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SCIENCE & INTELLIGENT DESIGN

Intelligent design is once more appearing in the guise of science. I say "once more" because the concept of intelligent design - that the universe by its very nature implies an intelligent designer - is not new. It's an old idea dressed up in new clothing. That this is the case can be seen from a review of the writings of 18th century natural philosophers and theologians.

Over the past year I have been reviewing the writings of renowned philosophers from this time period. Among the most interesting writers of this era from a scientific perspective is English philosopher David Hume (1711-1776). Late in his life, Hume wrote *Dialogues Concerning Natural Religion.* The work was published posthumously in 1779. Reading this work today will make one feel that it was written only recently, and in direct response to the claims of intelligent design proponents. Consider some of the following ideas that stem from this monumental work:

◆ In order for a claim to be scientific, it must be subject to and comply with the rules of scientific evidence; for a claim to be credible, it must be supported by evidence that satisfies scientific skeptics; scientific skepticism must be free from prejudice; the more amazing a claim, the greater the required evidence.

◆ God is defined by intelligent designers as that which created the universe; this definition does not provide knowledge with certainty, merely unsubstantiated belief; a definition does not imply knowledge; there are no incontrovertible proofs of God's existence; if we assume a god as creator, we are less concerned about a belief in that god and more concerned about his nature.

◆ Religious belief based on authority is not as certain as scientific knowledge based on empirical observation; for instance, it is reasonable to infer from experience that houses and watches have house builders and watchmakers; no similar claim can be made for the universe because we cannot make a general inference based on a single observation; a god's creation of the universe is merely conjectural.

◆ Order in the universe does not necessitate intelligent design; there are examples of order which are quite natural; for instance, consider crystals and density columns; inferences must be based on experience and are specific to experience; while ships have builders, it is not reasonable to assume that the universe does; arguing from analogy - a posteriori - is at best weak, and a poor substitute for direct evidence of the existence of a god.

◆ The study of a leaf can not lead to necessarily correct implications for the origin of a tree; only a preponderance of a wide variety of evidence can lead to reasonable implications; unlike the creation of a house, a watch, or a ship, the creation of the universe is not self-evident and undeniable; we must be careful to distinguish reasoning from experience, but especially when it relates to matters of fact; we don't have enough experience with the creations of universes to draw sound conclusions.

◆ Explaining the order of the universe by referring to a god explains nothing; we merely replace ignorance about the origin of the university by something which is itself conjectural; we are obliged then to find out more about the cause of this cause which is impossible to satisfy; objective scientists avoid the demand for closure and leave unanswerable questions unanswered until such time as evidence itself forces a conclusion; admitting ignorance is better than drawing unsubstantiated conclusions about a god whose existence is merely conjectural.

◆ By studying a universe supposedly designed by a god, we can conclude something about the attributes of the designer; the universe does not appear to be free from "every error, mistake, or incoherence" in the designer's undertaking; consider pain, sickness, and death, and their relation to modern medical sciences; consider hunger and starvation, and their relation to the green revolution; humans are constantly improving upon creation; can we infer thereby that the deity was inexperienced, negligent, cruel, shortsighted, and inferior - with a deficit of perfections?

◆ With the apparent conflicts between good and evil in our world, the tug and pull of countervailing forces in the universe, we can not preclude the idea that the designer might have been two instead of one; the designers/creators of the universe might be good/evil or male/female, each contributing traits to creation; intelligent design weakens the proof for the very existence of the one God that intelligent design proponents seek to show exists.

Given these few points - only some of the many more made by Hume over 200 years ago - those who promote intelligent design should be careful of the consequences on religious beliefs that promoting this concept as "science" might have. To promote intelligent design as science is to open religious belief to the critique of rational empiricism. All science teachers - as well a promoters of intelligent design - would benefit from a careful reading of Hume's *Dialogues Concerning Natural Religion.*

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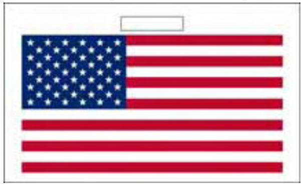

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REVIEWERS

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JPTEO

Physics teacher preparation: Dreams and reality

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This paper examines the knowledge and skills that a 21st century physics teacher should possess, suggests a list of goals for a physics teacher preparation program, and describes the structure and the course content of a program guided by these goals. One of the goals is building teacher pedagogical content knowledge - a unique blend of physics and pedagogy. A carefully chosen sequence of physics-related methods courses and clinical practice focuses on the epistemology of physics, physics reasoning, formative assessment, and reflection on learning.

What a physics teacher needs to know and be able to do

American students studying science are expected not only to master the fundamental concepts of the discipline, but more importantly, to understand the methods of scientific inquiry — using scientific methods to design experimental investigations, devise and test models of natural phenomena. They need to learn to how collaboratively and to communicate effectively[1]. Research in education demonstrates that the success of the current reform goals in K-12 science education depends on the preparation of teachers[2, 3]. In addition to knowing the content and the methods of scientific inquiry, teachers should be able to create learning environments in which students can master the concepts and processes of science while working with their peers; most students will not learn if teachers attempt to simply transmit content knowledge to them. Teachers should know how people learn, how the human brain functions, how memory operates and how a brain develops with age. However, the content knowledge and the knowledge of learning and learners cannot be considered separate domains. Teachers should possess "special understandings and abilities that integrate their knowledge of science content curriculum, learning, teaching, and students. This special knowledge, called pedagogical content knowledge (PCK), distinguishes the science knowledge of teachers from that of scientists"[1] (p.62). Pedagogical content knowledge, defined by L. Shulman as "the special amalgam of content and pedagogy that is uniquely the providence of teachers, their own special form of professional understanding" [4], has become a key word in teacher preparation and assessment. Another important idea is that teaching science based on the methods advocated by current reforms is fundamentally different from how teachers learned science themselves[5]. Yet research indicates that teachers, unfortunately, tend to teach the way they have been taught[6].

Building a physics teacher preparation program

The considerations above suggest that in a successful physics teacher preparation program, future teachers should learn the content and the methods of the discipline in environments similar to the ones that they will need to create for their students. They also need to acquire pedagogical content knowledge (PCK - Fig. 1). Traditionally teachers learned content knowledge by taking courses on physics departments and pedagogical knowledge by taking courses in the schools of education. Physics and pedagogy were different knowledge domains and teachers were supposed to somehow integrate the two to figure out how to build "physics pedagogy". Recently, a new knowledge domain – Pedagogical Content Knowledge emerged. In physics, Pedagogical Content Knowledge can be described as an application of general, subject-independent knowledge of how people learn to the learning of physics. For example from the studies of the brain we know that human brain actively constructs knowledge[7]. From the studies of electric and magnetic phenomena we know that a changing magnetic field produces an electric field. Pedagogical content

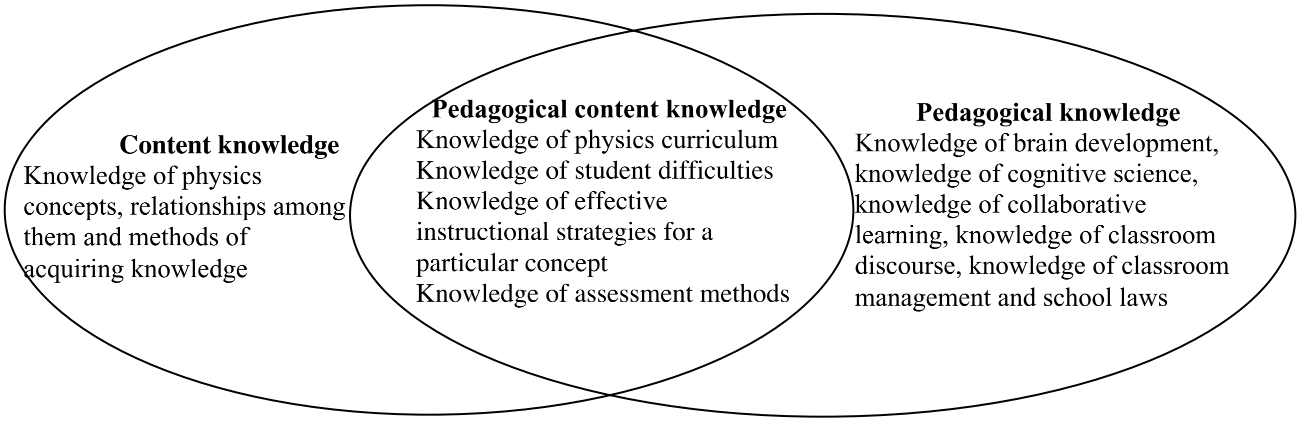

Fig. 1. The structure of teacher knowledge

knowledge in this case is the knowledge of how to structure student experiences in a physics class so that they actively construct the concept of electromagnetic induction. Another example is a pedagogical principle that says that concrete experiences and analogies help people develop abstract concepts. In physics, one of the mathematical relationships that students have to learn is the relationship between electric current, voltage, and resistance. How does one structure students' experiences so that they move from concrete to abstract? What equipment does one need to assemble? How much or how little instruction should students receive? What questions should a teacher ask or not ask? What difficulties might students have? What questions might students ask? What are helpful analogies for current, voltage, and resistance? What analogies might confuse students more than help them? To answer these questions, one cannot simply add the knowledge of educational psychology to the knowledge of physics but needs instead to access a new field of knowledge, which is the pedagogical content knowledge for that subject. PCK encompasses but is not limited to:

- Knowledge of physics curricula (the sequence of topics that allows a student to build the understanding of a new concept or skill on what she or he already knows, and what topics are better suited to build certain scientific abilities). For example one needs to understand the ideas of impulse and momentum in order to construct a microscopic model of gas pressure. Or the analysis of the Atwood machine is a good place to help students understand the importance of assumptions that we make while solving physics problems.
- Knowledge of student difficulties (what student ideas, recourses, facets, or difficulties when they are constructing a particular concept are, or how they need to interpret physics language that is different from every-day language). For example while students learn electromagnetic induction, it is important to know that the difficulty in students understand of the concept of flux is often due to the fact that in every-day language the word "flux" means "change".
- Knowledge of effective instructional strategies for a particular concept (what specific methods or specific activity sequences make student learning more successful). For example when students learn Newton's laws, it is helpful to label any force with two subscripts indicating two interacting objects; or before one engages students in learning of current and voltage it is useful to give students a small light bulb, a battery and one wire, and ask them to light the bulb.
- Knowledge of assessment methods (what are the ways to assess student conceptual understanding and acquisition of problem solving and general scientific abilities, how to help students self-assess themselves, and how to engage them in a meaningful reflection). For example, physics jeopardy problems in which a student has do describe a situation matching a given equation[8] are an effective way to assess whether students understand the meaning of mathematical equations that they use to describe physical processes and to solve problems.

However, if one cannot learn physics by just listening and reading but needs to be engaged in the active process of knowledge construction, the same should apply to the PCK; one can only acquire PCK by actively constructing it in the process of teaching. Thus clinical practice, an opportunity to engage in interactions with learners that model good teaching, becomes equally important for teacher preparation. We can now define the characteristics of a successful physics teacher preparation program.

1. Future teachers learn physics through the same methods that they should use when teaching.
2. They acquire knowledge of how people learn and how they learn physics.
3. They engage in teaching in environments that mirror the environments that we want them to create later.

Two more considerations are important. Teachers prepared today will be teaching for the next 25-30 years. Thus, we need to include elements in the teacher preparation program that will give teachers ways of keeping abreast of new technological developments. We also want the teachers to be able to bring the spirit of authentic science into the classroom. We can now expand the characteristics of a teacher preparation program:

4. Future physics teachers master the technology that they can use in the classroom and acquire methods of updating their knowledge and skills.
5. They learn ways to engage their students in actual scientific practices.

