of scientific evidence with students. It again serves as one of the bases upon which NOS teaching is based at Illinois State University.

- In order for a claim to be scientific, it must be testable (Popper's principle of falsifiability); by this definition a claim need not be accurate to be scientific.
- The ultimate authority in science is empirical evidence based on observation or experimentation.
- Scientific conclusions must be based on *public* evidence; it is improper to accept any claim without sufficient supporting evidence.
- Correlation should not be confused with cause and effect; scientists do not accept coincidence or unlinked or unsupportable correlations as proofs.
- Scientific claims, to be acceptable, must not conflict with what is known with relative certainty; nonetheless, it should be kept in mind that scientific creativity sometimes contradicts conventional understanding.
- Scientists should be skeptical of claims that conflict *with accepted views of* reality; they should avoid bias and be particularly objective in their treatment of claims of which they are skeptical.
- Scientists should test and independently verify all significant and apparently justifiable claims, especially those that appear to contradict conventional thinking and/or prior evidence.
- The more unconventional a claim, the greater the requirement for supporting evidence; anecdotal evidence is insufficient proof of any scientific claim.
- Scientists must not make selective use of evidence; they must not promote a particular belief by suppressing evidence or fail to seek evidence by avoiding investigation.
- Only one positive instance is required to refute a negative claim.
- Multiple positive instances alone cannot prove a positive claim unless all cases are examined.
- *One should not assume as certain that which one is attempting to demonstrate; this can lead to false conclusions.*
- If several explanations account for the same phenomenon, the *more elegant* explanation is preferred (parsimony or Ockham's razor); a single comprehensive proposition is to be valued over a number of ad hoc propositions.

IV. Postulates of Science

Postulates of science are the assumptions upon which science operates. They serve as the basis for scientific work and thought, and to some extent determine what is admissible or inadmissible under the rules of scientific evidence. The postulates of science are often referred to, but they – like the rules of scientific evidence – appear not to have been codified to the best of the author's knowledge. Nonetheless, for the sake of educating Illinois State's teacher education majors about NOS, we have adopted the following statements as representative of the postulates of science. Again, as with the rules of scientific evidence, there is no guarantee that this list is comprehensive or that all scientists or philosophers of science would agree with these postulates and their characterizations. Indeed, in the light of quantum physics some philosophers of science have argued that several of the postulates are mutually exclusive. We have adopted a pragmatic view for the sake of our teacher candidates studying and teaching classical physics during their student teaching practicum.

- All laws of science are universal and not merely local.
- There is a consistency in the way that nature operates in both time and space; the natural processes in operation today can explain physical events – past, present, and future.
- No observed effect exists without a natural cause, but sequence – no matter how frequently repeated – does not necessarily infer cause and effect.
- Scientists do not accept any kind of explanation for which no test is available; while objective scientists will preclude theological explanations, this must not be taken to imply that they are necessarily atheistic.
- Science admits, in addition to observable, repeatable observations, natural entities that might not be directly observed but whose existence can be theoretically inferred through reason.

- Scientific knowledge is durable but tentative, and is subject to revision; science does not *provide us with absolute certainty.*

- *While science does not provide for absolute certainty, proofs beyond a reasonable doubt are possible.*

- Science is not a private matter that concerns the individual scientist alone; rather, science is a social compact, and scientific knowledge represents the consensus opinion of the scientific community.

V. Scientific Dispositions

Science for All Americans (AAAS, 1989) identifies several general characterizations that describe suitable dispositions for scientists. *Benchmarks for Science Literacy* (AAAS, 1993) similarly addresses *desirable* "habits of mind" – the values and attitudes – *looked for in* scientists. We have encapsulated the major points of these two works in the following listing.

Desirable characteristics of scientists are:
- curious and skeptical – they are on the lookout to discover new things and demand suitable evidence for claims; they avoid unwarranted closure.
- objective and not dogmatic – they demonstrate intellectual integrity and avoid personal bias; they are open to revision in the face of incontrovertible evidence.
- creative and logical – they attempt to provide rational explanations on the basis of what is already accepted as established fact.
- intellectually honest and trustworthy – they realize that science is a social compact, and abide by the ethical principles of the science community.

VI. Major Misconceptions about Science

McComas (1996) has identified what he feels are the major misconceptions about science held by many non-scientists (and even some scientists). These myths are listed in Table 3. Readers are referred to the McComas article for explanations.

An Implementation Model for Achieving NOS Literacy

In addition to possessing an understanding about the nature of science, teachers need to have appropriate models and activities to help their students acquire an adequate understanding of NOS (Abd-El-Khalick, et al., 1998; Bell, Lederman & Abd-El-Khalick, 2000).

How, then, can teachers successfully promote student understanding in relation to NOS? What pedagogical practices should teachers use in an effort to effectively promote NOS literacy among their students? When does a teacher deal with the subject matter of NOS?

Figure 1 depicts the model that guides the work of the Illinois State University Physics Teacher Education program. Our model consists of six pedagogical practices geared toward helping students attain the required understanding: background readings that describe NOS, case study discussions that incorporate NOS, inquiry lessons that model NOS, inquiry labs that reflect NOS, historical studies that involve NOS, and multiple assessments that address NOS.

1. There exists a scientific method that is general and universal.
2. Hypotheses are really only educated guesses.
3. Hypotheses turn into theories that eventually become enshrined as laws.
4. Scientific knowledge is based mainly on experiment.
5. High objectivity is the hallmark of science.
6. Scientists always review and check the work of their colleagues.
7. Certainty results when facts are accumulated and analyzed.
8. Science is less creative than it is procedural.
9. The scientific method leads to absolute truth.
10. All questions posed by the universe can be answered via the scientific method.

Table 3. *Ten major myths about science. (After McComas, 1996)*

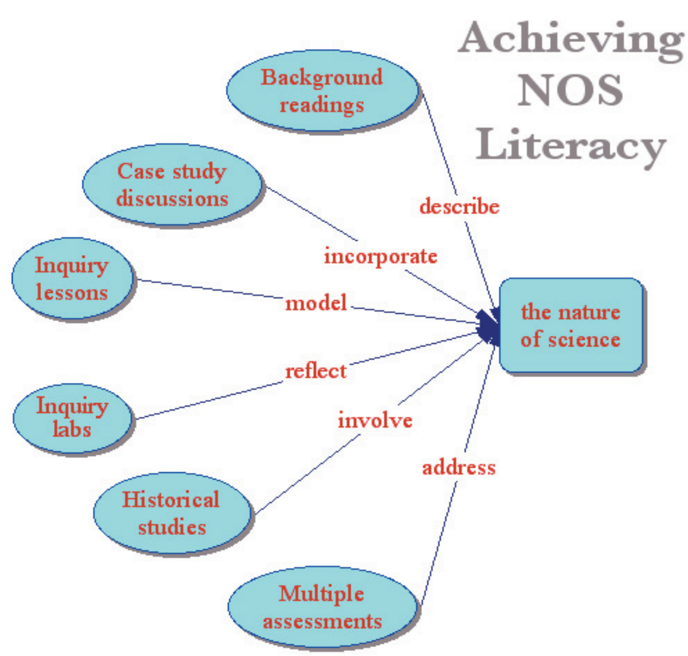

Figure 1. *ISU NOS implementation model. Pedagogical practices we believe are most suited to helping students achieve nature-of-science literacy.*

We believe that this approach helps our candidates gain a relatively comprehensive understanding of the nature of science. It is a model that we promote among our high school physics teacher candidates to help them achieve NOS literacy among their own students.

Background readings from books and articles that deal with the nature of science can have a very significant impact upon a student's understanding of the nature of science. Such readings can also heighten appreciation for science itself. Many books are available that deal reasonably well with the nature of science theme. Reading these books, and writing book reports or book reviews, can provide substantial background that can readily be brought to bear on classroom discussions. In the PTE program at Illinois State University, physics education majors are required to complete and discuss a number of readings in relation to NOS in Physics 310 – Readings for Teaching High School Physics. They are also required to read and write a review about one of the books listed in Table 4.

Case study discussions (Herreid, 2005) are excellent forums for helping students develop an understanding of NOS. Case studies typically present a dilemma or an issue, and students are asked to help resolve the problem. At ISU we have integrated 17 case studies (see sample) over two courses that help PTE majors learn about NOS through what is often very spirited discussion.

Doubt and Certainty. Rothman, T. & Sudarshan, G. (1999) New York, NY: Perseus Printers.
Fact, Fraud and Fantasy. Goran, M. (1979) Cranbury NJ: A.S. Barnes and Co., Inc.
Fads and Fallacies in the Name of Science. Gardner, M. (1957) Dover Publications.
Great Feuds in Science. Hellman, H. (1998) New York, NY: John Wiley & Sons, Inc.
Science and Its Ways of Knowing. Hatton, J. & Plouffe, P.B. (1997) Upper Saddle River, NJ: Prentice Hall.
Scientific Literacy and the Myth of the Scientific Method. Bauer, H.H. (1994) Urbana, IL: University of Illinois Press.
The Borderlands of Science: Where Sense Meets Nonsense. Shermer, M. (2001) Cambridge: Oxford University Press.
The Demon Haunted Word: Science as a Candle in the Dark. Sagan, C. (1996) New York, NY: Ballantine Books.
The Game of Science. McCain, G. & Segal, E.M. (1989) Belmont, CA: Brooks/Cole Publishing Co.
The Structure of Scientific Revolutions. Kuhn, T. (1962) Chicago, IL: University of Chicago Press.
Uncommon Sense: The Heretical Nature of Science. Cromer, A. (1993) New York, NY: Oxford University Press.
Voodoo Science: The Road from Foolishness to Fraud. Park, R. (2000) Cambridge: Oxford University Press.
Why People Believe Weird Things. Shermer, M. (1997) New York: W. H. Freeman and Co.

Table 4. *A list of books from which ISU physics teacher education majors must select to write a book review. Additional selections are also available.*

Sample Case Study: A Haunting Experience!

Fourteen-year-old Akimbo is afraid to enter the upper rooms of his 4-level mansion home. The mansion is a former plantation house that has been around since about 1850; the plantation was the site of a bloody 1863 Civil War battle. Many say that the mansion is haunted. Akimbo has been told by house workers that "spirits of dead soldiers" inhabit the upper rooms. According to these house workers, restless spirits move things around the rooms, and at night foot falls and even clashing swords can sometimes be heard from beneath each of the rooms. No one has ever seen these spirits. Still, those who visit the rooms often report having a "creepy" sensation, and feel as though someone is watching.

Are the various claims made by the house workers to be believed? Why or why not?

What might explain the "creepy" sensations and the feeling that someone is watching that visitors to the rooms report?

What other explanations might account for the reports?

Which is the best explanation for these supposed phenomena?

On what basis to do you accept some explanations and reject others?

These case studies cover most of the topics addressed in this article. (These cases can be found online at http://www.phy.ilstu.edu/pte/ by following the hyperlinks to Physics 311 and Physics 312.) Case studies need not be of long duration; it's amazing what insights students can gain in relation to NOS with just a 5-minute discussion. Case studies can be used intermittently as "problem of the day," during pre- and post-lab discussions, and as fillers when extra instructional time presents itself at the end of a class period.

Inquiry lessons, as one of the levels of the "inquiry spectrum" (Wenning, 2005a), provide an excellent forum for student learning in relation to NOS. Inquiry lessons by their very nature are predisposed to modeling science processes. As teachers conduct inquiry lessons, they can use think aloud protocols to provide insights about the workings of science; they can guide student thinking through focusing questions; they can talk explicitly about procedures being employed; they can give explicit instruction while modeling scientific inquiry practices. Inquiry lessons are a great way to teach NOS explicitly. Great care is taken during Physics 310 – Readings for Teaching High School Physics to model inquiry through appropriate inquiry lessons, and in Physics 311 – Teaching High School Physics – through "Lesson Study" (Stigler & Hiebert, 1999). This helps our physics teaching majors understand the comprehensive nature of the inquiry lesson planning approach. They can also come to understand the value of including it in their planning considerations for NOS literacy, and learn about the various barriers that exist in relation to its implementation (Abd-El-Khalick, Bell & Lederman, 1998; Wenning, 2005b; Wenning, 2005c).