These five characteristics are the features of the physical science teacher preparation program at Rutgers. In the state of New Jersey all certification programs require a major in the subject being taught. Rutgers has two teacher preparation programs that both result in the same master's degree and a certificate to teach physics and/or physical science. One is a post baccalaureate program and the other is a 5-year program. In the 5-year program students begin taking courses in the school of education in their 4th year of undergraduate studies and then continue in the 5th year. Both are 45-credit semester-hour programs that can be completed in a minimum of two full academic years. The majority of the students are post baccalaureate. They usually are former engineers, or workers in pharmaceutical or computer industry who want to become physics teachers. The distribution of the course work is as follows:

- *Physical science methods courses* where students acquire physics PCK, the knowledge of using technology and how to bring authentic science into learning physics – 18 credits
- *General education courses* where students acquire the knowledge of learners – 12 credits
- *Clinical practice* where students observe teaching and teach physics - 9 credits
- *Graduate level (300-400) physics courses* - 6 credits.

It is important to note that students study in cohorts in the program– they take all physical science methods courses together, simultaneously do student teaching and look for jobs. Being in the same courses with each other for two years helps build a community that later self-supports itself when the graduates start teaching.

Fine-tuning the preparation of physics teachers

The main threads running through physics-related methods courses and clinical practice are the epistemology of physics, physics reasoning, formative assessment (assessment of student work in the process of learning), and reflection on learning. Although students have (or are finishing) an undergraduate degree in the discipline, they usually learned the subject through traditional lecture-based instruction and not through the methods that they will need to use when they themselves teach. Thus, in all courses pre-service teachers re-learn (re-examine) physics ideas via the methods that they can later use with their students. In particular, we use a framework of the *Investigative Science Learning Environment* (*ISLE*). *ISLE* is a comprehensive (involves all parts of the course) physics learning system that replicates some of the processes that scientists use to construct knowledge. In each conceptual unit students construct concepts by analyzing patterns in experimental data and then test their ideas by using their own concepts to predict the outcomes of new experiments (that they often design). When students first encounter a new phenomenon, they use their own language to describe and explain it and only later, when they feel comfortable with their explanations, the instructor tells them about scientific language and accepted models. *ISLE* uses a combination of inductive, hypothetico-deductive and analogical reasoning, which are types of reasoning most commonly used by scientists[9]. In addition, *ISLE* explicitly focuses on helping students learn how to represent ideas in multiple ways. Many activities that students perform after they construct an idea consist of representing a physical process in different ways—sketches, diagrams, graphs, data tables, and mathematical equations... The labs involve student design of their own experiments without a recipe. In summary, the features of *ISLE* match closely the guided inquiry-style teaching that the National Science Education Standards encourage teachers to employ[10]. *ISLE* is used in high school and college physics classes.

In the physics methods courses, future teachers, guided by the *ISLE* sequence, learn to select phenomena for their students to first observe and later explain. They learn to design experiments to test explanations and to use hypothetico-deductive reasoning to make explicit predictions of the outcomes of the testing experiments[11]. In other words, they engage in scientific investigations and by doing this learn how to engage their future students in similar activities. They participate in a learning process that we want them to model in the future. There is a serious focus on formative assessment and feedback; when a student completes any assignment, she/he receives feedback suggesting improvements and subsequently revises the assignment. In all courses students teach a lesson in class – the lesson plan receives multiple feedback before it is conducted. In each class meeting, students reflect on the methods that were implemented. However, it is important to note that class work is not the only exposure to PCK that future teachers get in the program. They apply what they learn in classes during clinical practice: in the first year they teach recitations and labs in *ISLE* reformed university courses under a supervision of the program faculty. In the summer they observe program faculty teaching high school students using the *ISLE* method and reflect on their experiences. In the fall of the second year, pre-service teachers do student teaching. There they design and implement their own lessons. This progression of more and more independent teaching is based on the theory of cognitive apprenticeship[12].

Physics teaching methods courses

Development of Ideas in Physical Science[13] (1st year, fall semester) – students learn the processes that scientists used to construct concepts and relationships that make up the content of physics courses in a high school. For example, how did scientists figure out the size of Earth, how did they learn that objects fall with constant acceleration, how did they decide what quantity should be called a force, how did they decide that kinetic energy is $^1/_2\, mv^2$ and not mv^2, and where did they get the idea of molecules?

Students learn to distinguish between experimental work, theoretical explanations and modeling, and testing of explanations. They read and discuss original texts, replicate classical experiments and learn to adapt them for a high school setting. Students learn about the personalities of the scientists who were involved in the construction of an idea and consequently encounter all the difficulties and the drama of scientists doing science at that time in that country while surrounded by their contemporaries. Simultaneously, they learn how historic difficulties that scientists experienced in the process of struggling with a new idea resemble the difficulties that their students will have mastering the concept (based on the PER findings). Every week they write a journal in which they describe how a particular idea, discussed in class that week, was developed by scientists. In their journal they need to specify whether that piece of knowledge was based on experimental evidence, or whether it was a product of reasoning (or sometimes simply a definition). They also need to find whether scientists ever used the idea to make a prediction of the outcomes of new experiments, and how the outcomes affected the acceptance or rejection of the idea[14].

In the second half of the course, after having some experience with the analysis of the history coupled with epistemology and physics content, the students complete their own project where they trace the historical development of a new idea, for example, the ideal gas law, or elementary charge, or a photon. As a part of the project they design and teach a 2-hour lesson that engages high school students in the construction of a particular concept following a historical sequence of events (for example, a historical sequence of investigations of cathode rays that helped shape the concept of the electron). They enact a story telling piece (as a mini-play) about the life of one of the physicists involved in the development of that idea. The students design the lesson, receive feedback, revise it, and only then teach it in class.

Teaching Physical Science[15] (1st year, spring semester) — students re-learn and re-examine the physics curriculum again through the lens of inquiry-based interactive teaching methods. They participate as students in *ISLE*-based physics lessons[16] and then reflect on their experiences. They also investigate other physics curricula and resources: tutorials, interactive demonstrations, workshop physics[17], TIPERs[18], ActivPhysics[19], etc., master different methods of assessing their students and discuss the difficulties that high school students might have with various concepts[20]. At home, students write reflective journals reconstructing class experiences[21]. They design a curriculum unit (Electrostatics for example) and a lesson that is a part of that unit. They go through the same process; they first attempt the unit and the lesson on their own (working in groups), receive feedback from the instructor, revise, rehearse the lesson and then teach it in class. Students also attend a 6-hour RTOP[22] workshop learning how to use the instrument to evaluate their own teaching.

The course ends with an oral exam during which students need to present in class their thoughts about helping students learn and assess their learning of a particular concept. A month prior to the exam they receive a list of 30 questions related to teaching of physics that were or will be addressed in the course. For example, "What should your students know about friction? How will they learn it? How will you assess their learning?" During the exam students are assigned randomly to present answers to two of them. The purpose of the exam is to engage students in a cooperative preparation (as it is almost impossible for one person to prepare all 30 questions). They meet on a regular basis, exchange their ideas, and share responsibilities to prepare the answers. They use the electronic discussion board and hold their own review sessions. Preparation for the exam usually starts building a community that will later support the future teachers when they do student teaching, search for jobs, go through the interview process, and later when they leave the program and become teachers.

There is another aspect of the course that needs to be mentioned. Once a week for 10 weeks students attend a high school observing different science lessons and assessing them using the RTOP protocol. In class meetings they reflect on their experiences. This process prepares them for student-teaching during the next fall.

Demonstration and Technology in Science Education (1st year, spring semester) – students learn how to use computer interfaces to collect and analyze data, videotape physics experiments, design web pages and use them in the classroom. They learn about available technology-based physics learning software such as ActivPhysics, Webtop, etc. There are two final projects. One project is to make a movie of a physics experiment and embed it into a lesson. The second project is to design and teach a lesson involving computer-based data collection and analysis (for example using a temperature and a pressure probe to help students construct an idea of absolute zero).

Research Internship in X-ray Astrophysics[23] (summer after 1st year) –the future teachers observe high school juniors learning physics/astrophysics via *ISLE* methods in preparation for conducting research in X-ray astrophysics (the program is called Rutgers Astrophysics Institute[24]). There are three major goals of this course: (a) pre-service teachers witness the teaching method in action and see how high school students respond to it; (b) they learn how to conduct research using public-accessible NASA data bases (this work is done with a university faculty involved the X-ray research); (c) the philosophy of X-ray research process closely resembles the *ISLE* philosophy, which allows students to connect the history of physics to the curriculum development and to contemporary science.

During the one month of program in the summer, pre-service teachers work with high school students on the problems, listen to their group discussions and record how students respond to different class situations. They simultaneously learn the content that involves stellar evolution, X-ray production, new computer operating systems, and data analysis methods, etc. At the end of each 6-hour day they reflect in a group discussion on what happened in class that day. Then at home they write a reflective journal where they describe: what they learned in terms of physics and astrophysics, how they learned it, and what they learned in terms of teaching. They also write two observation papers: one of an individual student over an extended period of time and the other one of a group of students working though one day's assignments. They need to learn about student personalities, observe how the same student responds differently when working in different groups, what difficulties this particular student experiences and is her/his style of learning. They also need to observe and record group dynamics, interactions, etc. At the end of the course pre-service teachers devise a course syllabus for a potential research course.

Student Teaching Internship Seminar[25] (2nd year, fall semester) - accompanies student teaching. In their student teaching, students first spend two weeks observing lessons taught by their cooperating teacher, reflecting on their experiences, and planning their future teaching. They often use RTOP to assess the lessons. Then, they start teaching and every week in the seminar reflect on their experiences, share problems, and learn more about teaching strategies for the specific topics that they are teaching. A part of the seminar course work is using RTOP to evaluate every lesson that they teach and explaining why a particular score was assigned. Students also design a curriculum unit and lessons, receive feedback and use these materials directly in their student teaching experience. They create a teaching portfolio to use when applying for a job, including their teaching philosophy statement.

Student teaching becomes a challenging experience for some. Those who are placed with teachers who follow traditional methods often have difficulties convincing the cooperating teachers that it is okay to let students struggle, that working in groups will not ruin the discipline, and that they can "cover" the required content. We try to place students with the teachers who are graduates of the program, but it is not always possible. The seminar thus is vital to reduce anxiety and help students tackle these problems. Another support often comes from the virtual discussion group started in the spring of the previous year. Students post their questions, worries, concerns and their peers respond instantly with suggestions, support and just warm notes of encouragement. Often a question about physics arises and then again, students work together figuring it out. Sometimes one day brings 8-10 postings on the discussion board.

Multiple Representations in Physical Science[26] (2nd year spring semester) –helps students reexamine physics though the lens of different representations and learn how to apply these representations to solve problems. In physics these are motions diagrams, free-body diagrams, momentum and energy bar-charts[27], etc. They study research articles examining the role of different representations in learning science; they think of how their future pupils will learn to use them for problem solving, they create multiple representation tasks and rubrics for assessment. A great deal of class time is dedicated to solving complex problems and practicing different problem solving strategies. The purpose of this focus is not only to help pre-service teachers practice solving problems that they will later use with their students but also to spend enough time practicing expert-like problem solving strategies to replace "finding-the-right-formula approach" that they develop in undergraduate courses. Pre-service teachers design a lesson dedicated to problem solving that involves the use of a particular representation. For example, students design a problem-solving lesson dedicated to the concepts of energy and momentum conservation. They devise a sequence of activities that starts from simple tasks involving representing different situations with momentum and energy bar charts, then move to more complex problems involving one of the principles of conservation and mathematics and finally finish with a multi-step problem that uses both the concepts of energy and momentum. Their lesson plan receives feedback from the instructor; then they revise it, and finally teach the lesson in class. These lessons now resemble the lessons of expert teachers much more than the lessons that students taught in the "Development of Ideas in Physical Science Class" almost two years prior. The response of their peers during the reflection on the lesson is also different; they can see the details of the interactions that occurred during the lesson, offer constructive suggestions and explain the reasons for difficult moments.

Clinical practice (teaching) has a strong emphasis in the program. In the fist year students teach recitations and labs in reformed interactive-engagement physics courses; in the summer they work with high school students in the Rutgers Astrophysics Institute. In the second year they do four months of student teaching, often being placed with the graduates of the program, who can reinforce what students are learning. In summary, the sequence of physics teaching methods courses combined with clinical practice offers students an opportunity to:

- re-learn physics content knowledge in a science-like environment,
- learn how to help their future students construct understanding of physics concepts in similar environment;
- learn how to use the advantages of contemporary technology while teaching physics;
- engage high school student in authentic research;
- build expert-like problem solving skills, and
- practice this new, reformed style of instruction with students of different ages with different degrees of autonomy.

Does the program work?

The first indication that the program is succeeding is the number of graduating students (1 student in 2003, 5 students in 2004 and 7 in 2005). For a small school of education (we graduate about 60 elementary teachers per year), these are good numbers. We think that one of the reasons for the increase is the unique structure of the program, which focuses on learning how to teach physical science as opposed to simultaneously learning to teach all sciences.

The second indication that the program is succeeding are the changes occurring to the students in the program as they come to understand what good teaching is and what a person should know to be a successful physics teacher. These changes are documented through open-ended questionnaires that pre-service teachers fill out when they start the program, after the summer course work and at the end of the program. All three questionnaires ask students to describe what it means to be a good teacher and the second and third questionnaires in addition ask them to describe what teaching knowledge and skills they are acquiring in the program. Small numbers do not allow a statistical analysis. However, 100% of the responses to the first questionnaire say that a successful teacher has one or more of the following characteristics:

- She/he is knowledgeable in the content,
- She/he has good organization skills, and
- She/he can make physics fun.

After the first year, the responses to the same questions become more diverse. The characteristics listed below are the ones mentioned most often:

- She/he can engage students in an inquiry exploration of nature,
- She/he knows how students learn,
- She/he knows what will facilitate learning of the most difficult, abstract concepts in physics and is able to plan lessons with all that in mind.

When asked about knowledge learned in the program, students consistently list the knowledge of physics and being able to see physics everywhere, the understanding of how scientists construct their own knowledge, and the understanding of how students learn. When asked about skills, students say that they learned how to write a unit plan, plan a lesson and teach a lesson; how to design a test that probes a student's true understanding of the material and creativity as an experimenter. They often mention that they learned how to engage students in scientific investigations; how to motivate students using challenging problems, how to organize lessons so that new material builds on previously learned knowledge, how to use multiple representations in a classroom, how to organize students in groups, and how to write an exam using non-traditional questions. Although the above might sound impossible to master, the fact that students think they learned these things tells us that they are aware of their importance[28].

The third indication that the program is succeeding are the comments of cooperating teachers during student teaching. In interviews they mention the unique preparation of Rutgers interns: their content knowledge, their ability to bring inquiry to the classroom, their ability to use technology in a productive way, their skill at lesson planning, and implementing what was planned, and, most importantly, their ability to make students active individual and group participants in learning.

It is difficult to say what happens to the graduates of the program after they finish, as the first teacher prepared after the program was restructured according to the description in this article has been teaching for only 2 years. This fall the third cohort left the program. All of the graduates found jobs and 92% are currently teaching physics, physical science, or chemistry. One graduate is pursuing a doctoral degree in school administration. Those who teach in the high schools self-report using the knowledge and skills acquired in the program, and the examination of tests that some of them devise shows that the problems that they use reflect the concepts that they learned and activities that they did in different physics methods courses. However, a longitudinal study is needed to find whether the graduates remain in teaching longer than average, whether their students have higher learning gains and whether their instruction reflects the PCK that they acquired in the program.

It is also important to mention the problems that the program encounters. The first is the cost. The program costs about $22,000/student. There is very little money for the scholarships in the Graduate School of Education, so students mostly support themselves through loans. Teaching in the Department of Physics and Astronomy helps a little but students do not get appointed as TAs, even if they teach a full load – they get paid as part-time lecturers. This pay does not cover their tuition costs and does not provide health insurance. Some students continue to work part-time holding their old jobs for the first year but they need to quit during the second year when they do student teaching. With financial support, the program would have more students. This brings us to a second problem. It would be difficult to service more than 10 students per year, as the preparation is so intense. The philosophy of the program dictates the teaching methods, one of which is formative assessment with feedback. This places a heavy burden on the faculty and makes it impossible to work with a large numbers of students. The third problem is the lack of five-year Rutgers students in the program. The Physics Department recently reformed several introductory courses that serve as a foundation for future teachers' PCK. Hopefully, these reforms will attract more students to teaching. We need to increase the recruitment efforts coupled with financial aid to bring more of the Rutgers graduates into the program. Perhaps the comment that one graduate made when meeting with a new cohort, "In my first year of being a high school teacher I had more happy days at work than in all ten years of being an engineer" can help.

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Endnotes:

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JPTEO

Minimizing resistance to inquiry-oriented science instruction: The importance of climate setting.

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Establishing and maintaining a classroom atmosphere conducive to student learning should be a goal for all teachers. As science teachers shift from traditional didactic forms of instruction to inquiry-oriented instruction, they sometimes encounter resistance from students, parents, administrators, and even teaching colleagues. In advance of and following changes in classroom pedagogy, it is imperative that teachers properly consider and take actions to set and maintain an appropriate atmosphere. Teachers must also be prepared to react to negative external influences that might originate with parents, administrators, and fellow teachers. The author describes several forms of resistance, and offers techniques of climate setting that, if used properly, can alleviate concerns and help create classroom, school, and community atmospheres conducive to student learning via inquiry.

Resistance to Inquiry

The author of this article is project director of a grant-funded initiative* to introduce and sustain inquiry-oriented science instruction in the Chicago metropolitan area. The *Chicago ITQ Science Project* is a school-university partnership involving 24 high school physics teachers and their designated administrators, as well as two expert Modeling instructors, two experienced Modeling mentors, and three knowledgeable university-level teacher educators. All participants (with the exception of the administrators) met daily for three weeks during the summer of 2005 at Dominican University to learn about and practice the Modeling Method of Instruction. During several autumn follow-up meetings, it became evident that participating physics teachers were experiencing a small but discernable degree of resistance to inquiry originating with certain students and parents. While school administrators were committed to supporting their Modeling physics teachers, they sometimes experienced this resistance themselves from students and parents, but weren't always adequately prepared to defend the use of inquiry in the classroom. Finally, some teaching peers in high school science were skeptical of the inquiry practices being used in the Modeling approach. It has become clear that it is imperative for teachers who introduce inquiry methods into a school system – where "teaching by telling" is the status quo – understand the role that climate setting plays in creating an atmosphere that is conducive to inquiry-oriented science instruction.

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

Parental Resistance: An examination of compilations of posts to the Modeling Listserv at the Arizona State University Modeling Instruction website** (e.g., Parent Attitudes re New Modelers, Selling Modeling to Parents, Parental Pressure and Grades) show that teacher concerns about parental attitudes are well founded. However, the degree of parental resistance is, in most cases, significantly less than that originating with students. Parental resistance typically originates from students complaining to their

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** *http://modeling.asu.edu*

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

<u>Administrator Resistance</u>: A school administrators' resistance (departmental chairperson, school principal, or superintendent) to inquiry might stem from complaints by students and/or parents. Additional questions might arise from concerns about high stakes testing such as that associated with No Child Left Behind legislation. Other forms of resistance might originate from the fact that inquiry teaching does not align well with assessment instruments designed for use with didactic teaching styles. Fortunately, no such resistance has been encountered in this project due to the fact that school administrators were brought onboard early in the project, and were provided substantial information about Modeling goals, processes, and benefits. They also were given a scoring rubric designed specifically for assessing the quality of inquiry-oriented teaching. They have been periodically updated with information about teacher experiences, and have been provided additional background information in a timely fashion to help them cope with concerns expressed by parents and students.

<u>Peer Resistance</u>: More traditional science teachers sometimes are concerned about not "covering" enough subject matter due to the "slowness" of inquiry. They are sometimes concerned about the methods of inquiry due to a failure to understand the philosophy, pedagogy, and benefits associated with inquiry-oriented instruction. Because student attitudes about science and an instructor can be strongly affected by the degree of active involvement, some peer teachers are concerned about "popularity contests." This can result in strong student preferences for one subject over another or one teacher over another. Teaching peers sometimes fear being "forced" to use an inquiry approach with which they are unfamiliar or uncomfortable.

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

Classroom Climate Setting

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

take responsibility for their own learning, and construct knowledge from experiences.

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

Climate setting might be thought of as a process of "negotiating" the classroom atmosphere. Teachers who employ inquiry-based instruction need to be fully cognizant of the fact that students can interpret classroom activities in variety of ways, some of which can be antagonistic to inquiry. In the first column of Table 1 the reader will find a number of specific inquiry-oriented practices. In the next two columns the reader will find how students could interpret these practices. The second column relates to a more traditional interpretation, and the third column refers to the intended interpretation most suitable to the inquiry-oriented classroom. Teachers can use these distinctions to help

Specific inquiry-oriented teacher practices	Traditional interpretations of teacher inquiry practices	Intended interpretations of teacher inquiry practices
teacher asks questions of students	teacher's questions imply evaluation, monitoring, and efforts to control students	teacher seeks clarification and elaboration of students' ideas
teacher focuses on questions rather than answers	teacher doesn't understand the content of this course	teacher is interested in having us understand how scientist know what they know
teacher deflects "simple" questions to other students, or answers one question with another	teacher doesn't know the answer, or the teacher is too lazy to answer the question.	teacher wants us to learn how to think for ourselves, and/or learn from others
teacher engages a single student in an extended discussion while most of the class waits	teacher believes that the student must misunderstand or has the wrong idea; this attention is unfair to the rest of the students	teacher appears to believe that the student has something uniquely valuable to share, and is providing an opportunity for other students to learn from someone other than the teacher
teacher makes very selective use of or de-emphasizes use of textbook	teacher is a "big shot," and wants to show us what he or she knows	teacher wants us to learn from nature, not authorities
teacher engages students in active and extended scientific inquiry	teacher wants the students to do all the work while (s)he merely wanders around the lab; doesn't care if we learn	teacher wants students to understand the methods of scientific experimentation, and how scientists come to know
teacher provides opportunities for scientific discussion and debate among students	teacher doesn't care what we learn or if we are confused	teacher wants us to see that science is a social compact, that knowledge is empirical and depends upon a consensus among scientists
teacher works to make student understanding visible through student presentations and student answers to questions	teacher wants students to feel inferior, stupid, or incapable	teacher wants to know what we think we know so that misconceptions can be identified, confronted, and resolved
teacher spends time on conceptual development at the expense of back-of-the-chapter exercises	teacher doesn't have a good understanding of the phenomenon under study and wants to hide ignorance of exercise-working skills	teacher really wants us to understand the concepts of science, not just mathematical number crunching employing formulas
teacher focuses on depth of understanding rather than breadth of coverage	teacher doesn't want students to know that (s)he has limited knowledge of the subject matter	teacher wants students to understand the content, processes, and nature of science by studying fewer topics in greater depth

Table 1. Negotiating the classroom atmosphere by providing alternative interpretations of inquiry-oriented teacher practices. Many of the above characteristic activities come from *National Science Education Standards* (NRC, 1996.)

their students understand the value of what it is that they do when they employ various inquiry-oriented practices.

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

- be present and ready to work, contribute to the project, and do the work assigned
- communicate accurately and unambiguously, fully expressing ideas
- substantiate claims using evidence
- pass judgments on the value of ideas and not individuals
- ask questions when an idea or fact is presented that they do not believe or understand

In addition, teachers might also want to include the reflective group processing approach mentioned by Johnson, Johnson & Holubek (1988) to help students understand what works and doesn't work from an interaction perspective.