Inquiry labs, as opposed to traditional cookbook labs (Wenning, 2005a), help students learn and understand the intellectual processes and skills of scientists, and the nature of scientific inquiry. Inquiry labs are driven by questions requiring ongoing intellectual engagement, require the use higher-order thinking skills, focus students' attention on collecting and interpreting data, and help them discover new concepts, principles, or laws through the creation and control their own experiments. With the use of inquiry labs, students employ procedures that are much more consistent with the authentic nature of scientific practice. With inquiry labs, students learn such things as nomenclature and process skills, and do so implicitly. Pre- and post-labs provide opportunities for explicit instruction about NOS. The ISU Physics Department has recently undertaken great strides to convert our traditional labs into inquiry labs (Wenning & Wenning, 2006) through which all native physics teacher education majors progress. In addition, inquiry labs are a central focus in the physics teaching methods courses Physics 302 – Computer Applications in High School Physics and Physics 312 – Physics Teaching from the Historical Perspective. At the conclusion of five semesters of inquiry-oriented labs in the area of classical physics, our teacher candidates have a fairly good grasp of the nature of scientific inquiry in the areas where they will focus their attention during the teaching of high school physics. A required two-semester sequence of Physics 270 – Experimental Physics provides teacher candidates with additional experiences in more modern aspects of physics research.

Historical studies can prove to be a powerful tool for not only teaching about NOS, but for putting a human face on physics and increasing student interest in the subject. The *National Science Education Standards* suggest the use of history "to elaborate various aspects of scientific inquiry, the nature of science, and science in different historical and cultural perspectives" (NRC, 1996, p. 200). The components of *NSES* dealing with history and the nature of science are closely aligned with similar standards described in Project 2061's *Benchmarks for Science Literacy. Benchmarks* notes, "There are two principal reasons for including some knowledge of history among the recommendations. One reason is that generalizations about how the scientific enterprise operates would be empty without concrete examples. A second reason is that some episodes in the history of scientific endeavor are of surpassing significance to our cultural heritage" (AAAS, 1993, p. 237).

Each of the sciences has at least one "great idea" that can be used to incorporate the historical perspective: Physics – models of the atom; Chemistry – periodic table of elements; Biology – evolution; Earth Science – plate tectonics; and Space Science – nature of the solar system and/or Big Bang. Historical research findings can be presented in a class presentation, in a paper, or by any other means. In Physics 312 – Teaching Physics from the Historical Perspective – we include approximately 30 vignettes to help make our students more aware of the historical background of physics.

Multiple assessments, alternative as well as more traditional, are important components in helping students to develop a deeper understanding of the nature of science. Alternative assessments such as presentations, written or oral reports dealing with historical subject matter, and periodic reflective journaling can be good ways to heighten student understanding of NOS. Test items such as multiple-choice and free-response questions on traditional exams can get students to focus attention and study time on the nature of science. Students tend to study those things that are addressed during assessment, and for which they are held accountable. A set of student performance objectives should be developed in relation to NOS goals, and students should be made aware of them. Lessons and assessments then should be aligned with these objectives. In Physics 310 – Readings for Teaching High School Physics and Physics 353 – Student Teaching Seminar – students complete a 30-item NOS literacy test dealing with the six elements addressed in this article. They subsequently use this assessment instrument as a pre- and post-test during student teaching to see what impact, if any, they are having on their own students' understanding of the nature of science (Wenning, in preparation).

Practical Advice for Implementing NOS Instruction

Based on a review of the literature, our experiences, and philosophical reflections, we offer the following advice for implementing instruction in relation to NOS: (1) The nature of science is best taught explicitly to both teacher candidates and students of science. Research has shown that students fail to develop many of the expected understandings of NOS concepts from traditional classroom instruction where it is assumed that students will learn about the nature of science by "osmosis" (Duschl, 1990; Lederman, 1992; Ryan & Aikenhead, 1992). NOS, therefore, should be taught explicitly when possible to develop the desired understandings (Bell, Blair, Crawford & Lederman, 2003; Khishfe & Abd-El-Khalick, 2002; Moss, Abrams & Robb, 2001; Abd-El-Khalick & Lederman, 2000; Akerson, Abd-El-Khalick & Lederman, 2000). Without directly addressing scientific nomenclature, intellectual process skills, rules of scientific evidence, postulates of science, scientific dispositions, and major misconceptions about science, it is highly unlikely that students will extract all these concepts on their own. Indeed, our own internal testing (Wenning, in preparation) shows that after several years of didactic science instruction, many science majors end up with only a vague and fragmented understanding of the nature of science. (2) The nature of science is best taught contextually. Students can develop a functional understanding of the nature of science only when they are taught in the context of scientific inquiry. NOS should not be treated as subject matter apart from the content of science, be it physics, chemistry, biology, earth and space science, or environmental science. (3) The nature of science is best taught experientially. Teaching science through inquiry helps student understand the nature of the scientific endeavor that simply cannot be meaningfully obtained in any other fashion. (4) The nature of science is best taught regularly. Addressing the nature of science once or twice, even if is dealt with as part of a discrete unit, is inadequate to the task of teaching students about NOS. Only repeated treatment of the subject matter of NOS covering a wide variety of situations will imbue students with a proper understanding. (5) The nature of science is best taught systematically. Teachers ought to know what should be taught in relation to this topic, and address the whole range of information about NOS with their students. To teach the subject haphazardly will result in substantial gaps in student understanding. (6) Only by helping teachers focus on the nature of science as an important goal in their instructional practice will result in more explicit science instruction (Lederman, Schwartz, Abd-El-Khalick & Bell, 2001).

Valuing NOS Literacy

Understanding the nature of science - its goals, assumptions, and processes inherent in the development of knowledge - has been one of the major goals of science education since the beginning of the twentieth century (Central Association of Science and Mathematics Teachers, 1907). Contemporary literature of the science reform movement also regards understanding the nature of science as one of the main components of science literacy (AAAS, 1993; NRC, 1996).

While a teacher's understanding of the nature of science and an implementation model are necessary prerequisites for teaching about the nature of science (Lederman, 1992), it is not sufficient. Teachers must also value an understanding of the nature of science before they will teach it (Lederman, 1999; Schwartz & Lederman, 2002).

Few individuals will question the value of studying the key concepts of science; however, there are many who might question why we should understand the nature of the scientific process. *Benchmarks for Science Literacy* brings up the following key point about why NOS should be valued, "When people know how scientists go about their work and reach scientific conclusions, and what the limitations of such conclusions are, they are more likely to react thoughtfully to scientific claims and less likely to reject them out of hand or accept them uncritically" (AAAS, 1993, p. 3).

In addition, NOS literacy is important in helping students of science confront the "new age of intellectual barbarism" that seems to be encroaching upon modern society. It helps them to make informed decisions relating to science-based issues, develop in-depth understandings of science subject matter, and help them to distinguish science from other ways of knowing. (NSTA, 2003) NOS literacy helps student defend themselves against unquestioning acceptance of pseudoscience and reported research (Park, 2000; Sagan, 1996).

The media are filled with hucksters making all sorts of unsubstantiated and unsupportable pseudoscientific claims about fad diets, supposed medical cures, herbal remedies, ghosts, alien abductions, psychics, channelers, astrology, intelligent design, mind reading, past life regression therapy, and so on. Students who have a good understanding of the content and nature of science as well as healthy scientific perspectives (e.g., skepticism) will not likely fall prey to flimflam artists who promote technological gadgets of dubious worth, dogmatists who promote beliefs of doubtful credibility, or purveyors of simple solutions to complex problems. NOS literate students will be able to, in Paul DeHart Hurd's words, "distinguish evidence from propaganda, probability from certainty, rational beliefs from superstitions, data from assertions, science from folklore, credibility from incredibility, theory from dogma" (Gibbs & Fox, 1999).

The valuing of NOS literacy by teacher candidates appears to come from experiencing a curriculum that includes essential elements pertinent to the learning and teaching of the nature of science. Throughout the sequence of the aforementioned physics teaching methods courses, we have seen among our physics teacher candidates a growing philosophical bent and fascination with the nature of science. Class discussions, especially case studies, result in many impassioned conversations that continue long after class. This alone is enough to suggest that our students do, indeed, find NOS literacy of considerable value and interest. To further encourage our teacher candidates to include considerations for NOS literacy in their own teaching, we have created a nature of science literacy assessment instrument that student teachers use as pre- and post-tests during student teaching. This assessment, currently in piloting phase, will be the subject of a future article.

Belief Statements Relative to Achieving NOS Literacy

A series of belief statements undergird NOS-related teaching practices within the Physics Teacher Education program at Illinois State University:

We believe that teachers can pass on to their students only what they themselves possess. Teachers must therefore possess an understanding of the nature of science if they are to impart that understanding to their students.

We believe that teachers must value NOS literacy before they will impart that understanding to their students. An understanding of NOS alone is not enough to make teachers to value or teach it.

We believe that teachers must be provided with an effective and practical means of achieving NOS literacy among their students before they will make the attempt to do so. To this end we deploy the implementation model described in this article.

We believe that teachers tend to teach the way in which they themselves were taught. It is only reasonable, therefore, that we should teach in the way that we expect our candidates to teach, and this includes considerations for the nature of science.

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Shifts in beliefs and thinking of a beginning physics teacher

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This case study traces the changes in beliefs and thinking of a beginning physics teacher, from his preservice work through his first three semesters of teaching. It examines the teacher's changing metaphors of himself as a teacher, and changes in his beliefs about student learning and classroom management. In addition to providing an analysis of teacher thinking, the study suggests that teacher preparation programs need to guide preservice teachers to confront their beliefs about teaching and learning.

> "I suppose that this is a pretty big shift in my philosophy…I remember feeling very strongly that students should not have a house-of-cards understanding of physics. [Now] I've become more of an advertising agent for physics."

This is a quote from Dennis, a beginning physics teacher who, over the course of his first three semesters of teaching, experienced a significant shift in his thinking about teaching and his role in the classroom. During that time, he evolved from a young idealist who believed that all his students learned as he did, to a practical realist focused on helping students learn in various ways. In addition, Dennis made a remarkable shift in his thinking about organization and student learning. This research study examined Dennis' shifts in thinking about teaching and his changing metaphors of himself as a teacher, as well as the conflict between two of those metaphors. It presents an analysis of teacher thinking at various career stages, and resulting implications for teacher preparation.

Background Literature

Preservice Teacher Beliefs

The beliefs about teaching and learning held by preservice teachers have been explored in much previous research (Calderhead, 1988; Pajares, 1992; Anderson, et. al, 1995; Carter & Doyle, 1995). This research revealed that the naïve beliefs that preservice teachers hold about teaching and learning are based in large part on their own experiences in school. They often view themselves as prototypes of their students (Holt-Reynolds, 1992) and believe that their students will learn in the same manner that they learn. This is an especially strong belief for courses in the teaching major, in which preservice teachers are generally successful students (Carter & Doyle, 1995).

In considering their role as teachers, preservice teachers tend to value aspects of teaching other than the content to be taught and learning goals related to that content. Dunkin & Precians (1992) identified four dimensions of teaching that preservice teachers consider as most important in enhancing student learning: encouraging activity and independence in learning, motivating learning, establishing interpersonal relationships conducive to learning, and structuring learning. Weinstein (1989) found that preservice teachers tended to emphasize and overvalue affective outcomes and undervalue cognitive and academic outcomes.