Individual Climate Setting: Perhaps one of the most overlooked components of education in traditional and inquiry-oriented classrooms alike is the role of metacognition and its relationship to student self-regulation. Metacognition – knowing what one knows and doesn't know – is characterized by a student's ability to self-monitor levels of understanding. Self-regulation deals with a student modifying behavior in an effort to learn without direct teacher intervention. Metacognitive and self-regulatory practices aid significantly in student learning in science (NRC, 1999, 2005). Because successful inquiry practice in the classroom depends strongly upon individual student's abilities in these areas, teachers who promote metacognitive and self-regulatory practices are less likely to encounter resistance to inquiry-oriented instruction. While conducting individualized climate setting can be done with a whole class of students, the focus should be on individual cognition and accountability. Other individualized climate setting practices consist of promoting appropriate academic skills – from note taking to test taking. A teacher can help improve students' academic performance by making them more cognizant of the general procedures of "studenting." In order for students to be the best possible students they can be, teachers must have a comprehensive understanding of what it means to be both teacher and student. From the teaching perspective, a teacher should be certain to clarify objectives, motivate students, supply models, sequence subject matter appropriately, guide initial student trials, manage practice effectively, provide for recall, help students apply knowledge to new situations, and provide for self-assessment (Rhodes, 1992). The topics of metacognition and student self-regulation are addressed elsewhere, and readers are referred to key resources such as *How People Learn* (NRC, 1999), and *How Students Learn* (NRC, 2005).

Working with Non-Students

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

Non-Students Generally: High school students who have been educated through the use of inquiry practices generally will be better prepared as college and university thinkers than will students who have merely memorized lot of facts and have learned how to do "plug and chug problem solving." Proponents of inquiry-oriented instruction should be prepared to point out that post-secondary faculty are aware of this fact. As a result, inquiry approaches are now being integrated into post-secondary instruction. College and university faculty members are more interested in students who know how to think than in students who know lots of facts. Research by Sadler & Tai (1997) dealing with the performance in introductory physics courses for almost 2000 students at 19 colleges and universities in the United States shows the value of inquiry-oriented high school instruction on post-secondary performance. Sadler and Tai noted that a smaller number of topics covered with increased depth of study leads to significantly higher grades in college physics courses. This approach is typical of inquiry-oriented instruction. An examination of compilations of posts to the Modeling Listserv at the Arizona State University Modeling Instruction website** (see High School Preparation for College) suggests that Modeling as an inquiry-oriented form of instruction really does better prepare high school students for post-secondary education. As Vesenka et al. (2000) point out, there is a growing recognition among higher education faculty that inquiry-oriented instruction such as the Modeling Method improves the level of performance in the areas of critical thinking and problem solving. As a result of these and similar findings, more and more high schools, colleges, and universities are turning to this mode of instruction. This paradigm shift in secondary and post-secondary instruction has been well documented on physics education research group web sites such as those at the University of Washington (McDermott, 2005), State University of New York-Buffalo

(MacIsaac, 2005), University of Maryland (Redish, 2005), and the University of Maine (Wittmann & Thomson, 2005) among others.

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

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

Making the Case for Inquiry

Whether or not teachers are climate setting proactively or reactively, knowledge of how to make the case for inquiry is critical for the inquiry-oriented teacher. The points below stem from such diverse sources as Francis Bacon's *Novum Organum* of 1620 (Anderson, 1985), *Goals of the Introductory Physics Laboratory* (AAPT, 1998), and *Inquiry and the National Science Education Standards* (NRC, 2000). Among the key philosophical arguments and research-based claims that can be made in favor of inquiry-oriented instruction are the following:

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

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

Through inquiry-oriented instruction students learn science with considerable understanding. Rather that merely memorizing the content of science only to be rapidly forgotten, students learning science through personal experience learn with increased conceptual understanding. Appropriate classroom and laboratory activities help students master basic science concepts. Experiential learning results in prolonged retention, and refines students' critical thinking and problem-solving skills helping them improve standardized test scores. A deep understanding of subject matter is critical to the ability to apply knowledge to new situations. The ability to transfer learning to new situations is strongly influenced by the extent to which students learn with understanding. Learning via inquiry is learning that lasts, and not learning that merely suffices for the demands of schooling.

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

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

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

Critical Need for Climate Setting

Forms of inquiry-oriented instruction such as the Modeling Method, cooperative learning, and problem-based learning, are all subject to various types, degrees, and frequencies of resistance from students, parents, administrators, and teaching colleagues who do not understand the value of inquiry. Even the teacher of inquiry can lose heart and begin to question whether or not inquiry is worth it upon encountering signficant resistance if he or she is unaware of the case that can be made for inquiry. Teachers employing these methods, therefore, have a critical need to understand the value of inquiry, and an ability to conduct climate setting.

During the three-week summer session of the *Chicago ITQ Science Project,* participants' attention was drawn to the need for conducting climate setting to offset resistance to inquiry. However, the importance and procedures of climate setting and classroom, school, and community atmosphere were neither sufficiently stressed nor properly appreciated. It was only through the autumn follow-up sessions with participants that it became clear that not enough time and attention were focused on this aspect of inquiry teaching during the summer workshop. As the work of the *Chicago ITQ Science Project* continues, teachers will be encouraged to regularly perform climate setting to help students and others understand how and why inquiry-oriented instruction is different from traditional didactic instruction.

Encountering resistance is relatively common among teachers who employ inquiry-oriented instruction. Fortunately, the resistance typically encountered by our teachers has been neither frequent nor strident. Resistance to inquiry eventually dissipates as students, parents, administrators, and peer teachers gain an understanding of the value of the various inquiry-oriented approaches employed. The importance of climate setting cannot be over emphasized in minimizing resistance to inquiry-oriented science instruction.

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Six years of Modeling workshops: Three cautionary tales

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Modeling instruction embraces the fundamental principles of the scientific method in order to assist students with constructing physics knowledge and enabling ownership of their learning process. I have used Modeling for eight years in college physics and six years in professional development outreach to middle and high school science and math teachers in California and New England. Nationally recognized research-based assessment tools have been deployed to gauge the success of this process and to help me meet the needs of the student and teacher population I work with. This evolution includes the recognition of the importance of selling our product to indirect consumers, i.e. student's parents and administrators. Three cautionary tales are presented as to what can go wrong if our consumers are ignored, and the important lessons that were learned.

Program Description

The previous article[1] describes the importance of minimizing resistance to inquiry-based instruction both inside and outside the classroom. My physics teaching philosophy has been greatly influenced by the Modeling instruction theories first published by Wells, Hestenes, and Swackhammer[2] and recognized by the U.S. Department of Education as an exemplary K-12 science education program[3]. The Modeling approach does not claim to have invented this effective physics-teaching paradigm. However, Modeling instruction does condense many years of physics education research into a package that can be systematically deployed to help students construct understanding. It helps students build a scaffold to better understand and explain the physical world around them. I have deployed the same objectives in the training of regional math and science teachers through NSF, statewide and vendor-sponsored summer workshops in Modeling instruction.

Impact: Long before outcomes assessment were popularized by the "No Child Left Behind Act", physics education research groups were busily developing tools to analyze basic misconceptions in mechanics[4]. I have used these tools, along with other assessments[5], and have found Modeling instruction to at least double the average student's comprehension of physics concepts over traditional instruction (Fig. 1). Unlike didactic teaching in which physics content is quickly forgotten, students completing Modeling instruction retain concepts long after completion of the course. Post "post-tests" (tests taken a year after completion of the course) indicate over 80% retention, compared to 0% for traditional lecture instruction. This long-term retention has also been observed for those teachers participating in professional development Modeling workshops. Furthermore, these results are not the most impressive. Many Modeling instructors routinely report gains three times traditional techniques. This information should be part of the ammunition used by those teachers attempting to persuade administrators and parents - indirect consumers - of the importance of in-depth, guided-inquiry instruction. In the previous article[1] the author makes a persuasive argument for setting the proper classroom climate to draw students into the Modeling process. Other resources available to Modelers include PowerPoint presentations that can be tailored to the audience (colleagues, administrators, and school board)[6].

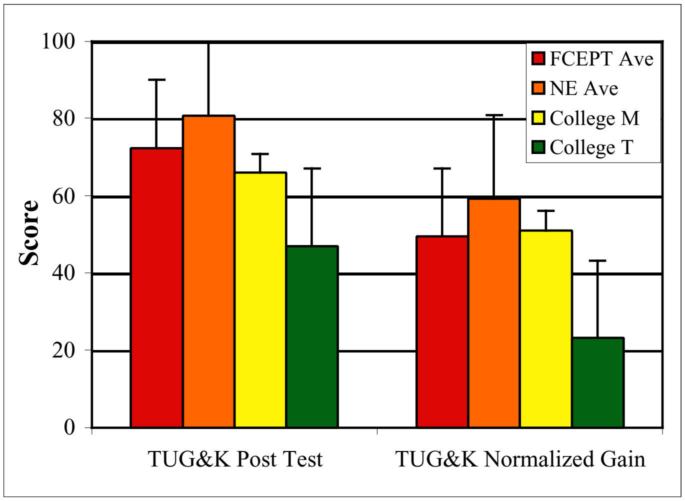

Figure 1: Comparison of TUG&K[4] post-test results and normalized gains for teacher professional development workshops in California (FCEPT, N=128), New England (NE, N=63), College Modeling Instruction (College M, N=514) and Traditional College Instruction (College T, N=140). About the same gains have been posted for two-week professional development workshops as for semester-long college Modeling instruction -- more than twice the gain of traditional semester-long instruction. Similar results have also been recorded for the Force Concepts Inventory[7].

Personal Evolution: I participated in the third phase of NSF-sponsored Modeling instruction workshops[2]. For years my students achieved mediocre normalized FCI gains (20%)[8] using traditional instruction. I became a rabid adherent of the Modeling approach when my students' gains doubled! I actively promoted the use of Socratic dialog, whiteboarding, and microcomputer based laboratories. My colleagues were impressed with the results. One of them suggested I submit a proposal for a summer workshop to the Maine Mathematics and Science Alliance[9]. I applied and the grant was funded. I embarked upon my first professional development workshop using the same recipe as the national workshops. We had two master high school physics instructors and 16 very experienced participants, as could be measured by the high pre-test scores on the FCI (79%). We covered kinematics through dynamics over an intensive two-week course. By all accounts the workshop was successful and the newly acquired techniques were enthusiastically deployed in each participant's classroom. I had successfully secured an NSF grant that supported continued professional development the following summer. Many of the first year's participants returned and shared their stories of Modeling instruction. Several had "interesting" stories to relate. What are the consequences of embracing Modeling instruction without convincing the consumers? Here are three cautionary tales.

Cautionary Tale 1 - The Greenhorn's Lament

Joe (not his real name) taught at a small private academy. His physics class had a single set of probes and three computers for seven students. Six of his students were described as high achievers. The low achiever struggled with the whiteboard presentations and described the Socratic questioning as "humiliating". Two engineering-bound seniors felt his course did not cover "enough" material. They disliked having no text from which they could pull out equations to solve homework problems. These two students became increasingly resistant to Modeling instruction as the school year advanced. They refused to take the FCI post-tests to ascertain their progress. Even though Joe covered substantially more than what a typical new Modeling instructor covers, he was sacked at year's end by the school's administration. A post-mortem investigation of Joe's experience suggested that a combination of affluent parents and weak administration lead to his dismissal. Joe had failed to effectively communicate to his principle and the children's parents what he was trying to achieve through Modeling instruction. He had failed to set a classroom climate that promoted a sense of confidence in the approach being used. Instead, preconceived notions about what physics was "supposed to be" became the source of contention. To be fair to Joe, he was a new teacher placed in a challenging environment. What would an experienced colleague have done?

Cautionary Tale 2 – Reassigning an Old Hand:

Sue (not her real name) had 20 years teaching experience in the public schools when she participated in her first Modeling workshop. For years she had tried to use the latest developments in high school education research to make her physics classroom fun and stimulating. Sue had an excellent grasp of the subject (100% on her TUG&K, FCI, and Force and Motion pretest scores) and was aware of the common misconceptions found in mechanics. However, until Modeling instruction she did not have a satisfactory means of addressing these "alternative" conceptions. Sue observed that her nearly 100 seniors enjoyed whiteboard presentations and believed it allowed her a way to confront the common misunderstandings in mechanics that stifled her students' conceptual physics progress. She noted that her primary battle appeared to be addressing the state's broad educational assessment test, a test that focused on "factons" rather than true comprehension and deployment skills. Sue's secondary battle began in the spring semester after her students had already secured college entry and needed only a passing grade in physics to sustain that entry. Her students came down with serious cases of "senioritis" and their grades plummeted. Sue observed a spike in their resistance to Modeling instruction. She began to receive more irate phone calls from parents claiming she was not teaching them what their children needed to know. Her administration stepped in and she was reassigned to teaching ninth grade physical science. Sue still uses Modeling instruction and is inarguably much happier teaching students at an earlier stage in their physical science development. Still, her reassignment appears to be the result of not effectively communicating the Modeling process to her students, their parents, and her administrators.

Cautionary Tale Number 3 - The Messenger Gets Shot

Adapting and implementing Modeling instruction into traditional lecture and laboratory time presented several logistical challenges for me personally. Though whiteboards could easily be deployed in lab as a formative assessment tool, my students were hesitant to present homework on whiteboards in the lecture hall. Because communication is one of the hallmarks of Modeling instruction, I was reluctant to abandon whiteboard use in class as it was clearly effective in preparing the students to discuss workbook activities. Still, the students lacked confidence in their solutions and complained that I was not "teaching" them. Though all assessments showed excellent normalized gains the students participated in these activities with great trepidation.

I was in my fourth year of college Modeling instruction when a student informed me that a petition was being circulated *during my classes* to relate the concerns some members had with my instruction. Both my department chair and dean supported my position. Still I felt the need to respond to this criticism in a constructive manner. With the assistance of the dean of students, a group meeting was arranged at a convenient time in which students from both sections could attend. The chairs were set up in-the-round to encourage participation and I sat amongst the students to try to encourage openness. Student concerns were expressed without rebuttal, free of potentially discussion-stifling defensive responses. The meeting was designed to be informational and the students appeared comfortable speaking freely. 29 students out of 88 in two sections chose to attend. The dean of students was invited to the meeting as a witness. The criticisms presented by the students were fascinating and included such comments as:

- We prefer "chalk-talk", less technology and more writing on the board.
- You cover material too fast and need to slow down.

- The problems on the tests seem unrelated to/harder than our homework.
- We prefer seeing theory first and lab second.

These students were uncomfortable with change, AND with building and using their own physics scaffold to assist them with non-rote problem solving. An unbiased observer attending the above meeting would never have known that I regularly “explained” the Modeling process to these students. I had unwittingly violated one of the central tenets of Modeling instruction. Instead of facilitating an understanding of Modeling, I was telling them! I had failed to set up a classroom environment to satisfactorily address their concerns. They were not investing themselves in the Modeling process in part because general physics was being treated as a hurdle to be overcome rather than an important building block in their science foundation. The remainder of the semester was spent alternating between fundamental processes and models. Discussion time was set aside weekly to animate each model and help make the models relevant to student interests. After pre-lab and paradigm lab activities were complete, the classes were asked if they could relate the quantitative lab activities with the core models under investigation, again with an emphasis on application to career interests. This grueling process helped me revise the second semester models I covered. Captive audiences such as mine (i.e., required to take physics) need to convince themselves of the value of the material they are studying.

Present and Future

Getting students invested in their education has been a tremendous challenge. Partly this has been accomplished by taking precious classroom time to discuss examples related to each student’s major. To provide this time whiteboarding in class has given way to Eric Mazur’s “Peer Instruction.[10]” Lecture-demonstration problems are analyzed by the students. Pre-determined answers, provided by PowerPoint presentation, are voted on. The results are tallied automatically[11] followed by a discussion of the “distractors” and each correct answer. Electronic feedback from student responses allows for a better picture of student comprehension, enabling a form of “Just-in-time” teaching[12] to help me better pace the concept development in class. Peer instruction permits valuable student-to-student discussion of events, though not always the correct explanation of the phenomena. This approach has worked satisfactorily for the particular audience regularly enrolling at my college. Ultimately, I am seeking a small lab studio physics environment for the students to better emulate high school Modeling instruction. With regard to professional development, the mantra I have adopted is simply this, “If you get fired, then everyone loses”. I recommend that workshop teachers adopt as much Modeling instruction as their educational system will allow. They must educate parents and administration, as well as their students, about Modeling instruction, how it satisfies standards, and how the instructional approach has long-lasting benefits.

Summary

The bottom line, underscored by the previous article[1], is that it is imperative to understand your audience. Setting up a proper classroom climate and communicating with all the consumers of your teaching requires being on the offensive and being vigilant. In light of all the other demands of teaching, this might seem to be just one more burdensome task. Nonetheless, in my opinion it is probably one of the best investments in time that any teacher can make. This is especially true for science instruction in which we would be grateful if the only problem our students had was ignorance of the subject.

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Endnotes:

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[3] http://modeling.asu.edu/

[4] e.g., The Force Concepts Inventory and Mechanics Baseline Test, http://modeling.asu.edu/R&E/Research.html

[5] Test of Understanding Graphs in Kinematics, http://www2.ncsu.edu/ncsu/pams/physics/Physics_Ed/Article.pdf; Conceptual Survey of Electricity and Magnetism, http://tycphysics.org/CSEM_5_2.htm; University of Maryland Wave Diagnostic Test, http://www2.physics.umd.edu/~wittmann/research/umd_wavetests.pdf; and Conceptual Survey of Fluids, http://foundationcoalition.org/home/keycomponents/assessment_evaluation.html.

[6] http://modeling.asu.edu/modeling-HS.html

[7] J. Vesenka, G. Munoz, F. Judd, & R. Key, “A comparison between traditional and “modeling” approaches to undergraduate physics instruction at two universities.” *J. Physics Teacher Education Online* **1**(1), 3-7 (2002).

[8 Research has shown that a gain of 20% can also be attained by a student undertaking independent study WITHOUT the help of a trained physicist! Hestenes’ Lectures, http://modeling.asu.edu/modeling/HestenesLectures/1.Expertise.pdf.

[9] http://www.mmsa.org/

[10] http://mazur-www.harvard.edu/research/detailspage.php?ed=1&rowid=8

[11] http://www.optiontechnologies.com/

[12] http://webphysics.iupui.edu/jitt/jitt.html

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Physics activities for family math and science nights

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Family Math and Science Nights (FMSN) at local elementary schools provide excellent opportunities for preservice physics teachers, physicists, and physics educators to promote interest in physics, and for future elementary and middle school science teachers to receive practical experience in conducting laboratory activities and demonstrations. Several suggestions for interesting physics activities that should be included in any FMSN are included in this article.

Physics Activities for Family Math and Science Nights

As my wife and I go through life with our two young children, we have the daily fortune of being exposed to a variety of new experiences and gaining new knowledge that we were somehow either never interested in before or had lost our interest with age. Although I can neither name nor recognize one single recent Nobel Prize winner in physics, I can, however, name and recognize most of the characters from *Sesame Street*, *Teletubbies*, *The Wiggles*, and the *Rescue Heroes*. In addition to having read most every book about snakes, sharks, and dinosaurs contained in our local library and memorizing most of the books written by Dr. Seuss, I have also become aware of the existence of Family Math and Science Nights (FMSN), an event hosted annually across the country by many elementary and middle schools.

Three major purposes of hosting a FMSN at a neighborhood elementary or middle school are:

1) to promote interest in mathematics and science,
2) to spur parents and other caregivers to become more involved in the education of our nation's children (who will just happen to be the scientists, engineers, and policy makers during our generation's "golden years"), and
3) to "showcase" mathematics and science activities that are taking place in the school.

Many parents, including those from traditionally underrepresented groups, have expressed a desire to be more involved in their children's school activities. Daisey and Shroyer (1995) found that 57% of the 94 "ethnically and socio-economically diverse parents of K-6 children" surveyed in their National Science Foundation-funded project recommended that they "receive more invitations to attend after-school demonstrations and to become more directly involved in instruction" (p. 25). Furthermore, these parents "thought that the parent-teacher association ought to be more involved in instruction rather than keeping parents in the role of fund-raisers" (p. 25). Because "science activities are a natural for increasing parent involvement in early childhood programs" (Sprung, 1996, p. 31), Family Math and Science Nights and other similar programs serve as a great opportunity for parents to become more involved in their child's education (Cardoso, Educacao, Branco, & Solomon, 2002).

Although the format of a FMSN can vary, most generally allow for large group demonstrations and/or small group activities in which participants can conduct some type of experimental investigation (Barrow, Burchett, Gernann, & Callison, 1994) or construct and take home some type of demonstration device. For example, Mulcahy (1995) describes one Family Science Night event in the UK as beginning the evening with a large group "ice-breaker" in which everyone is asked "to complete a simple task" before continuing with "parents, children and any other interested members of the community circulating around various areas of the school where an assortment of related activities have been set up" (p. 19). Watts (2001) even describes a format in which "family teams" meet together twice: the first time for a large group astronomy session in which they receive instruction and home project assignments; the second time approximately six weeks later to share their projects with other "family teams." Program formats such as these provide an excellent opportunity for the involvement of secondary and undergraduate physics students and experience for preservice elementary teachers who will one day be teaching students at any grade level (Rommel-Esham & Castellitto, 2003).

Unfortunately, in addition to disturbing research findings that many elementary teachers dislike teaching science and have low perceptions of their ability to teach science (Worch & Gabel, 1994), most elementary teachers have little or no background in either physics or the physical sciences. Therefore, unless the district and/or campus makes use of a strong kit-based comprehensive science curriculum that includes the physical

Father and sons constructing electric motor

Photos taken by Shannon Bryan and printed with permission from the subjects.

sciences, such as FOSS (http://www.lawrencehallofscience.org/foss/scope/index.html), AIMS (http://www.aimsedu.org/), or GEMS (http://www.lawrencehallofscience.org/gems/gemsguidestopic.html), when science is taught, its “curriculum revolves around plant and animal activities” (Sprung, 1996, p. 30). As a result, it is unlikely that a locally produced FMSN will incorporate activities that would serve as examples of physics content that could generate interest in these young students to pursue physics related fields. Even otherwise excellent FMSN publications developed in part with support from the National Science Foundation, such as “Science Night Family Fun from A to Z” (ISBN 1-883822-21-1), contain few physics activities.