Preservice teachers also hold definite beliefs about their success as teachers. When they envision their future careers, they believe that they will not face the problems that other classroom teachers experience and that they will be better teachers than their peers (Pajares, 1992). They tend to have simplistic beliefs about what it takes to be a successful teacher and believe that liking children is sufficient (Lasley, 1980). Preservice teachers also believe that good classroom management is both a necessary and sufficient condition for learning to occur (Joram & Gabrielle, 1998). In terms of making the transition from college students to teachers, preservice teachers view that transition more as "an occupational shift than an intellectual transcendence" (Goodlad, 1990, p. 214). In summary, preservice teachers enter preparation programs with strong beliefs about teaching and learning, about their role as teachers, and about their potential for success, and these beliefs color how they receive and interpret information presented in these programs.

Teacher Change

Related to the issue of teacher beliefs is that of teacher change, since changes in teacher behavior are driven by changes in beliefs. The research in this area has frequently focused on the factors that limit the implementation of a specific curriculum or use of specific behaviors in the classroom. This focus on behaviors may be too narrow to fully capture the extent of teacher change and the contributing factors. According to Richardson (1990),

> the major shift from a focus on change in teachers' behaviors to change in teachers' practical knowledge and cognitions seems very promising…a strong focus should be placed on teachers' cognitions and practical knowledge…and these should be considered in relation to actual or potential classroom activities. (p. 13)

Rather than looking solely at behaviors, it is critical to consider these behaviors in the context of the classroom and school, and to consider teacher change as a manifestation of teacher thinking. One valuable way of characterizing teacher thinking is with the use of metaphors, which consist of images or verbal descriptions related to teaching (Tobin & Tippins, 1996). According to Duit (1991), "A metaphor compares without doing so explicitly. It appears to be the very essence of a metaphor that the grounds of comparison are hidden. Metaphors always have some element of surprise" (p. 650). Metaphors provide a link between new and existing knowledge and between language and images. By characterizing teaching with a metaphor, a teacher can reflect on the implications of the metaphor and use that reflection to enrich or change the associated practice. As described by Tobin and LaMaster (1995), development of a new metaphor can lead teachers to reconceptualize their role and change their classroom behaviors.

As noted previously, preservice teachers' beliefs about teaching and learning are well established before they begin teacher preparation programs, as a result of their own learning experiences and how they view the role of a teacher. Further, belief systems, unlike knowledge systems, do not require general consensus. They are relatively static, and when they change it is not because of sound reasoning but more likely because of a ''conversion or gestalt shift'' (Nespor, 1987, p. 321). In the research reported here, the beliefs of a beginning physics teacher were examined, and a "gestalt shift" in some of those beliefs was probed. In addition, the teacher's changing metaphors of his role were examined, to provide a window on his thinking about teaching and learning.

Research Design

This particular study is part of a larger examination of the impact of the science teacher preparation program in the College of Science at The University of Arizona. This research used an interpretive case study design, which is "an examination of a specific phenomenon such as a program, an event, a person, a process, an institution, or a social group. The bounded system, or case, might be selected because it is an instance of some concern, issue, or hypothesis" (Merriam, 1988, p. 9). This particular case was developed to illustrate the interplay of teachers' personal beliefs about teaching and learning and their experiences as preservice and beginning teachers. The research questions that guided the data collection and analysis were:

- What impact do preservice experiences have on beginning teachers' beliefs and behaviors?
- What impact do early-career experiences have on beginning teachers' beliefs and behaviors?

This particular teacher's experiences were chosen for analysis because he was particularly articulate and reflective about his preservice and early-career experiences. Data were collected from a variety of sources, which allowed for triangulation (Lincoln & Guba, 1985). Data collection spanned the course of the teacher's four semesters in a preservice program and first three semesters as a beginning teacher. From preservice work, data sources included weekly reflective journals from science pedagogy courses, bimonthly student teaching evaluations, and e-mail correspondence with the author. From the first three semesters of teaching, data sources were observation field notes from monthly visits to the teacher's classroom (by both the author and his program mentor), interviews conducted by the author, and additional e-mail correspondence with the author

The data were analyzed using inductive analysis (Bogdan & Bicklen, 1992), in which the data were repeatedly examined to identify important themes. The teacher's written work, correspondence, evaluations, and interview transcripts were read several times and sections were coded as representative of the main themes that emerged in the teacher's thinking. These themes were then tested for validity against the larger data set and refined until they accounted for the majority of the data. Themes that emerged from the data collected during preservice work were used to frame field observations and to develop interview questions. In this way, the existence of these themes was validated with data collected during beginning teaching.

The Case of Dennis

Dennis' Background

Dennis* entered the science teacher preparation program after having completed a B.A. degree, with a philosophy major and physics minor, including 34 units of physics courses. Dennis completed all of the required courses in the program, participated in field experiences with capable mentor teachers, and completed his student teaching in December 2002. The next month, he accepted a teaching position at a local public charter school that focuses on serving Latino and Latina students. He remained at that school for the next year and a half, teaching two sections of middle-school physical science, two sections of high-school physics, and one section of middle-school math. The school did not specify a particular science or math curriculum and thus, Dennis was left to formulate his own curricula for the courses he taught. The school also did not provide any mentoring and induction support for its new teachers; Dennis was mentored by one of the adjunct instructors in his preservice program. The school met in an abandoned shopping center; Dennis first occupied an attic room that was later condemned. This forced Dennis to move to a small cubicle separated from other classrooms by partial walls. Since the school climate did not impose much structure on students' movements, this environment presented multiple distractions for both Dennis and his students. During his last semester at the school, he was able to move his classroom to a separate storefront in the same shopping center. This change of environment had an enormous impact on his teaching, as described in later sections. Near the end of his third semester of teaching, Dennis decided that he needed a school with greater student accountability, resigned from the charter school position, and secured a teaching position at a local public school.

In analyzing the data collected from Dennis, three strong themes emerged that characterized the changes in Dennis' beliefs and thinking about teaching:

- Role as a teacher
- Reality of student learning styles
- Value of classroom management

Each of these themes is elaborated in the sections that follow.

* *Dennis is a pseudonym for this teacher.*

Role as a Teacher

One of the strongest themes that emerged from the data analysis was that of a shift in Dennis' view of his role as a teacher, and the metaphors he used to characterize those roles, before and after the shift. Dennis entered his teacher preparation program with very definite ideas about his role. In an early paper, he stated: "The teacher's position…is to provide the students with exciting experiences that are relevant to the subject—acting mostly to provide a stage for learning" (September 15, 2000). In a reflective journal in one of his later courses, he wrote, "My thought on this has always been that one of the fundamental goals of a good science teacher is to inspire the scientists within them [students]" (August 31, 2001). Thus, as a preservice teacher, Dennis believed that he should serve as an inspiration to students and provide them with exciting learning experiences.

Closely tied to this view of himself as a teacher was Dennis' strongest experience of himself as a learner. He described a favorite physics course:

> When I was working [in this physics lab] on how a television works, because I was interested in it, there was a student who was trying to find out everything about a violin. There was another kid exploring everything about baseball bats and what's the best baseball bat. And I envision a classroom someday; the perfect classroom…there are all these students interested in random things that I would have never thought of. (interview, May 17, 2004)

Dennis' vision of his ideal classroom was also built on his love of building and tinkering with things: "What I think [of] as the perfect classroom…[is] a laboratory with tools for building/engineering, instruments for studying, and books and the Internet for researching" (e-mail, April 14, 2004). Thus, while Dennis' apprenticeship of observation (Lortie, 1975) included lecture-based courses, it was not these courses that resonated with him and gave him a vision for his own classroom. Rather, Dennis envisioned a classroom for his students very much like the classroom in which he learned best.

Unlike many beginning teachers, Dennis did not revert to a teacher-centered focus in his own classroom (Simmons, et. al., 1999). From the beginning of his work at the charter school, Dennis tried very hard to implement his vision of an ideal classroom. During his first two semesters, he involved students in lab investigations and projects such as building a water-balloon launcher. Observations of his teaching revealed that he continually posed questions of his students, had them work in groups to answer questions and solve problems, and tried to push them toward asking their own questions.

During his third semester of teaching, Dennis attempted to recreate the physics lab that had so captivated him as a student and driven his vision of an ideal classroom, by inviting students to investigate questions of their own choosing. His classroom contained sufficient materials and tools to facilitate just about any project they could choose, and he had a large collection of books and four computers connected to the Internet to provide additional resources. As students completed their projects, he organized several opportunities for them to present their work to the rest of the school.

At the end of that semester, Dennis' metaphor of himself as a teacher (Tobin & Tippins, 1996) reflected the impact of his teaching experiences and a shift in his perceived role: "I am like an infomercial and I don't like that, but basically I feel like *what I'm doing up here is advertising and trying to engage them for a period of time and offer them experiences*" (italics added). When asked what his infomercial was trying to sell, he replied, "I really want them to buy into confidence… confidence in themselves. And to have ideas…I guess I'm trying to advertise that there is this wealth of fun that can be had with physics" (interview, May 17, 2004).

When asked about his ideal metaphor of himself as a teacher, his answer was one in which students would bear a greater responsibility in their learning, "Ideally…there are two [metaphors] that come to mind. One is like the conductor of an orchestra, and the other one, I think of a finely tuned machine or driving a car" (interview, May 17, 2004).

It is important to note that both of these ideal metaphors rely heavily on the individual parts, the members of the orchestra or the parts of the car, performing well and in concert with the rest of the components. These metaphors broke down for Dennis because most of his students weren't able to perform at the level to make either metaphor a reality, except for brief instances with a few students. However, he was also very dissatisfied with the realistic metaphor of teacher as an infomercial, because that suggested to Dennis that his students weren't deeply engaged in learning, but were merely being "sold" on the value of finding things out. In spite of this dissatisfaction, Dennis saw his role as a teacher shifting from a source of inspiration to a salesman.

Reality of Student Learning Styles

Like many beginning teachers, Dennis believed that his students would be prototypes of himself as a learner (Holt-Reynolds, 1992). Another significant theme that emerged from data analysis was Dennis' growing realization that his ideal learning environment was not necessarily ideal for his students. Dennis was continually frustrated that his students were not as interested in posing and answering questions as he was. And while he spent an entire semester with students engaged in various individual and small-group projects, he was disappointed by the large role he was forced to assume in motivating the students. Many times during the final interview, he contrasted his students' lack of enthusiasm to his own passion for exploring the answers to questions.

> This semester, I've given the students the opportunity to explore things of their choice. To me, I was offering them this huge spectrum that would fulfill every learning style. And, what I found, for the most part, is that they wouldn't do anything. They would say, "I don't have any ideas." Or if I would give them an idea, they would run out of steam super quick. (interview, May 17, 2004)

In reflecting on this dilemma of viewing himself as a prototype of his students, Dennis commented:

> In the past I believed that students, given the opportunity to study whatever they wanted, would study something. They don't. Some do, but many have no ideas. There are quite a few who need me to feed them my own ideas. Nowadays, I think my ideal classroom, at least a realistic one, is [one in which] they have goals to accomplish within a set time and I am a facilitator. I want my classroom to run more like a machine. It needs to function on its own and I need to just be there to keep it running right. (interview, May 17, 2004)

When confronted by a wide range of students, Dennis was forced to realize that he needed to provide a wider variety of learning experiences, and provide more structure to those experiences than he expected. This tied directly to the final theme that emerged from the data, which is described in the next section. However, his ideal metaphor of the classroom as a "finely-tuned machine" is still evident here, in spite of the difficulties he experienced.