Session Title	Session Description
Fun with Electricity and Magnetism	Participants see demonstrations of electromagnetism, then construct and take home simple electric motors made from a dry cell, ceramic magnet disk, 2 paper clips, wire, and a rubber band
Fun with Light and Color	Participants see demonstrations of color mixing, then construct and take home simple spectroscopes made from hollow tubes and compact disk pieces
Newton’s Balloon Races	Participants inflate balloons, attach them to straws on a string, and let them race as an application of Newton 's 3rd Law of Motion
Music and Sound	Participants examine pitch as produced by air columns and vibrating metal pipes, then construct and play simple reed instruments made from plastic straws
Basic Electric Circuits	Participants construct a working electrical circuits using a “lemon battery” and test various materials for electrical conductivity
Wave Modeling	Participants model transverse and longitudinal waves, then model and measure wave characteristics
Static Electricity	Participants examine static electricity
Slinky Waves	Participants investigate wave characteristics and properties using large coil springs – can be performed as a large group demonstration or by participants
Images from Converging Lenses	Participants investigate converging lens candle images as portions of the lens are covered
Advanced Electric Circuits	Participants construct and investigate series, parallel, and combination circuits using light bulbs and dry cells
Newton’s First Law of Motion	Participants perform a variety of activities demonstrating Newton’s 1^{st} Law of Motion
Radioactive Decay Simulation	Participants simulate radioactive decay using either dice or a random number table – includes graphing skills
Plane Mirror Images	Participants examine full length reflection in large plane mirrors – includes measurement skills

Table 1. FMSN Physics Activities

Here and below: *Viewing lights using homemade spectroscopes*

Although numerous physics laboratory devices offer an ideal *WOW! factor* and would be suitable for large and small group demonstrations, the outcome desired in a FMSN is the active participation of children and their parents and/or other relatives in some type of “make it and take it” activity, or some activity that can be replicated at home. Thirteen of these activities (with more on the way!), listed in order of what I believe provide the most “bang for the buck,” are described in Table 1. Suggestions for leading these sessions and handouts for participants may be downloaded from Texas A&M’s *Center for Mathematics and Science Education* web site at http://www.science.tamu.edu/CMSE/fmsn/default.asp. Each of these activities are suitable for sessions lasting 15-30 minutes, which is a typical time frame for most FMSN sessions, but may be modified to fit most any time schedule. Many of these are identical to activities performed yearly by many students in introductory physics courses and may be found in numerous print and World Wide Web resources.

The relatively small number of physics degrees conferred yearly by our nation’s universities, the shortage of qualified physicists for research

Making an electric motor

and industrial positions, and the high percentage of secondary physics teachers without a degree in either physics or physics education is well-documented by the American Institute of Physics’ *Statistical Research Center* (access via the World Wide Web at http://www.aip.org/statistics/) and other sources (Sprung, 1996). Those with physics backgrounds also know that there are many simple physics demonstrations and activities that would generate an incredible interest in our field through their *WOW! factor*. It is for these reasons that physicists and physics educators should actively participate in these special events, even when no direct ties to the local school exist. Many of you, like me, have had no past involvement in these events simply because we were unaware of their existence. Well, now you know and should act accordingly. Several universities and academic organizations around the country lead workshops for teachers who wish to plan a Family Math and Science Night for their school (see http://www.col-ed.org/equals/family.html and http://www.umich.edu/~eqtynet/emsp.wisc.html as examples). You may even be able to obtain grant funding to support the training and/or implementation of this type of project. Contact your local school district to find out when a FMSN is scheduled at a school near you. If none is scheduled, take the initiative and begin organizing one. Your efforts will be greatly appreciated by the school and community.

The photos accompanying this article were taken during a FMSN at L. B. Johnson Elementary School, a National Blue Ribbon School of Excellence in Bryan, Texas. To request more information about these FMSN activities, or to suggest other inexpensive demonstration or “make it and take it” physics activities that are appropriate for an elementary and/or middle school FMSN, please contact the author of this paper.

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Here and above: *Making a spectroscope*

Turkish primary school students' alternative conceptions about work, power, and energy

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This study aims to determine seventh grade of Turkish primary school students' misconceptions of about work, power and energy concepts. Sample includes six students selected randomly from one of primary schools in the city center of Trabzon. In the study, in order to determine the misconceptions of the sample about work, power and energy subjects, interviews about facts and situation method is used and eleven questions were asked to them. Data obtained from each student was assessed as different cases. There are some important results obtained from the study such as Turkish primary students have many misconceptions about the work, power and energy subjects, bring many concepts which are used in daily life to the science classrooms without changing their forms, thus, students do not consider the scientifically meanings of those concepts in an expected level.

Introduction

It was understood after mid 1970's that, students think different about most events they faced in science courses from the scientifically accepted ones and develop different concepts about them (Ebenezer & Fraser, 2001). These student understandings come to place with different names in the related literature, however, their meanings are the same from as misconceptions, preconceptions, alternative frameworks, children's science, preconceived notions, nonscientific beliefs, conceptual misunderstandings, vernacular misconceptions and factual misconceptions (Nakhleh, 1992; Nicoll, 2001). Misconceptions are not self-developed thinking kinds. A teacher's teaching method in a course may cause them and knowledge forms presented in the books as well. One of the thing on which many researchers are agreed on, is that language students use in everyday context is different from scientifically language and social environment leads students to develop many wrong concepts (Nakhleh, 1992). In addition to this, many researches show that teachers also have misconceptions about their teaching subjects and concepts (Kruger, 1990; Kruger, Palacio & Summers, 1992; Schulte, 2001) and it is possible to transfer them to students (Pardo & Portoles, 1995).

Researches, which are related to examination of those misconceptions, which are, appeared as scientifically unexpected ways, and to solve those problems, have become an expert-area of science education. International literature is full of conceptual studies for about 30 years, however, in Turkey; those kinds of studies have gradually increased in the last decade. Researchers and science educators have tried to answer especially for those questions: "Which misconceptions students have? What is the source of those misconceptions? How much those misconceptions are common among students? Why those misconceptions are not unraveled? What can teachers do to ease conceptual change? " (Pardo & Portoles, 1995). The literature is full of studies, which have tried to find reasonable answers to those questions, thus we do not need to discuss much more here.

Many students cannot understand the difference between formal and concrete structure of physics, thus, some misconceptions come to place (Legendre, 1997). There are a lot of studies toward determination of students' alternative conceptions about physics subjects. There are a few conceptual studies in the Turkish educational literature about movement and force, gravity, light, thermodynamics, electricity, earth and sky; however, there is not a study about energy.

Energy is an important concept because it has common useless in the daily language and basic subject of physics, chemistry and biology (Watts, 1983; Beynon, 1994; Goldrin & Osborne, 1994; Osborne & Freeman, 1989). Energy is a concrete physics concept; so, it has an important place within the conceptual studies. Children face many times with energy concept in the life thus come to classrooms by holding some pre-ideas and experiences with themselves (Goldrin & Osborne, 1994; Watts, 1983). Nevertheless, many of those concepts are different from scientifically accepted ones (Prideaux, 1995). That of energy concept, also, is difficult as many of the other science concepts; thus, it is explained as difficult to teach (Diakidoy, Kendeou & Ioannides, 2003). In addition, some of the researchers believe that this subjects is concrete and theoretical-based thus needs to be eliminated from elementary program (Warren, 1982).

Energy Subject

Energy is defined in science as a capacity of work done. It is also believed by scientists that although it is directly observed it is not energy itself but it is an effect of energy transferring through objects.

In the preceding studies about another concrete physics concepts like energy, it was found out that students are inclined to conceptualize those concepts as material entities (Reiner, Slotta, Chi & Resnick, 2000). English primary teachers investigated as in a similar inclination about energy with students (Kruger, Palacio & Summers, 1992).

A potential pre-concept, which comes to place about energy, is that energy is a force (Duit, 1984; Kruger et al., 1992; Ionnides & Vosniadou, 2002). By general mean in the daily language, it is believed that while lifting or pushing objects, it is needed force, and adults have much more power than children is common. In the same time, it is also common that adults spend less effort than for the same work thus adults spent less force. Thus, superficial teaching of energy concept as a capacity of doing work can lead students to understand it as a physical force. For this reason, it can be much more fixed with force within itself (Diakidoy, Kendeou & Ioannides, 2003). From those explanations, student's possible misconceptions about energy are listed below:

a) The idea of energy is spent thus work is done
b) Energy is matter
c) Energy is a force
d) Energy is a kind of force
e) Energy cannot be stored

This subject is firstly taught in the Turkish educational system to seventh grades of students. In the new science teaching program implemented by 2000 and is also known as "student-centered program- the aim of the related subject is defined as "students' comprehending the different kinds of energy its conservation, productive useless and chance in the useless of it with observations, practices, experiments and different activities and preparing different models" (Journal of Notification, 2518). Besides some student gains are identified, but no knowledge is included about teaching activity or method for teachers. In a superficial analyzes of seventh grade science textbooks, it was understood that the existence of energy kinds, transformations and conservation were given along some explanations and examples (Büyük, Salmaner, Bas & Görür, 2002). However, the fact that it is possible for students to have some misconceptions about energy, and this can lead them to have difficulty in learning, so, pre-knowledge and experiences should be explained in detail, required to be included in the text books for especially science teachers.

From moving all the researches which have been examined in this section, it can be extracted that determination of the Turkish

Question	***Activity***	***Aim***
1. Please give information about work, power and energy and define those by making sentences.	-	To determine a student's understandings about those concepts and also reflections of those concepts into daily life
2. Please explain if you do work here.	A student is told to push the table in front of him/her	To determine if a student understands the work concept in a scientifically accepted way.
3. Please explain what is the relation of this event with work and energy.	A student is told to close the injector's tongue, push the piston forward, and when it is set free, sees the piston returning to its original position	To determine if a student can establish the relationship between work and energy.
4. How does the amount of energy change when you or your father lifts the same load?	-	To determine if a student understands the relation between power and energy.
5. Please explain whether or not you can see energy in the petroleum with an electron microscope.	-	To determine if a student perceives energy as matter.
6. Please explain what kinds of energy does the battery have in the closed electrical circuit on the table.	There is an electrical circuit with a battery on the table.	To determine if a student understands different kinds of energy.
7. What is the reason for the car's movement and then stopping?	A student is given a toy car and asked to wind it up and then set it free on the table.	To determine if a student can find a relationship between the event and energy.
8. What is happening with heat energy and is work being done?	A student is asked to think about a teapot full of water sitting atop a warming plate; a picture sequence showing the warming plate being turned is shown.	To determine if a student can understand the transformation of energy.
9. What do you know about the energy crisis?	-	To determine if a student understands the idea that energy reserves are finite.
10. What do you think about energy being stored?	-	To determine if a student knows energy can be stored.
11. What happens when the bow string is set free and why does the arrow start to move?	A student is provided with picture that shows a bow and arrow, the bow is drawn with an arrow in place.	To determine if a student knows the relationship between energy and force.

students' misconceptions about the work, power and energy and comparison of it with international literature can provide a contribution to solve the common problems in teaching energy. This study was conducted to find out seventh grade primary students' alternative conceptions about work, power and energy. This conceptual study is especially important from three points:

a) It can explain in depth about how energy concept is understood by Turkish students.
b) It can provide us to compare the obtained results with other countries.
c) It can provide science teachers a useful material to determine their students' misconceptions about work, power and energy.

Method

In this article, to find out sample seventh grade students' misconceptions about work, power and energy, interviews about instances and events method were used and students were interviewed in depth how long it took. Thus, the study adopts a qualitative mode. Literature explains that in determining misconceptions, not using tests in which students marks a question but taking students' ideas about an observable instance or event and examining their thoughts is much more effective (White & Gunstone, 1992). In this kinds of interviews, it is aimed to examine students' thoughts in mind in depth. Furthermore, to define concepts reasoning to their understandings, observable and related events of knowledge and misunderstandings' coming to place are aimed. In these interviews, students' understandings of the concepts were researched and their explanation abilities were also measured. The sample consists of six seventh grade primary school students who were selected from one school of Trabzon in Turkey. For selecting the sample, in the first phase, students in the classroom were separated in three groups by taking into consideration of their science teachers' views about their achievement levels in the science course as lower, intermediate and upper level. Then, two students –one male the other female- were selected randomly from each group was interviewed one by one and asked interview questions through observing some instances and by performing some events with them. Each interview section took almost one course time- 40 minutes- and students were said that this is not a quiz and the important thing is to explain clearly what they think. Required materials and tools all were prepared beforehand. Data obtained from each of student and recorded with a voice recorder and then analyzed in different cases. Common misconceptions related to work, power and energy were presented in Table 1 by its % and frequency values.

The participants were asked total of 11 questions. The process of interviews and activities and the target misconceptions of each questions were presented in detail in figure 1.

Findings

The qualitative data is presented for different cases. Each case includes a student's understanding level and/or misconceptions about energy. Those six case studies are followed by a Table which shows how much of those misconceptions is hold by students with their frequency and quantitative values in percentages.

A] Samet:

He is from the lower group. He related energy work to potential and kinetic energy concepts and explained that electrical energy is transformed to light energy. He gave battery and accumulator as examples of energy sources and explained power as "a work done in a unit time". Then, he explained that he is pushing the table but not moving it and he said that he does a pushing work [misconception: the idea of energy is spent thus work is done]. In the injector activity, he explained when he pushed the piston, air in the injector is constricted and air is having energy, and this let the piston turn back [misconception: energy is a kind of force]. He explained about the fourth question that because of the fact that both of them would spend energy as much as the box's weight, thus the amount of energy which is spent is the same.

He explained about the fifth question that he could see the energy in petroleum with electron microscope. He even put forward that this energy is in liquid form and have burning energy [misconception: energy is in a liquid form and flying character] and [misconception: energy is a kind of matter]. He explained about the sixth question that it has light energy. He explained about the seventh question that its energy finishes and it takes its energy from the bow in it. He thought about the teapot activity that heat energy are transformed to water and it does work. He gave a reason for this that water's boiling.

He explained about the energy crisis that energy is not produced in dams and energy ends. He explained about if or not energy could be stored in a battery and accumulator. He also said that energy cannot be stored as box by box and when it burns it can fly. He explained about the 12th activity that a bow applies a force to an object and the object had kinetic energy and started to move.

B] Ayfer:

She is from lower group. She explained that when she lifts something in a daily life, spends energy for example, when she puts a book into a shelf and, defined energy as "a force applied to an object", kinetic and potential energy as energy kinds and next talked about heat and solar energy [misconception: energy is a power]. She said that each person has a capacity of lifting a load, thus, she cannot lift everything, can do it as much as her energy. She also explained that if a child does not have a breakfast, no power he/she has and foods have power in them.

When she pushed a table as a reason for not moving it, she explained that it is too heavy and her power is not enough to achieve it. She also put forward that her power pushes less heavy objects but she does a pushing work [misconception: the idea of energy is spent thus work is done]. Related to injector activity, she explained that when piston turns back, air covered more place but she could not find a relation with work and energy. She taught when she pushed the piston and congested the air; her applied force is already energy [misconception: energy is a kind of force].

Related to fourth activity, she explained that both of them spent the same amount of energy.

She explained that if she uses an electron microscope she cannot see the energy in petroleum because it is liquid, however if it is solid, she could see small particles in it [misconception: energy is a kind of matter]. Related to closed electrical circuit, she has no idea about the kind of energy in a battery. Related to a toy car activity, she said that bow in it, wanted to turn its own position. Teapot activity- she said that heat energy is transformed to teapot thus that water gets warm, heat does a work and this leads water to boiling.

She taught about the energy crisis that energy sources end and water in dams provides electrical energy. She believes that energy could be stored in generators and accumulators. Related to pressured bow activity, she explained that pressured bow applies a force to an object and it takes its energy from the bow.

C] Yücel:

He is from intermediate group. He explained that energy is a source, which is existed in the nature; energy is required to do a work. He said that energy is being in the nature as a cycle, with no increase or no decrease, it is stable, also explained energy transformation as energy's being stable is in the nature. He continued that electrical energy is being produced from water, power is needed for energy and power means energy sources. Related to table activity, he said that his force is not enough to move it thus he could not do a work. He talked about the injector activity that when he pushed the piston, air could not come out, it is congested, when he set it free, because of gas is congested, piston came to back, he also said that he applied a force with his hand, spent energy and did a work [misconception: work is done because energy is spent].

When he and his father lift the same amount of load, he believed that the energy both spent is the same. He thought that he could see energy in the petroleum [misconception: energy is a kind of matter]. Related to circuit activity, he explained that a battery in the closed circuit has an electrical energy because when he turned on the lamb, electricity comes out. He talked about the toy car activity as that when he pulls the bow back energy is gathered in it, when he set it free, it emerged from the bow and the car starts to move, and about why the car stops he said that its energy ends. In the teapot activity, he said that heat energy is transformed to water and gave evaporation event as a clue to this. He also said that a kitchen tube transforms to heat energy however he did not have idea about a work is done or not. He explained about the energy crisis that energy's' decrease, energy sources decrease, much more production of energy. He believed that energy can be stored, if it can not be stored no work can do, work can be done if energy is stored, while he stores energy he gains power, and uses it later [misconception: power is a kind of energy source]. He talked about the row activity that energy is stored in the row and applied a force to the object.

D] Zümre:

She is from intermediate group. She explained that when she lifts a table she spends energy, when she does a work she spends energy, energy sources are existent. She believed that when people lift weight they gain both power and energy [misconception: when a load is lifted energy is gained]. When she pushes a table it does not move however she believed that she did a "force work" [misconception: work is done because energy is spent]. In the injector activity, when she pushed the piston, air is congested and air pressure pushed the piston back. She said that it pushed piston because of energy and while pushing it does work [misconception: energy is a force]. She explained that when she and her father lift the same amount of load, they spend different amount of energy. She said that she could see energy in the petroleum as small spherical objects [misconception: energy is a kind of matter]. She said that a battery in a closed electrical circuit has light energy. In the toy car activity, she said that how much she pulls the row the row could be congested; when she set it free it would open [misconception: energy is power]. In the teapot activity, she believed that heat transformation appeared, heat does the work and gave reasons of water's heating, boiling and evaporation as clues of it. Related to energy crisis, she said that energy is a little in the night. She also believed that energy cannot be stored but she could not give an explanation to this [misconception: energy cannot be stored]. In the row activity, she said that row is congested and when she sets it free, it opens and pushes the object in from of it.

E] Zühre:

From an upper group of student. She explained that electrical energy can be transformed to heat energy, while doing a work energy is gained, and also the energy is spent [misconception: energy is gained while doing work]. She said that energy comes from dams, however she did no idea about power concept. In the table activity, she said she applied a force and did a pushing work. In injector activity, she said that air in the injector started to move and pushed the piston, while pushing it, air applied a force to it and a physical work is done [misconception: work is done because energy is spent]. However, she could not explain a relation with energy.

When she and her father lift the same of load, she believed both spend the same energy, because lifting object is the same weight. She believed that she could see energy in the petroleum with electron microscope [misconception: energy is a kind of matter]. She thought a battery in the electrical circuit has an electrical energy. In the toy car activity, she said that row is pushing and turning the wheels and thus, the car first moves then stops. In the teapot activity, she believes that work is done but has no idea about it.

Related to energy crisis, she gave examples about energy's decrease and said that energy cannot be stored [misconception: energy cannot be stored]. In the row activity, opening row applies a force to an object in front of it.

F] Abidin:

He is from upper group. He said that while doing a work he spends energy, fuel energy transforms to heat energy and electrical energy. Coal-black, firewood and some underground sources are energy sources. He has no idea about force concept. He said that he spent energy to push the table thus did a work [misconception: work is done because energy is spent]. In the injector activity, he explained that when a piston was pushed, movement energy transformed to state energy and later it stops, injector transformed to movement energy and come to back. He also said that injector it self did a work.

He talked about that when he and his father lift the same amount of load; they do the same work and spend the same amount of energy. He thought that he couldn't se energy in the petroleum but he can see it if it is active but later changed his idea and said that he cannot see energy but he can see work done by energy. He said that a battery in the closed circuit has state energy and when he turns on the lamb, by spending movement energy, electricity in it started to move. In the toy car activity, he said that when the row is set, it has state energy and it transformed movement energy.

In the teapot activity, he said that heat transfers to water, work is here, and energy heats water and boils it and fire does the work. Related to energy crisis, he said that energy is itself not enough. He explained that energy is stored in a batter to boil water as static energy and later it is used. He explained about the row activity that the row is elastic and when it is set free, turns to its own position and applies a force to an object in front of it. It has state energy and when it is set free it transforms to movement energy, and energy is stored.

Frequency and % values of all misconceptions about work, power and energy that are determined from interviews about instances and events are presented in Table 1 below.

Table 1. Distribution of identified misconceptions about work, power, and energy

	f	%
Work is done because energy is spent	6	*100*
Energy is a kind of matter	5	*83*
Energy is a force	3	*50*
Energy is a power	2	*33*
Energy cannot be stored	2	*33*
Energy is in liquid form and has a "flying" character	1	*16*
Energy is gained when lifting a load	1	*16*
Energy is gained when doing work	1	*16*
Power is a kind of energy source	1	*16*

Result and Discussion

Energy subject has a common use in three disciplines of science as physics, chemistry and biology. In many science and physics textbooks is explained that energy is the capacity of doing work. Beynon (1994) stated that it sounds right because people often speak of a physically energetic person as someone who is capable of achieving something. However, he discusses in his study or book whatever that the word *capacity* may unwittingly suggest that energy has substance-like qualities. What about using it as an ability to do work? Hicks (1983) claimed that the definition of energy as the ability to do work should not be used even as an initial definition, even with remarks to its inadequacy, because it is so short and so memorable that students may retain it long after studying it. She proposed that any simple definition of energy is be voided. Trumper (1990) believes that energy as has been pointed out, it is not just the ability or capacity to do work. Thus, what is energy? How teachers should teach it for their students? Those all are always encountered-problems when studying with energy.

In the current article, interviews about instances and events related to work, power and energy concepts were conducted with the sample students including lower, intermediate and upper levels of seventh grade students according to their science achievement. The sample nearly all (five ones) and not concerned with student science academic achievement levels, conceives energy as a matter. The reasons are of this need to be carefully discussed. Before discussing the reasons, we think that this point is not taken into consideration enough in science textbooks, and science teachers also did not stress it in their teaching. However, we need extra data to support our claim. We believe that daily use of energy concepts is one of the basic reasons of this misconception. For example, we eats something and have breakfast so we full of energy, later we spend it and our energy ends. In addition, in the Turkish context, to say an energetic person or full of energy person is common. This –understanding energy as a material entity- is not a case for the just Turkish educational context; also many who hold this misconception about energy from different countries is common (Diakidoy, Kendeou & Ioannides, 2003). Idea of energy as a force is held about half of participants and rather than applying a force, applying an energy is frequently explained by the sample (question 11). In addition to this, mixing work done in daily life with scientifically work done (question 2) and the idea of work is done when energy is spent are the most other important misconceptions, which requires consideration. Here, we need too much focus on students' using energy spend similar to doing work is common. Because, students related to the activity of pushing a table believe that they apply a force, spend energy and even if the table does not move, they nevertheless do work. We think the units in the seventh grade Turkish science textbook about work, power and energy can be effective. This is "energy is work and work is energy". Here is the complexity. Teachers should stress here that when someone spends energy, he/she couldn't do a work in scientifically means. He/she spends energy and spent effort but if an object does not move he/she does not do a work.

In the content of this article, from interviews with seventh grade primary students, we can claim that they have not enough understandings about work, power and energy. This fact is much more critical if we consider that they taught this subject before a short time ago –a few week- we start to conduct interviews with them. This study's results also put forward the fact that students bring many concepts with them in to science classrooms without changing the daily use of forms of them and they did not take into consideration as an expected level of scientifically use. Here, we can explain that misconceptions are really resistant to change. This fact constrains students' understanding of energy in especially in the conceptual level.

Regarding this study we can say that science teachers need to know students' misconception about work, power and energy beforehand and develop and use convenient teaching strategies and activities toward those misconceptions. At this point, preparation of conceptual change texts, which are used much more in impeding students' misconceptions and develop a constructivist-based teaching program and implement it in schools, is believed to be effective. The preceding study's results support this idea (Çepni, San, Gökdere & Küçük, 2001; Çepni, Küçük & Bacanak, 2003).