Value of Classroom Management

Unlike many preservice and beginning teachers who worry about classroom management (Joram & Gabrielle, 1998), Dennis' vision of teaching did not initially include much organization, as this was something that Dennis struggled with in all aspects of his life, while at the same time espousing its value. During his preservice field experiences and his student teaching, Dennis worked with mentor teachers who modeled strong classroom organization and procedures. At one point in his internship, Dennis commented, "The biggest thing I learned this week is that teachers really do have to be organized. It made me reconsider my usual go with the flow attitude—this will not work in a classroom of freshman" (reflective journal, October 8, 2001). Later, he commented,

> We discussed management a little bit today. He [the mentor teacher] said that during the first few days rules and procedures had to be outlined. Students fell into a pattern and now it works well. I will take all of these things into consideration when I become a teacher. (reflective journal, October 13, 2001)

In spite of these declarations, during his student teaching and throughout his first two semesters as a beginning teacher, Dennis continued to struggle with classroom organization. On an evaluation during his student teaching semester, his evaluator wrote,

> Dennis took attendance at the start of the class while the students were sitting and waiting...a starter activity would help focus them and prevent confrontations such as the one with [a tardy student]. While he was circulating to answer questions, he got sidetracked by checking on students' grades and handing out make-up work. Procedures for group presentations were not apparent or were not used consistently. (evaluation form, November 2, 2002)

And, from an observation in his second semester of teaching,

> "[Dennis] speaks of the need to be more organized in his teaching, recognizes to some extent the need for order in the classroom, but doesn't easily practice being organized" (observation notes, November 4, 2003).

As mentioned earlier, during his third semester of teaching, Dennis was able to move his classes to a separate storefront in the same complex. He also underwent a remarkable transformation in his approach to teaching, especially in regards to classroom organization. From an observation during that semester,

> When [students] arrived, they immediately picked up their folders from a cabinet near the door, took the stools down off the tables, and proceeded to start on the day's bell work. As soon as they were all settled, Dennis announced that they had ten minutes to do the bell work. While students worked, Dennis took attendance. Two students who arrived late came in quietly and started to work. After discussion of the bell work, Dennis announced that he wanted to see students' written plans for their projects before they started work. For the next 90 minutes, he circulated around the room, checking written plans, answering questions, getting materials for students, and monitoring student work. At 10:03, Dennis announced that it was time to start cleaning up. Dennis did a walk-around to check on clean-up and called several students back to finish the process. Before making his closing comments, Dennis waited until all the students were listening. The changes in classroom procedure and organization noted seem to have greatly improved the learning environment. (observation notes, April 1, 2004)

When asked to reflect on the reasons for this dramatic shift in his classroom climate, Dennis commented:

> I basically felt out of control in that classroom [in the main school area]. And I think the students could sense that. I would avoid doing things that asserted my control for fear of demonstrating how out of control things were. Looking back, I wonder how much I actually could have succeeded in that classroom if I had run a tighter ship. My heart wasn't in it so I didn't try. Now I believe that I can succeed. I know that whatever effort I put in to making it well-managed and well-organized will pay off. (e-mail, April 6, 2004)

When asked about his vision of good teaching at the end of this third semester, Dennis reflected a much-different philosophy than in his preservice days.

> Good teaching is, first and foremost, about good management and good organization. I remember [that] I was very adamant…that first and foremost, you need to be inspiring. I remember I said that a number of times. [Now,] I would say it's not about inspiring, because you can inspire all you want and if nobody's paying attention…(interview, May 17, 2004, italics added)

This is a striking change from his view of the teacher's role as a preservice teacher, and reflects Dennis' growing awareness of the realities of the classroom. It is also key that Dennis' ideal metaphor of a teacher, that of an orchestra conductor, inherently contains a great deal of structure in order for the orchestra to function successfully. Thus, even in his more idealistic thinking, Dennis unknowingly recognized the need for effective classroom organization and management. And it was his increasing need for organization and structure in his teaching that caused Dennis to move to another school.

Discussion

This analysis of Dennis' journey from preservice to practicing teacher revealed three key themes. First, over the course of his first three semesters of teaching, Dennis adopted a more realistic, albeit not entirely satisfying, metaphor of himself as a teacher, that of teacher as infomercial. He came to view his role as "selling" students on the benefits of figuring things out and being able to find answers, in books, via the Internet, or by doing experiments. At the same time, Dennis still clung to his idealistic metaphor of teacher as a conductor of a complex web of student-directed projects, and he saw glimpses of that metaphor while working with some students. And, while Dennis was not able to convince all his students they could learn successfully, he still believed that, with the right students, his ideal classroom would work. At this stage in his career, he had not yet developed a metaphor to guide him to the middle ground between his ideal classroom and the real world.

Second, his view of how students best learn was deeply rooted in Dennis' experiences as a learner and was resistant to change during preservice experiences. Although he could intellectually acknowledge that not all students learned as he did, he began his teaching career convinced that his preferred style of learning would work, through his effectiveness in inspiring students' interest in "free exploration." He changed these views only after being continually confronted with students who didn't learn in this way, and reluctantly acknowledged that he needed to broaden his repertoire of teaching strategies. However, at this stage in his career, he lacked a broader repertoire on which to draw in order to help all his students learn.

Third, Dennis only came to truly value organization when he became deeply dissatisfied with feeling out of control in his classroom. Throughout his preservice work and his first two semesters of teaching, while he acknowledged the value of classroom routines and rules, he remained convinced that he wouldn't need them, because his students would respect him too much to cause problems. Again, when confronted with classes that felt out of control, Dennis was forced to admit the value of routines and rules, and began to impose an organizational structure on his classes that dramatically improved the learning environment. By the end of his first year and a half of teaching, he had almost moved completely to the other end of the spectrum, claiming that good teaching was primarily about good classroom management. And Dennis will probably continue to value some degree of classroom management, as his ideal metaphor of "teacher as an orchestra conductor," to which he keeps returning, contains a great deal of structure and organization.

Implications for Teacher Preparation

In spite of extensive field experiences in classrooms of teachers who clearly valued and modeled strong classroom organization and accommodation of various learning styles, Dennis left the teacher preparation program with his own ideas about classroom organization and how his students would best learn. He believed that he would be able to inspire his students to become so involved in projects of their own design that all their learning would be achieved in this manner, and he wouldn't have to worry about classroom management. How could the program have been more successful at helping Dennis confront some of his ideas and test them out in a preservice setting? Indeed, could Dennis have been sufficiently challenged to change some of his ideas about teaching before working in his own classroom? As part of the last interview (May 17, 2004), Dennis was asked whether he thought he could have applied techniques he learned in his program to his classroom right from the beginning.

> Yeah, I could have [but] one side of it is that I wouldn't have learned how important they are. But, I would say that if I had started right from the get-go doing the tricks, I probably would have never been faced with the problems that I had.

When asked why he hadn't applied those techniques from the very beginning, Dennis replied,

> I guess I gave too much responsibility to the students right off the bat…I basically thought that if they were given the responsibility that they would take it and act like adults…things that were just way too high a standard to set for kids this age. And so…implementing organization and structure, it's changed everything. Not only that, but this structure which I thought would have been condescending and belittling…this very structure was appreciated by the kids. (interview, May 17, 2004)

During that interview, Dennis also reflected on his changing thoughts about student learning:

> In my idealistic view of back then, and even still a little bit now, I pictured a bunch of "me" sitting around a table.

> And all these kids would be saying, "Oh, Dennis, what is this? Why does that work?" And I would be loving this experience of feeding these kids who are just so hungry to learn. And I learned just the opposite, that really there are a small handful of those kids in each class, but the vast majority of them are not interested. And even the ones who are interested, it's amazing how much you have to draw them out to get them to follow your lesson plan. (interview, May 17, 2004)

Perhaps to some extent, Dennis needed to discover the need for organization and the reality of different student learning styles in his own classroom before being able to utilize the instructional and organizational techniques that had been presented in his courses and modeled in his field experiences. Or, following the example of McDiarmid (1990), in which she guided preservice teachers in analysis of very non-traditional elementary math lessons, perhaps Dennis could have been guided to more carefully reflect on the practices of mentor teachers that were significantly different from his views of effective teaching. But as pointed out by McDiarmid, "…the strength of each individual belief about teaching, learning, learners, subject matter knowledge, and context is formidable. Interwoven, the strands constitute a web of remarkable resilience; severing one strand barely diminishes the overall strength of the whole" (1990, p. 18). It is not clear that Dennis' beliefs could have been shifted during his preservice years. Perhaps he needed to fully experience the deep dissatisfaction with his own classroom before experiencing the "gestalt shift" that led to dramatic changes in his practice. On the other hand, given the concerns of retaining science teachers (Ingersoll, 2001) and the requirements for "highly-qualified teachers" that are part of the No Child Left Behind Act (NCLB, 2001), it is worrisome that a promising teacher experienced deep dissatisfaction in the beginning of his career. In the final interview in this study, Dennis shared his thoughts about continuing his career, "I don't see myself at 40, 45 years old…[as] just your average high school physics teacher. I will always want to continue working with kids but it would be in a different capacity where I'm not the infomercial" (interview, May 17, 2004).

Dennis' case provides some preliminary suggestions for teacher preparation programs, in that preservice teachers' beliefs need to be illuminated and challenged throughout the preservice program. Given that virtually all practice teaching occurs in environments structured by the mentor teachers, it may be particularly difficult to set up situations for preservice teachers to test out their beliefs about teaching and learning. However, it appears that this is a critical aspect in guiding preservice teacher thinking toward a reality-based model of a productive learning environment.

In response to Dennis' case, as well as to other data collected as part of ongoing program assessment, the College of Science Teacher Preparation Program has increased its emphasis on analysis of student work to identify evidence of understanding, as one way to guide preservice teachers in confronting their beliefs about teaching and learning. Samples of student work are analyzed in several of the program's courses, including the student-teaching seminar, where preservice teachers analyze their own students' work, and discuss to what extent their instructional decisions led to student understanding. Also as part of the student-teaching seminar, preservice teachers write an analysis of a dilemma and reflect on how that dilemma has impacted their beliefs about teaching and learning (Talanquer, Tomanek, Novodvorsky, in press). Finally, one of the science pedagogy courses in the program has been linked to a general-education science course on campus. (Previously, the field experience for that course took place in area middle and high school science classrooms.) Preservice teachers share responsibility for teaching the science course, under the guidance of the professor, who teaches that course and the related science pedagogy course. In this way, the program has a great deal of control over the "field experience" and the professor is able to guide the preservice teachers in confronting their beliefs about teaching and learning, based on shared teaching experiences. Through all of these efforts, the program hopes to better challenge preservice teachers' beliefs, guiding them toward a more reality-based view of teaching.

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Developing outdoor activities and a website as resources to stimulate learning physics in teacher education

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This paper presents conceptualization and development of the "outdoor physics" approach in science teacher education in Umeå, Sweden. The Cultural-Historical Activity Theory (CHAT) *in combination with theoretical construct of* embodied knowledge *and curriculum standpoint of* inquiry learning *provided the theoretical ground and methodological framework of the project. This paper describes how these theoretical perspectives contributed to shaping the development of the "outdoor physics" approach and a multilingual web portal (http://outdoorphysics.educ.umu.se). The author argues that outdoor activities with web-based support can facilitate students' investigations in natural settings, stimulate their questions, and increase interest in the learning of physics.*

Introduction

Decreasing motivation and competence in physics studies among students at different educational levels has been an issue broadly discussed by researchers and politicians (Reiss, 2000, Sjöberg; 2001, van der Hoeven, 2005). Our previous research shows that students' school experience of practical work in physics is often characterized by adherence to cookbook-types of instruction. Many students perceive physics mainly as applied mathematics with limited connections to everyday life (Popov, Zackrisson & Olofsson, 2000).

To challenge these views in teacher education, we decided to explore an 'outdoor physics approach' in working with prospective science teachers. This decision was grounded in consideration of Swedish socio-cultural traditions and existing experiences within our department. In particular, in Sweden, all people have rightful access to the countryside granted by the "Allemansrätten" (literally: everyman's right). This is a unique Swedish tradition that gives every person free access to nature regardless of land ownership. One consequence of this is that in many Swedish schools outdoor education is an important curriculum component (see e.g. http://www.naturskola.se/ and http://www.skogeniskolan.se/).

Over the years, in Umeå's Department of Mathematics, Technology and Science Education a number of outdoor education courses have been developed. These courses have high enrollments and result in good student evaluations, but their content includes mainly biology, ecology and general pedagogical skills development. The outdoor physics tasks had been used as a compulsory part of a 'didactics of physics' course at the department. However, changes in the teacher education curriculum led to abolishment of the course a couple of years ago.

Thus, based on these experiences, the 'outdoor physics approach' was developed in a project form and presented on the website http://outdoorphysics.educ.umu.se with support from the Swedish Council for the Renewal of Higher Education. The goals of the project were defined as follows:

- To increase students' interest and motivation to study physics
- To provide opportunities for learning authentic ways of knowledge acquisition
- To facilitate understanding of the nature of science
- To encourage students to be more interactive with the learning process.

The project introduced physics concepts and laws in a hands-on inquiry manner. We aimed to help the prospective teachers to acquire confidence in themselves and their abilities to learn and teach physics in an innovative way.

Our 'frame of mind' toward 'outdoor physics'

We found useful in our work the term 'fame of mind' as it has been used by Bonnett (2004). According to him, this concept "involves a certain cognitive/conceptual outlook, but also involves ... a gamut of affective, moral, aesthetic, imaginative and other receptions and responses. … It denotes how one is disposed towards the world at a particular time and carries connotations of fundamental orientation." Bonnett also includes in this concept "a sensing of things that may occur as much through bodily contact as through more overt cognitive perception" (Bonnet, 2004, p. 128-129). Our 'frame of mind' in this project embraces a theoretical view of the Cultural-Historical Activity Theory on human development and learning, a concept of embodied knowledge and a curriculum idea of inquiry teaching/learning presented below.

The Cultural-Historical Activity Theory

The Cultural-Historical Activity Theory (CHAT) is used as a theoretical ground and methodological framework of the project. CHAT belongs to a family of socio-cultural theories originating from the works of Vygotsky and his research fellows in the early 20th century. CHAT underlines the centrality of cultural and social contexts in human development. Context-relatedness of learning is central in Vygotsky's theory. We decided, following this line of thought, to place some studies of physics (i.e. laws and properties of nature) directly in natural settings. Any natural context that is easily accessible to students today has strong cultural and social dimensions. We assume that the new context will create new opportunities for learning.

Departing from Vygotsky's ideas, Leont'ev (1981) built up a theoretical description of human psychological development and behavior based on the study of the human activity. According to Leont'ev (1981), the first and most fundamental form of human activity is external, practical activity. Thus, we designed a pedagogical approach based on meaningful practical activities outdoors.

The fundamental claim of the CHAT is that a human activity (on both the interpsychological and the intrapsychological plane) can be understood only if we take into consideration technical and psychological tools that mediate this activity. In Outdoor Physics, investigation techniques or processes of science are artifacts that have particular significance. These mental and manipulative skills serve as important tools in the culture of science and in our project. The big scale physical artifacts (like cable drums, cars, barrels, etc.) have also been used as tools for stimulating learning. We have departed from the idea that "size does matter" when students' have the possibility to explore physical phenomena outside of the classroom walls. For example, in the study of torque there is a 'traditional' physics experiment with a spool. If the line leaves the spool from the bottom of the axle, and is gently pulled, how the spool will move? In the forward or in the backward direction? We adapted this experiment to the outdoor environment using a rope and a cable drum, see Fig. 1 below.

Fig 1. *Changing scale of the experiment outdoors*

According to Leont'ev (1981), activities are object-related. Content of the human activity is determined first of all by its object. The object of activity is always a value-loaded social object (i.e., a human-nature or human-technology system). In doing Outdoor Physics, objects of learning activities are material objects (natural or human made) with their properties reflected in scientific principles, laws, and theories of physics. Thus, content of learning was the acquisition of knowledge (embodied in learning objects) about properties and laws of nature. For example, in making a warm-air balloon, the content of learning was the understanding density, heat transfer and Archimedes law.

CHAT is based on understanding of activity as a constantly developing complex dynamical process. Leont'ev often referred to constant transfers within the system "subject – activity – object" (Stetsenko, 2005). The primary distinguishing characteristic of the learning activity in general is that its main expected outcome is not only object transformations, but also development of the subject of the activity (the learner). This means that such an activity has to result in learner's personal development. In Outdoor Physics approach, experiences with cognitive and physical tools, instruments and artifacts (like building a water rocket and exploring its properties, doing experiments and measurements with help of binoculars) are valuable for development of the learner's scientific worldview and his or her skills in and attitudes towards science.

Embodied knowledge

Teaching in traditional educational settings often neglects the knowledge that we possess through bodily contact with the world, but this is a constituent part of our worldview. Our learning about nature is also shaped by this way of knowing. As Bonnett (2004, p. 98) suggests, "In our bodily intercourse with the world the abstract idea plays less dominant role, we engage with the world less through an ordering cognition and more through a responsive sensing, as say when we feel the quality of the resilience of this piece of grass underfoot or the quality of resistance of a particular piece of wood to the chisel."

Learning about physical phenomena and properties of the surrounding objects can be assisted by direct bodily contact with them. Feeling the air-resistance force through the open car window gives 'first hand' experience and facilitates understanding of the physical properties of the air. We assume that if carefully used, embodied knowledge can be a complement to facilitate physics understanding.

Teaching science as inquiry

Teaching science as inquiry was the main curriculum standpoint of the project. In general, inquiry refers to the work that scientists do when studying the natural world (i.e., posing questions, gathering evidence and making explanations of natural phenomena). According to Tanner and Tanner (1990, p. 280), scientific inquiry is 'the method of gaining knowledge and transforming it into working power'. Acquired work methodology and knowledge build a base for development of individuals' analytical thinking and skills of investigation. Inquiry-based instructional strategies lead to learners' more autonomous problem-solving capacities and thus to 'freedom from depending of the teacher' (Tanner, Tanner, 1990, p. 275).

The OECD (2003) suggests the importance of learning in school science classes about general methodological principles of scientific activity (inquiry), such as:

- recognizing scientifically investigable questions;
- identifying evidence needed in a scientific investigation;
- drawing up or evaluating conclusions;
- communicating valid conclusions; and
- demonstrating understanding of scientific concepts.

Therefore, we assume that prospective teachers should acquire competence in these skills.

Science studies in general and physics in particular are subjects based on practical activities. According to the modern vision about practical/laboratory experiences, learning goals for such activities could be formulated as follows:

- mastery of subject matter;
- developing scientific reasoning;
- understanding the complexity and ambiguity of empirical work;
- developing practical skills;
- understanding the nature of science;
- cultivating interest in science and interest in learning science; and
- developing teamwork abilities (National Research Council, 2005).

Traditionally, these goals are to be achieved in laboratory or classroom learning environments. Yet we suggest that physics teaching/learning placed in natural settings can bring a number of pedagogical advantages. First of all, most of the outdoors activities naturally demand more open inquiry approach to work, in identifying and formulating the problems, and planning and drawing up experiments. Besides, in studying real objects and phenomena, the students must learn to select the key factors, evaluate other relevant parameters and do appropriate design of activities. Most of the outdoor activities naturally demand teamwork, as it is simply impossible to do them individually. Addressing these issues is especially important in science teacher education.

The project focus issues and core activities

Fundamental to Outdoor Physics was our commitment to the hands-on inquiry-based learning. Other important goals were extending learning environment to the outdoors and augmenting it with use of Internet computer tools.

Many of our students are interested in outdoors pedagogy but they lack knowledge of how to teach physics content in the open air. We had anecdotal evidence that the situation is quite similar in the most of the schools in Sweden where teacher declare interest but lack competence in this form of teaching. Therefore, we decided to help our students and teachers in schools to deal with teaching physics outside the classroom.

The students were actively involved in the study of the situation in schools and development of the website. They were also working practically with development and checking of the viability of outdoor teaching examples – cases. Some of them carried out the pilot studies with cases for their course work and examinations. In several occasions, cases were tried out during the teaching practice in schools. Student teachers have also studied pupils' and teachers' attitudes toward science activities outdoors. The feedback from students on the context, process of development and results of their field work were studied by the teacher educators involved in the project in order to find ways of incorporating such approach into existing curricula in schools and teacher education.

Selection of the outdoor physics cases

The work on development of the general principles for selecting cases for outdoor activities was intertwined with the practical trying out of the concrete cases and the web-site development. The following criteria were appearing in this process:

- Relevance to the socio-cultural and natural context. The familiar natural environment and everyday life context of the cases are considered as important factors.
- A practical exploratory activity should be involved in each case. Preference should be to cases where experiments can be done only outdoors (exercises like launching a water rocket, counting snowflakes, making explosions, etc.), or practical activities can be naturally done outdoors (like measuring the speed of water flow in a river, or finding a 'temperature changes' in the soil with depth during the day).
- Preference to cases encouraging exploration of open-ended authentic problems. Dealing with natural objects and phenomena, students should have possibility to formulate their own study problems or concretize suggested ones. The results of the inquiry can generate additional questions, research issues and problems and give impulse for further investigations and corrections.
- Cases should be attractive for students. The formulations of problems should call for students' curiosity.
- Cases are organized in three levels of difficulty:
  <u>Initial level:</u> Based on students' practical experience of dealing with everyday problems without preliminary physics knowledge.
  <u>Medium level:</u> Conceptual physics without or with very simple formulae like $v = s / t$.
  <u>High level:</u> Activities are more advanced and complex. Calculations are often required. Cases are based on creative problem solving.

These criteria were formed gradually during the project work and they can evolve further.

Examples of outdoor physics cases

A variety of outdoor activities was developed and tested by our students. Some of them are presented below.

Fig. 2 *Lifting the teacher's car with help of a lever*

Lift a car

A prospective teacher is exploring 'lever principle' with his class during the school practice. The grade 7 students have faced the task of finding a way to lift teacher's car 'to change a flat tire' without using a jack. This is an example of a case at initial level of difficulty.

Study flying capacity of a water-rocket

Launching a water-rocket is probably one of the most popular science exercises conducted outdoors in schools around the world. Construction tips and design suggestions for different types of water-rockets can be found on the Internet (see for example [Water rocket index for teachers and students]). Google gives about ninety thousand hits for 'water rocket'.

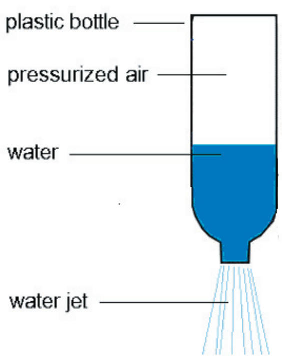

Fig. 3 *Schematic picture of the water-rocket construction*

Students are challenged to change different parameters in launching a rocket (like proportion of water and air in the bottle) and observe how they influence a rocket's flying capacity. This is another example of a case at initial level of difficulty.

How high is a birch?

Measurements are of the greatest importance to scientists. In making measurements they have to consider what accuracy they require and how far it can be achieved with the particular instruments used. Scientists are seldom satisfied with one measurement for a particular quantity and often take the average of several readings.

Students were asked to do measurement of the height of a birch using as many different methods as they can find and discuss the precision of the measurements. About twenty different solutions were found. Some of the suggestions are illustrated in Figures 4 and 5.

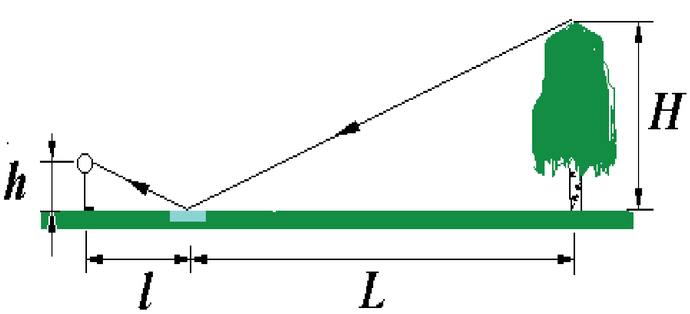

Fig. 4 *Finding out the height of a birch using a mirror.*

By making measurements of h, L and l (see Fig. 4) it is possible to find the height of the birch H = h L/l. This is an example of a case at medium level of difficulty.

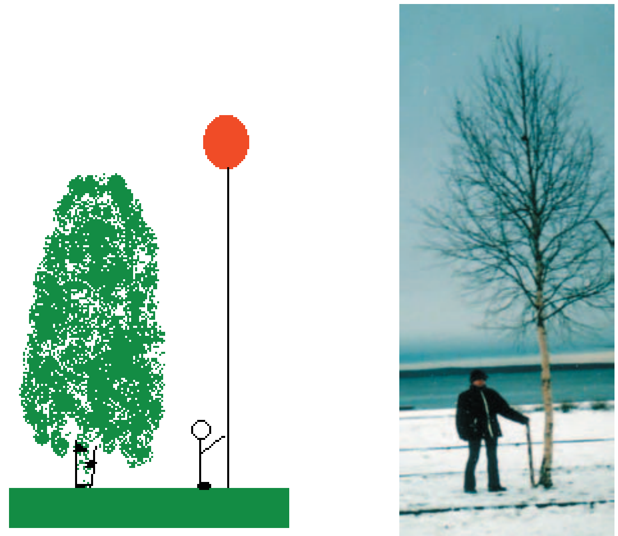

Fig. 5 *Finding out the height of a birch using a helium-filled balloon and making a photograph*

Find out the speed of an air gun bullet

The task is to find out the speed of a bullet from an air gun. The students can use different methods to check and control their findings. A couple of the designs are presented in the pictures below.

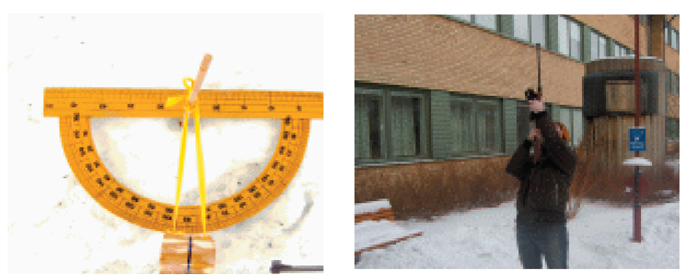

Fig. 6 *Shooting in a chunk of wood and upwards*

In the first case, students fire the gun at a suspended chunk of wood and by measuring the angle of vertical deviation they can calculate the change in the chunk's potential energy. Changes of kinetic and potential energy are equal therefore it is possible to calculate the initial speed of the bullet by measuring the mass of the bullet, the mass of the wood chunk and the length of the suspension. In the second case, they attempt to find the speed of a bullet by measuring the total time it takes for a bullet from leaving the barrel to return to the ground. The students have to decide how many attempts to make and what methods to use to get reliable data. They discuss possible sources of error in the measurements. This is an example of a case at high level of difficulty. These and many other cases can be found in the outdoor physics project website presented below.

Development of the website

Designing and working out the website (http://outdoor-physics.educ.umu.se) as a bank of cases and a database for the students' work activities has been another priority of the project. The website is oriented for teacher educators, school teachers, and prospective science teachers.

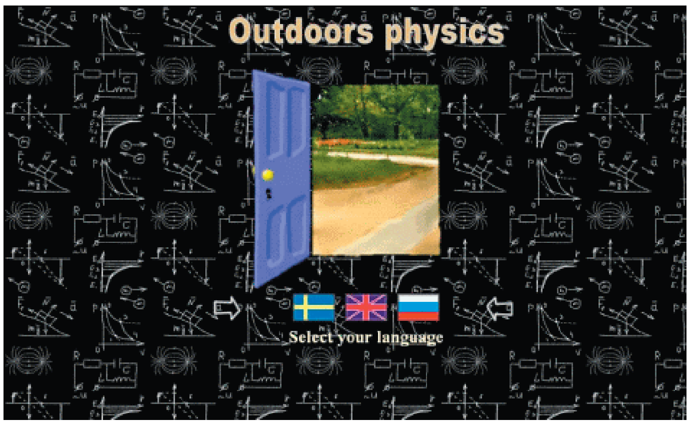

Fig. 7 *Entrance to the multilingual 'outdoor physics' website*

The learning tasks presented on the website (the cases) are organized with respect to the level of difficulty, field of physics and natural objects used in the activity. The structure of the website is presented in Figure 8.

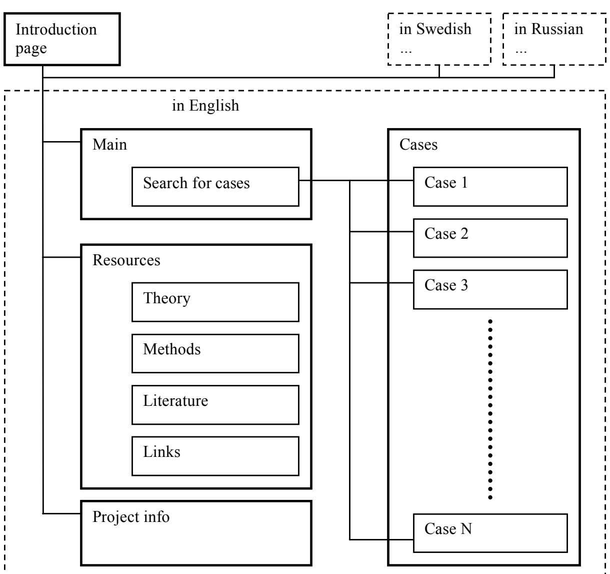

Fig. 8 *The structure of the website*

We attempted to present each case as an open authentic problem with various possible solutions and usually only few hints are given for conducting the practical activity or explaining the results. Hyperlinks are provided for examples of other similar activities available on the Internet or students practical work in schools or courses with more detailed description of activities in working with cases.

Some cases are supported by interactive computer models (ICM) that are used to inspire inquiry, illustration and analysis of observed phenomena in order to make physics more explicit and understandable.

Practical implementation of the approach

Currently, in Umeå University, prospective teachers can choose to do physics activities outdoors in different forms and occasions, such as:

- doing course assignments during the general undergraduate science courses,
- student teachers can develop and try out 'cases' with pupils during the school practice,
- outdoor science experience can be part of minor research activities during diploma/examination work and master courses assignments.

On these occasions (several times per term), students are assisted and supervised in their work by the project members.

Different methods of conducting outdoor activities are used:

- Play and learn in the open air (PLOA).
- Predict – observe – control – explain (POCE).
- Prove through action and construction (PAC).
- Explore Authentic Problems (EAP).

In general, the students' and teachers' evaluations of these teaching methods showed appreciation of the activities and satisfaction with the approach. However, we did not do yet systematic research on implementation and evaluation of the approach; this will be done in the next stage of the project.

Perspectives and conclusions

This paper presents the work in progress. New teachers and students are getting involved in the activities of the project. A course for Summer University named "Exploration of science in the Northern Landscapes" based on the Outdoor Physics project is under preparation.

We face a new challenge of development of new methods of assessments and control of the quality of activities. The outdoor approach has clear practical orientation and naturally demands systematic formative assessment. This approach seems to be appropriate for creating new learning opportunities for students with special needs (e.g. with physical impairments) or from socially disadvantaged groups. We have started preparatory work in this direction in collaboration with Umeå municipality.

Some European colleagues became interested in our work, so we have successfully applied for the European project called OutLab – "Outdoor Laboratory" for innovative Science Teacher Education.

The cooperation in this area continues with the Pedagogical University in the twin city of Umeå – Petrozavodsk – in the North-Western Russia. The outdoor approach is integrated there in the introductory physics course in the faculty of physics and mathematics.

In summary, the teacher educators involved in the project could see evidence that the inquiry-based outdoor teaching can raise the level of interest and motivation among students in studying physics. Prospective teachers have through the project possibly have acquired more confidence to teach physics in an innovative way needed in schools. This gives us an inspiration for further development of the approach.

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A generic model for inquiry-oriented labs in postsecondary introductory physics

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While many involved with college- and university-level introductory physics complains about "cookbook" labs, few do anything about it. There are a number of inquiry-oriented lab models for postsecondary physics currently available, but such models appear to depend strongly upon the presence of lab instructors who are highly dedicated to inquiry, are well informed about associated scientific processes, and integrate lectures and labs. While integrated lecture/labs are the ideal, not many institutions have the resources or opportunities to implement those models. The Illinois State University Physics Department – led by its teacher education coordinator, undergraduate PTE majors, and cooperating faculty and staff – has recently completed nearly two years of work developing and implementing a generic inquiry-oriented lab model that we believe can be employed by institutions using less expert lab instructors and labs separate from lectures. After experiences with 15 different inquiry-based labs, 8 undergraduate teaching assistants, and 240 students enrolled in calculus-based physics courses, we give an initial report on the nature of our inquiry labs, the development process, and general observations arising from using this approach.

Physics teacher education institutions that are accredited though their state boards of education and/or the National Council for Accreditation of Teacher Education (NCATE) must comply with a substantial number of standards at both the university and program levels. At the program level for NCATE institutions, the teacher preparation process must satisfy criteria established by the National Science Teachers Association (NSTA). The inquiry "cluster" in the NSTA's Standards for Science Teacher Preparation (NSTA, 2003) clearly indicates the need for teacher candidates to learn about the nature and processes of science by being actively involved in the process of scientific investigation. This call for active involvement in the creation of knowledge mirrors the concerns of the American Association of Physics Teachers (AAPT). In 1998, the AAPT promulgated a policy statement dealing with introductory physics laboratory goals. The goals were enunciated by the AAPT's Committee on Laboratories (Gerald Taylor, Jr., Chair), working in cooperation with the Apparatus Committee, the Two-Year College Committee, the Committee on Physics in Undergraduate Education, as well as others. The policy statement was approved on behalf of the AAPT by the Executive Board at its October 1997 meeting in College Park, Maryland. The policy statement was published shortly thereafter in the *American Journal of Physics* (AAPT, 1998). A summary of the goals can be found in Table 1.

A question now arises. Do traditional "cookbook" labs commonly used in teaching introductory physics courses satisfy these goals? If the distinction between traditional cookbook labs and inquiry-based labs expressed in Table 2 holds true (Wenning, 2005a), then this is highly unlikely. If the AAPT goals are to be achieved and NSTA preparation standards met, there must be a significant shift in the way conventional introductory postsecondary physics laboratory activities are conducted.

There are a number of excellent inquiry-based approaches to laboratory available that clearly and effectively address the AAPT's Introductory Physics Laboratory Goals. Among these approaches are the Activity Based Physics program developed by the Physics Education Group (2004) involving the University of Washington, the University of Maryland, and Dickinson College among others. As University of Washington's McDermott states

Summary of Introductory Physics Laboratory Goals

I. **The Art of Experimentation:** The introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigations.

II. **Experimental and Analytical Skills:** The laboratory should help the student develop a broad array of basic skills and tools of experimental physics and data analysis.

III. **Conceptual Learning:** The laboratory should help students master basic physics concepts.

IV. **Understanding the Basis of Knowledge in Physics:** The laboratory should help students to understand the role of direct observation in physics and to distinguish between inferences based on theory and on the outcomes of experiments.

V. **Developing Collaborative Learning Skills:** The laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavors.

Table 1. *The AAPT policy states that laboratory programs should be designed with these five fundamental goals in mind. A detailed explanation appears in the original AJP article.*

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Cookbook labs…	Inquiry labs…
• are driven with step-by-step instructions requiring minimum intellectual engagement of students thereby promoting robotic, rule-conforming behaviors. • commonly focus students' activities on verifying information previously communicated in class thereby moving from abstract toward concrete. • 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. • rarely allow students to confront and deal with uncertainty and misconceptions; do not allow students to experience blind alleys or dead ends. • employ procedures that are inconsistent with the scientific endeavor; show an unrealistic linear process.	• are driven by questions requiring ongoing engagement using higher-order thinking skills and independent thought and action. • focus students' activities on collecting and interpreting data to discover new concepts, principles, or laws thereby moving from concrete toward abstract. • 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. • 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 much more consistent with authentic scientific practice; show the work of science to be recursive and self-correcting.

Table 2. *Fundamental distinctions between traditional cookbook and authentic inquiry-oriented lab activities* (Wenning, 2005a).

in *Physics By Inquiry,* "Through in-depth study of simple physical systems and their interactions, students gain direct experience with the processes of science. Starting from their observations, students develop basic physical concepts, use and interpret different forms of scientific representations, and construct explanatory models with predictive capability. All the modules have been explicitly designed to develop scientific reasoning skills and to provide practice in relating scientific concepts, representations, and models to real world phenomena." Richard Hake's *Socratic Dialogue Inducing Labs* (SDI) appears to do likewise. According to Hake (1992), "SDI labs emphasize hands-on experience with simple mechanics experiments and facilitate interactive engagement of students with course material. They are designed to promote students' mental construction of concepts through their (1) conceptual conflict, (2) kinesthetic involvement, (3) extensive verbal, written, pictorial, diagrammatic, graphical, and mathematical analysis of concrete Newtonian experiments, (4) repeated exposure to experiments at increasing levels of sophistication, (5) peer discussion, and (6) Socratic dialogue with instructors."

A generic model for inquiry-based labs

While the above forms of teaching introductory physics appear to approach the ideal of integrating physics instruction with laboratory activities, not all postsecondary institutions are willing and able to reformulate their course and lab formats and schedules to accommodate these types of instruction. This problem often stems from not having adequate preparation and/or release time for faculty, a necessity of using advanced undergraduate or graduate students to conduct lab activities, large sections in physics courses, inadequate lab space or materials, inflexibility of schedules, lack of financial resources, and so on. This conflict produces the need for a generic model for implementing inquiry-based labs under rather restrictive sets of conditions.

Illinois State University (ISU) historically has used the more traditional approach of separate lecture and lab. Still, there has been a growing desire among certain of the department's faculty members, the physics teacher education (PTE) coordinator, and the program's PTE majors to replace ISU's traditional cookbook labs with something that is more inquiry oriented. A way needed to be found to overcome the limitations imposed by working with lab instructors who have limited experiences with inquiry, courses with separate lab and lecture sections, and large enrollments with limited facilities. A decision was made during the spring of 2004 to create and pilot two inquiry labs that could be taught by the PTE major co-author who at that point was a highly experienced undergraduate lab instructor.

The first two inquiry labs developed dealt with the derivation of the ideal gas law, and the analysis of an RC circuit. Prior to writing these labs, the co-authors of this article defined the basic properties of inquiry labs in general. Inquiry labs would:

1) contain pre-lab activities including reading assignments and problems,
2) provide a detailed list of student performance objectives,
3) provide one or more tasks associated with each student performance objective,
4) include clear performance tasks but a minimum of instructions, and
5) be driven primarily by substantive, not trivial, questions.

The student author of this paper, with guidance and assistance of the PTE coordinator, wrote these first two inquiry labs using a guided inquiry approach (Wenning, 2005a). The labs were then conducted with two calculus-based lab groups containing approximately 20 students each. The inquiry labs incorporated for the first time computer-based lab sensors and a new graphing program. Subsequent to these labs, a debriefing session was held with the students who participated in the lab activities. Student reactions to using the inquiry approach were mixed. Some liked the approach; others preferred to "be told what to do," and still others indicated a desire to see a mix of inquiry and traditional lab activities. Students felt somewhat unprepared to perform some of the more advanced activities such as error propagation and dimensional analysis, and were unfamiliar with the sensors and computer programs. Most felt it was too much too fast, "sort of like drinking out of a fire hose." An end-of-semester survey was then conducted among these students. The most challenging labs were the inquiry labs; the inquiry labs were the least "fun." Students also felt that the inquiry labs were least beneficial as far as learning was concerned. Student concerns resulted primarily from our too rapid introduction of technology and computer programs, and their limited understanding of how to derive relationships from graphs. Our experiences with students showed that there are other specific problem areas that students failed to identify: graph creation and interpretation, understanding the meaning of a "physical fit" or "physical model", interpreting the meaning of constants, linear regression, data analysis, propagation of error, error assessment, and dimensional analysis to name but a few. Even with these expressions of student and instructor "concerns," we felt that if these obstacles could be overcome, the benefits of inquiry would be clear to our students.

Despite student concerns and even resistance to inquiry, it was agreed that the inquiry route was the best way for the Department to go given the extensive case that can be made for inquiry (NRC, 2000). During the summer of 2004, a "Lab Writing Group" was established within the ISU Physics Department that created and piloted with small groups of students about 10 new inquiry labs. The following accommodations were made to provide for identified concerns:

1) We started with a simple, sensor-free paradigm lab incorporating the use of a graphing program. This lab consisted of finding relationships between circumference and diameter of a set of aluminum disks, the relationship between a series of equal–area rectangles, and the relationship between air temperature and the rate of cricket chirps.
2) We followed the first lab with a second that oriented students to the use of sensors. A paradigm lab dealing with the factors that possibly could influence the period of a pendulum (length, amplitude, mass) was conducted. The relationship between period and length was worked out for small amplitude.
3) We conducted climate setting starting early and continuing on a somewhat regular basis thereby providing students with an explanation about why the inquiry approach is being used and how students will benefit from it.
4) We wrote a *Student Lab Handbook* containing critical background readings, made it available on-line (http://phy.ilstu.edu/slh/), and integrated it into pre-lab activities.

During the summer of 2005, the faculty and staff of the ISU Physics Department revised first-edition inquiry labs, wrote new inquiry labs, and revised several older lab activities for calculus-based introductory physics courses.

Student Lab Handbook

The *Student Lab Handbook* readings are considered essential to student growth as scientific experimentalists. It is most appropriate for all science students to become familiar with the knowledge base provided in these readings. Students benefit significantly from reading these articles prior to beginning the lab experiences. Knowledge of this information is often crucial for completing lab reports accurately. Most readings are typically 1 to 2 pages in length. All articles are written in simple, even "pedestrian" language, and include multiple examples. The writing focuses on student learning, not on scholarly elocution. All documents are available in "portable document format" (PDF). The titles currently contained within the *Student Lab Handbook* are the following:

- Absolute and Relative Error
- Chi-Square Test for Goodness of Fit
- Common Graph Forms in Physics
- Conversion Factors
- Deriving Relationships from Graphs
- Dimensional Analysis
- Error Propagation
- Generic Experimental Design
- Glossary of Technical Terms and Concepts
- Interpreting Slopes, Areas, and Intercepts of Graphs
- Lab Expectations and Policies
- Lab Goals (Position Statement of AAPT)
- Percent Difference and Percent Error
- Physical Interpretations and Graphical Analysis
- Preparing Graphs
- Quick Reference Guide for DataStudio
- Quick Reference Guide for Graphical Analysis
- Scientific Values
- Significant Figures
- Uncertainty in Measurement

General Observations

The main objective of most new inquiry-oriented introductory physics labs employed at Illinois State University is to have students design and conduct experiments that allow them to derive mathematical models of a relationship. These labs are taught by faculty members, administrative/professionals, and undergraduate physics majors. Having taught a variety of inquiry labs since 2004, we are able to make the following observations:

1) Nearly everyone involved with teaching inquiry labs for the first time is in need of some sort of "refresher" to help them deal with the complexities of the approach. Even those who

have taught cookbook versions of these labs for several years need to carefully re-think some of the processes so that they can help their students learn using the inquiry-based approach. We have found that it is best to have small groups of lab instructors meet each week to discuss and conduct inquiry labs that are new to them. During initial experiences with inquiry labs and new technology, we have found that it takes about 2-3 hours per lab to prepare adequately.

2) Lab instructors must resist the urge to provide answers to students about how to perform an experiment. Instead of providing answers, they should be prepared to respond to student inquiries with an appropriate line of focusing questions. Simple questions that do no relate to actually developing and performing the inquiry lab activity – such a how to use a caliper or how to use a particular component of a computer program – may be quickly answered.
3) Inquiry labs are best prefaced with pre-lab assignments that are due in lab at the beginning of the period. Pre-labs should focus on prerequisite knowledge, predictions, and the planning required to carry out a lab. Pre-labs engage students in pre-thinking the processes required to complete the lab successfully. They require students to learn critical skills and sometimes develop a "theory base" for designing and carrying out an activity. Making repeated reference to our *Student Lab Handbook* has proven a valuable means of getting students to understand such things as experimental design and error propagation that are often overlooked in the rush to complete a lab. In order to drive home the importance of the pre-lab content and references, it is important that this information be addressed in class and as part of tests.
4) Inquiry labs are hard work for students and instructors alike. In comparison to following a set of cookbook instructions, inquiry processes are intellectually demanding. Still, given the benefits of inquiry, such extra work as will be required to complete a lab activity is well worth it. In order to help students value the work of inquiry labs, it is our belief that inquiry labs should constitute a significant part of the grade in a given course.
5) Instructors should assess via testing what students were expected to learn in lab and pre-lab. The lab itself, with its requisite skills and intellectual processes, should be the subject of regular assessment. By holding students to a greater accountability, they will better learn the skills outlined in the AAPT position statement.
6) Course instructors should consider giving students a lab practical shortly after the beginning of the semester. This can serve as another type of assessment that can help ensure greater accountability.
7) Because most students (and some lab instructors) will not have had experiences with inquiry, it is imperative that students start with simpler paradigm labs before moving on to the more complex labs. For instance, it is relatively easy to conduct the pendulum experiment, and much more difficult to conduct an experiment dealing with deriving Newton's second law or the general form of the moment of inertia. Students can only develop the more complex skills required for more advanced inquiry by ramping up through a series of increasingly more challenging labs.
8) When introducing inquiry labs, it is important to conduct climate setting (Wenning, 2005b) so that students understand the benefits of the inquiry approach. We have found that students who understand the value of the inquiry process tend not to make negative comments concerning the approach.
9) Students report that they prefer to complete a lab and turn in their lab results at the conclusion of the lab session. Our approach avoids having students write and turn in "formal" lab reports. Using the short answer approach incorporated in our inquiry labs, students know exactly what they are supposed to get out of a lab experiences, and gone is the disconnect between lab activities and reports that so often results in poor student work.
10) The shift from traditional cookbook labs to inquiry-based labs can be a gradual process, with one or two inquiry-oriented labs being added to the line-up each year. Labs such as those noted in this article can be used as is or adapted as needed, or new labs can be written by those most familiar with and committed to introducing inquiry processes into labs.

Addressing Teacher Preparation Standards

NSTA program accreditation requirements drove our lab revision process. The NSTA clusters dealing with content (Standard 1), inquiry (Standard 2), and nature of science (Standard 3) were central to our efforts at revising the way we conduct our introductory physics labs. Starting with the 1998 NSTA standards, we thought for several years about how to meet these requirements, but didn't really start making program modifications until we were able to develop a generic model for inquiry labs. We propose this generic model for inquiry labs in postsecondary introductory physics to other teacher educators who share our concerns and interests.

It is our hope and expectation that all students – including physics teacher candidates – will have a better understanding of the nature of science and its attendant inquiry processes from their experiences with inquiry-oriented lab activities. If indeed students teach the way they are taught, then there is some hope that our PTE program graduates will use suitable inquiry lab processes in their own high school classrooms patterned after what they have learned through introductory lab experiences while at ISU. So important are inquiry labs to the understanding of physics, that PTE majors now focus attention on the lab as a form of instruction in the teacher preparation process. Physics 302 – *Computer Applications for High School Physics* – has been revised to take into account this new emphasis.

Several of our inquiry labs are currently available for inspection through the Physics 302 course syllabus – *Computer Applications for High School Physics* (http://phy.ilstu.edu/pte/302.html). The labs available through this Web page include: Graphical Analysis, Introduction to DataStudio, Free Fall, Resistance Relationships, Projectile Motion, and Moment of Inertia. The last lab follow this article as an appendix.

As a result of our two-year lab renewal odyssey, we have shifted from all traditional cookbook labs to mostly inquiry-oriented labs in calculus-based physics. We have been able to implement significant changes in the way labs are taught in a traditional university setting that still includes separate lectures and labs, and undergraduate teaching assistants. We have shown our faculty the need for and utility of introducing inquiry practices in the lab as a way of helping our students more fully grasp an understanding of both scientific processes and the nature of science. We have shown the way to address many of the problems associated with lab work such as getting students to understand the roles of graphical analysis and error determination. As proof of the worth of this process, our lab writing team has been asked by faculty members within the Department to prepare inquiry labs for use in algebra-based and even some lower-level general education courses in physics.

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Name: ____ Date: ______________________

Moment of Inertia PreLab

Instructions: Provide correct answers to the following questions. Complete this PreLab and turn it in to your lab instructor upon arrival in lab.

Review the Glossary in the *Student Lab Handbook* for important terms associated with this lab.

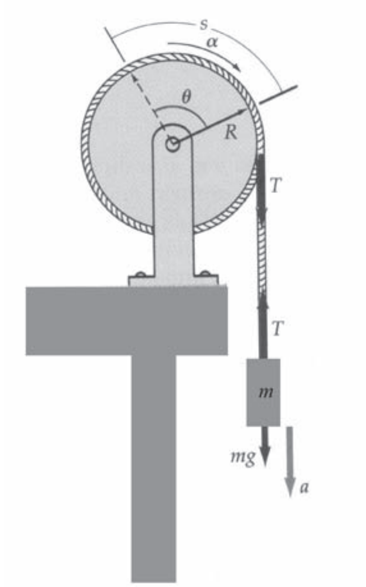
1) State the theoretical moments of inertia for a dumbbell, a thin cylindrical ring, and a solid disk rotated around their centers of mass.

$I_{dumbbell} =$ $I_{thin\ ring} =$ $I_{disk} =$

2) State the parallel axis theorem for moments of inertia.

3) Consider a disk that is free to spin about a horizontal axis attached to a weighted string (see figure). The string is wrapped around the outer rim of the disk and connected to a weight of mass *m* suspended over the edge of the level surface with a pulley. The disk has a moment of inertia *I*, and a radius *R*. The force of tension, *T*, arising from the disk, opposes the acceleration of the suspended weight. On the basis of Newton's second law one can conclude that $-T + mg = ma$ where *a* represents the linear acceleration of the weight. Given this relationship and assuming the definitions of torque, $\tau = TR$, angular acceleration, α, the relationship between them, $\tau = I\alpha$, and the relationship between linear acceleration and angular acceleration, $a = R\alpha$, show that the moment of inertia of the disk can be found using the following relationship:

$$I = mR^2\left(\frac{g}{a} - 1\right)$$



Name: ______________________________ Date: ______________

Moment of Inertia Lab Guidelines

Objectives: As a result of this lab, the student will:

- demonstrate a conceptual understanding of the phrase "moment of inertia."
- state a qualitative relationship between moment of inertia and amount and distribution of mass in a system.
- find the relationship between the moment of inertia and the amount of mass in a dumbbell system.
- find the relationship between the moment of inertia and the distribution of mass in a dumbbell system.
- verify the moment of inertia for a cylindrical ring with interior and exterior radii of R_1 and R_2, and rotated around its central axis.

Task 1. Demonstrate a conceptual understanding of the phrase "moment of inertia."

a. The moment of inertia is to rotational motion as mass is to linear motion. In a linear system, the mass can be thought of as a "measure of resistance to linear acceleration." In a rotational system, the moment of inertia can be thought of as a "measure of resistance to rotational acceleration." The parallels between the force and torque relationships are clearly evident: $F = ma$ and $\tau = I\alpha$. As force is responsible for linear acceleration, so torque is responsible for angular acceleration.

b. Conduct a qualitative <u>controlled experiment</u> to determine the affect of the <u>amount of mass</u> at a fixed distance on the perceived moment of inertia of a weighted meter stick. Hold the meter stick at the 50*cm* position, and quickly rotate the meter stick back and forth with changing amounts of mass located at the same position each time. Note any changes in the resistance to rotational acceleration.

Q1. How does the amount of mass affect the perceived moment of inertia in this system?

b. Conduct another qualitative controlled experiment to determine the affect of the <u>location of mass</u> on the perceived moment of inertia. <u>Use the same amount of mass each time</u>. Again, hold the meter stick at the 50*cm* position, and quickly rotate the meter stick back and forth with changing mass distribution. Note any changing resistance to rotational acceleration.

Q2. How does the location of mass affect the perceived moment of inertia in this system?

Q3. Given the above system of meter stick and masses, what other pertinent variable(s) beside mass and location of those masses exist that might affect the perceived moment of inertia?

Task 2. Predict the dependence of moment of inertia on the amount and location of mass.

a. From the first task, it should be clearly evident that the moment of inertia of two equal units of mass placed at an equal distance from the axis of gyration is a function of both the total mass, m, and the distance of the two masses, r, from the axis of gyration. That is, $I = f(m, r)$. Perform a dimensional analysis to determine the expected form of this relationship. Keep in mind that because $\tau = I\alpha$, the units of I should be those of τ/α.

Q4. How did you perform your dimensional analysis? Show all work.

Task 3. Determine the moment of inertia of the test apparatus.

a. In order to conduct this experiment, you'll need to use a rotary motion sensor and accessories along with the associated software. Using the equation derived in the PreLab

$$I = mR^2\left(\frac{g}{a} - 1\right)$$

experimentally determine the moment of inertia for the test apparatus. The test apparatus should consist of the base assembly, the three-wheel axel mechanism directly attached to it, and the black metal rod. Be certain to average the results of three or four test runs.

Important Warnings: *Be very careful in your use of the above equation; don't confuse the mass of the suspended weight – m in the above equation – with the mass of the weights added to the rotational motion sensor. Don't confuse the radius arm – R in the above equation – with the radius of gyration of the masses added to the rotational motion sensor. Also, be certain to calibrate your rotational motion sensor so that the pulley wheel selected (radii of 5mm for small, 14.5mm for medium, and 24mm for large) is the same as the pulley about which you will wrap your string. Lastly, determine the linear acceleration of the falling weight, a, by taking the slope of a velocity-time graph. Direct measurements of acceleration have proven to be somewhat imprecise using the provided rotational motion sensor.*

Q5. What is the moment of inertia of the specified test apparatus? Be certain to show your work and include units in your answer.

Task 4. Conduct a controlled experiment to determine how the amount of mass affects the moment of inertia.

a. Controlling for radius of gyration, perform an experiment using the test apparatus with identical masses set atop the test apparatus to determine what affect the mass of these objects has upon the measured moment of inertia. <u>Make certain that all masses are centered over the axis of gyration at all times.</u>

b. Create a graph of moment of inertia versus mass. If the graph is not linear, appropriately modify the way you graph the data in order to linearize the graph.

Q6. Does the regression line pass through the origin? Why or why not?

Q7. If there is a non-zero y-intercept in the above graph, what does the y-intercept represent?

c. Correct your data for the above factor by using a column formula if necessary.

Q8. What does this say about the nature of combination of moments of inertia? (Is the total moment of inertia a product, sum, difference, product or some other combination of individual moments?)

d. Give the linear regression a physical interpretation (e.g., Must the modified graph's regression line pass through the origin after the data are corrected for the moment of inertia of the test apparatus? Adjust your best-fit relationship so that you end up with a physical interpretation of the data.) Label this graph *Moment of Inertia versus Mass.* Print the graph and include it with your lab report.

Q9. What is the nature of the dependence of the moment of inertia, *I*, on the total mass, *M*, of this system? (e.g., $I \propto m$, $I \propto m^3$, $I \propto 1/m$)

Task 5. For two equal masses placed equidistant from the axis of gyration, conduct a controlled experiment to determine how the location of mass affects the moment of inertia.

a. Controlling for mass, perform an experiment using the test apparatus with two equal movable masses to determine what affect the distance of these masses from axis of gyration has upon the measured moment of inertia. Be certain to adjust the moment of inertia of your experimental system by the amount equal to the moment of inertia of the test apparatus. <u>Make certain that both masses are equidistant from the axis of gyration at all times.</u>

Q10. Note that the masses on the rod are not point sources. From "where to where" does one *correctly* measure the distance used to derive this relationship?

b. Create a graph of radius versus moment of inertia. If the graph is not linear, appropriately modify the way you graph the data in order to linearize the graph. Give the linear regression a physical interpretation (e.g., Must the regression line pass through the origin? Adjust your best-fit relationship so that you end up with a physical interpretation of the data.). Label this graph *Moment of Inertia versus Radius*. Print the graph and include it with your lab report.

Q11. What is the nature of the dependence of the moment of inertia, *I*, on radius of gyration, *r*, in this system? (e.g., $I \propto r$, $I \propto r^3$, $I \propto 1/r$)

c. It should be clear from the analysis that a series of "point" sources distributed in a variety of ways (disks, rings, rods, etc.) and the fact that moments of inertia about the same axis of gyration are additive, that a more complete definition of moment of inertia can be based upon the following formula:

$$I = \sum_{i=1}^{n} m_i r_i^2$$

Task 6. Verify the moment of inertia for a ring.

a. Integral calculus can be used to show that the moment of inertia of a cylindrical ring of mass *M* (with inner radius R_1 and outer radius R_2) rotated about its central axis is given by the following relationship:

$$I = \frac{1}{2} M (R_1^2 + R_2^2)$$

b. Calculate and then experimentally verify the moment of inertia for the cylindrical ring provided.

Q12. What values did you get for theoretical an experimental values of the moment of inertia? Clearly distinguish your answers, one from the other. Include units.

Q13. What is the percent error given these two values? Show the initial formula and calculation.

Q14. What experimental error might account for the difference between these two values?

Letters to the Editor

Editor:

I teach science education classes at Oregon State University and I was very disappointed when a future physics teacher brought in an article from your September 2005 journal, page 20, (Environmental physics: Motivation in physics teaching and learning by Renata Holubová) as an example of a demonstration that they would like to do with their class showing the greenhouse effect. In fact the demonstration in your journal reinforces a misconception held by many primary and secondary teachers.

CO_2 causes the greenhouse effect for two reasons, one of which is due to CO_2 being less thermally conductive than air and the other being that it absorbs and reflects infrared radiation more effectively than air. The effect due to infrared reflection is much larger than the thermal conductivity.

Unfortunately, the demonstration of the "greenhouse effect in a jar" shows a temperature difference of the thermometers only because of the thermal conductivity of the gas. The primary function of the CO_2 in the greenhouse effect is not illustrated whatsoever in this demonstration.

I have seen many teachers use this demonstration and they frequently also try other gases in the jar and incorrectly conclude that they can quantitatively compare the greenhouse effect of different gases based on this demonstration. Since the demonstration only involves the conductivity, gases with higher infrared absorption may be ranked lower than gases with poorer absorption.

I think it is important that future physics teachers not be given tools that reinforce incorrect preconceptions. I hope that you will publish a correction for this demonstration, along with an explanation of the correct physics of the situation.

Sincerely,

Leonard T. Cerny
Science Education PhD.
Student and Classroom Instructor
Oregon State University

The author responds:

I agree with L.T. Cerny, but the experiment in the article didn't contain the explanation of the greenhouse effect anyway. In this step the students only measure the temperature and compare data. The physics background must be explained by the teacher - there is a possibility to confront the glasshouse and the greenhouse, explain the thermal conductivity and the infrared reflection, the CO_2 cycle (chemistry) such as mentioned . A lot of materials due to the greenhouse effect can be found (articles, graphs). It depends on the level of education . The conclusion - the greenhouse effect as a phenomenon that it necessary for our life and that one made by the activity of men (industry, rainforest felling etc.). There are many more questions concerning the greenhouse effect that must be brought to students step by step.

Best wishes,

Renata Holubová