The literature supports alternative approaches to teaching energy and in collaboration with their teacher, its surprising success in a class of low ability pupils are examined (Kirkwood & Carr, 1989). Trumper's (1990) paper presents a constructivist approach to the teaching of the energy concept, which assumes that learning involves a rational interaction between new conceptions and pupils' prior ideas. We should not ignore the fact that pupils' minds are not *tabula rasa.* They generally adhere to some very well defined alternative frameworks about energy, which play a very crucial role in learning. It is also important that children's early alternative concepts about energy appear to arise from a context which is inappropriate for school science, but which is valid and valuable in their everyday world. Many concepts in science, like energy, are used differently in everyday language. Often a student can listen to, or read a statement in science, and assimilate it by using the everyday interpretation of the word.

Now, it is important when we should teach about energy and how. Energy is an abstraction from the physicists' quantity work. Thus one can only begin to learn about energy when one understands work (Warren, 1986). Work is an abstraction from the quantities displacement and force. Thus work can only be taught when these concepts have been mastered. Force is an extremely difficult abstraction, which can only be taught on an axiomatic basis. It must be emphasized that forces cannot be felt or seen but can only be deduced mathematically from the results of experiments. The level of abstract reasoning required to understand the simplest facts about force is considerable and can only be acquired by previous study of other physicists' quantities, which are less conceptually difficult.

From these considerations it is apparent that energy can only be introduced after students have received prolonged preliminary training. It is no more possible to learn about energy without first learning the basic concepts force and work. Energy was invented for use in the theoretical study of phenomena, and it has acquired very great importance in every field of pure and applied science. It must be taught in such a way that students know how to *use* it.

The last thing is that one of the limitations of this work is not taking into consideration of the samples cognitive or formal operational levels. Thus, in later studies we plan to take this point into consideration and research the relation.

Implications for middle school physics teachers

Energy is something stored in fuel, its move from fuel can get useful jobs done through changes from one form to another which is universally conserved, never manufactured or destroyed. The generally accepted definition of energy is: the capacity or ability for doing work. However, the definitions are presented in the science textbooks and taught in the science classrooms students hold misconceptions about physics concepts, one of them is energy. It is a common belief that physics subjects are very difficult because of their abstract nature. Besides many misconceptions that students have are about physics subject. It is found out that many children hold those misconceptions in their early years and it is really difficult to solve this problem even with a highly structured training. It is a problematical area of that how children develop misconception about energy and how this can be changed with more scientifically accepted ones. Watts (1983) says in his article that valuing their own ideas, and building on them could acquire children's scientific conception of energy. This can be achieved by giving children a wide variety of experiences, activities and discussions about energy. We found in the current work that it is possible for children to use the vocabulary as incorrect, and the ideas about energy are full of misconceptions. Nevertheless, a good physics teacher who is teaching at both in the middle or high school levels should not ignore those concepts.

Here, an important question maybe comes about at what stage children's energy concepts are required to be correction. Beynon (1990) explains that, like old habits, misconceptions also become harder to remove as time goes on. He further explains that the use of aids like useless energy (Solomon, 1982) and energy carriers (Schmidt, 1982) will not help these only reinforce misconceptions. This means that science and middle school physics teachers should use the words related to energy in a correct manner. Kruger (1990) says that it 'is an elusive idea to pin down'. He further says that 'the word energy has acquired a wealth of meanings from social usage'. This is why there is a need for scientific clarity if there is to be any real progress in the teaching of energy.

Time of teaching energy has been discussed. For example, Beynon (1990) supports the view that energy's teaching in schools should be abandoned until children are more receptive to abstract ideas. Program makers should consider this. In a study conducted with twenty practicing primary teachers, Kruger (1990) concluded that the responses of the teachers to various questions to test their understanding of energy contained, in the main, personal, rather than scientific, conceptions of energy. Thus, we think a major problem, which restricts to teaching energy, is that many educators, themselves; do not understand the concept thoroughly although the is not enough data, we strongly believe that. Moving from here, we believe that student middle school physics teacher candidates should be prepared as taking into consideration of this fact. Beforehand, middle or high school physics teacher candidates should be informed about that middle school students may have some misconceptions about physics concepts and it is really important to be aware of this. Nevertheless, not only being aware of this is enough to struggle with this but also they need to know how to cope with students' alternative concepts about physics subjects. Middle school physics teachers, if available, know how to learn about students' alternative concepts and while beginning to teach a physics concept they should evaluate students' prior knowledge about it. If they do this, they can sequence learning and teaching activities in order to change or develop students' alternative concepts with scientifically accepted ones. In the current work, we tried to determine seventh grades students' alternative conceptions about work, power and energy, which are really difficult to understand especially for primary or middle school students. Thus, misconceptions about those concepts, which we found in the Turkish educational context, may be valid for physic classrooms of many physics teachers. But we believe that the activities used in the study may also be used for the other physics teachers, in determining their students' concepts about those concepts. Those should be used as classroom activities while teaching energy.

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SAAMEE: A model for academic success

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Alchemists of the Middle Ages were concerned with finding the so-called philosophers' stone. They desired to use the philosophers' stone – an elixir that they believed had the power to transmute base metals into gold – to generate wealth. Unfortunately for alchemists, the philosophers' stone does not exist. As with alchemy, there is no philosophers' stone in the area of education either. No matter how hard teachers try, not all students will learn everything expected of them. Nonetheless, this doesn't preclude educators helping students find ways to maximize academic success. SAAMEE is a hypothetical model that, if shared effectively with students, could lead to significant increases in academic success.

Educators are not concerned with transmuting base metals into gold – would that they had such a simple problem! Gone are the days when the role of schools was merely to sort and rank students on the basis of test scores. Today, all students are expected to achieve, and all are expected to exhibit a minimum degree of competency so that no child will be left behind (Stiggins, 2005). In some cases, this appears to be a very elusive goal. While there is no equivalent to the philosophers' stone in education, there are several things that educational researchers have shown to be effective, in general, that can help students achieve the goal of academic success. Among them are the identification, confrontation and resolution of preconceptions, the use of organizational patterns, and promotion of metacognition and student self-regulation (NRC, 1999, 2005). The proposed model takes advantage of two of these principles.

As a physics teacher educator, as well as a former physics and astronomy teacher, I've often wondered about how best to get my students to achieve the aims, goals, and objectives of my instruction. Like other teachers, I've also wondered why some students succeed while other students fail. Over the years many students – both successful and not so successful – have asked me to help them maximize their academic performance. I've come to realize that there is no "science" of teaching and no "science" of learning; that is, there is no set of rules that I as teacher and students as learners can follow to guarantee across-the-board academic success. On the contrary, I have come to realize that teaching and learning are art forms for which there are few hard and fast rules. Still, I have struggled to make sense of what I have seen take place in my classrooms since I started college teaching in 1977. I have come to a conclusion based on nearly three decades of reflection that student success in science (and probably all other subject matter areas) is strongly dependent upon five more or less independent factors. I have organized these factors into a model called *SAAMEE* to help students realize academic success. As I tell students who seek assistance to improve academic performance, "If you want to be as successful as the best students in my course, you must use the "saamee" approach that more successful students are known to use." The recommendations stemming from *SAAMEE* are clearly in line with what common sense and research-base best practice appear to suggest. If anecdotal reports are to be believed, experiences with *SAAMEE* have shown it be helpful. It is my hope that readers will share *SAAMEE* with their students in an effort to increase academic success.

SAAMEE: A Hypothetical Model

SAAMEE states that a student's academic success *(S)* is a function of innate ability *(A_i)*, learned ability *(A_l)*, motivation *(M)*, effort *(E_1)*, and environment *(E_2)*. The relationship between these factors is given by the following expression:

$$S = A_i A_l M E_1 E_2$$

Student academic success is critically dependent upon each of the five independent variables contained in the equation. The fact that *SAAMEE* is a series of multiplicative terms should not be lost on the reader or the students being introduced to the model. Because success is a product of terms, a low "score" on any one of the terms will result in a low overall score for academic success no matter high the scores in other areas. Scores range from 0 to 1, where a lesser amount of a characteristic is represented by a lower number and visa versa. For instance, if A_i=1, A_l=1, M = 1, E_1=0, and E_2=1, there will be zero success (1x1x1x0x1=0). The model appears to explain such things as the varied degrees of student success associated with learning disorders, the success and failure of gifted and not so gifted students, changes in student performance over time, and the high impact of a single inadequacy. The model is not intended as a mathematical equation used to predict actual success; rather, it is intended merely to suggest the nature of the relationship between the dependent and independent variables.

Under *SAAMEE*, a student's academic success, *S*, in simplest terms is related to course assessment or evaluation where a "1" would represent the highest possible score or grade. Innate ability, A_i, appears to be most closely associated with what some call I.Q. Students who have a gift for learning are said to have high innate ability. Learned ability, A_l, can be related to such knowledge as study and test-taking skills, as well as other factors in the areas of metacognition and self-regulation. Motivation, *M*, is a drive internal to the student; it must not be confused with external coercion. Effort, E_1, is closely associated with such things as quality time on task. Environment, E_2, is closely associated with factors external to the student such as living and study conditions, and even human relationships. *SAAMEE* deals with learning from a student perspective. There is a similar model that deals with learning from the teacher perspective.

Rescorla and Wagner (1972) enunciated a model for animal learning that is represented by a similar simple equation. The Rescorla-Wagner model explains a variety of psychological phenomena – acquisition, overshadowing, blocking, extinction, conditioned inhibition, and the overexpectation effect. The mathematical form of the Rescorla-Wagner model is presented as follows:

$$\Delta V = \alpha\beta(\lambda - V_{sum})$$

That is, the change in learning, ΔV, is equal to the motivation of the subject to learn (α) times the saliency of the stimulus (β) times the difference between what has already been learned (V_{sum}) and what constitutes peak learning (λ).

Recall that Behaviorists define change in learning as an observable difference in behavior. Note well that motivation to Behaviorists is an entirely physical phenomenon and relates to basic drives such as food, sex, and self-preservation. Thirst, hunger, danger, or a potential mate for instance, can be powerful motivators. Second, the greatest amount of learning occurs when the salience of the stimulus is high. Using reinforcement through unexpected events during training can serve to increase the salience of a phenomenon. Under the Rescorla-Wagner model the greatest amount of animal learning will be achieved when the subject's innate needs are addressed. Third, the maximum change in behavior will occur when the subject is learning something entirely new. If a subject has little to learn, then there will be very little learning despite high degrees of motivation and saliency. Whether or not this model for animal learning derived from the study of pigeons can be applied to humans is uncertain. Nonetheless, it provides educators with some interesting and potentially useful insights that cannot be entirely divorced from *SAAMEE*.

While the Rescorla-Wagner model has been empirically derived, *SAAMEE* is merely conjectural. Its factors are hard to define with precision, and even more difficult to measure. There is no claim to completeness, or that the model can account for all observed variances. Nevertheless, *SAAMEE* is based on the author's accumulated teaching experience, and appears to provide a fruitful approach for improving success in the area of student learning. It can also provide an instructor with a valuable tool for helping students gain a greater understanding of what they can do to achieve academic success. It can be a key that unlocks the door to student academic success, and even enhance teaching performance.

Behavioral and Environmental Factors of Academic Success

Assuming *SAAMEE* to be at least approximately correct, educators who wish to increase student learning can work to maximize each of the controllable factors upon which a student's academic success depends. This includes such things as speaking explicitly with students about *SAAMEE*, teaching appropirate learning and study practices, and modifying teaching practices. Consider an explanation of each of the model's factors along with implications for teaching and learning:

Innate Ability, A_i: Unfortunately, there is little that a teacher or student can do about innate ability; nonetheless, *SAAMEE* could be a key to unlocking hidden abilities. Some students are inherently gifted while others are not. Not every gifted student tests well, and not every student who appears at first to be a prodigy actually is one. Despite limitations imposed by innate ability, learned ability can often go a long way toward compensating for natural limitations.

Learned ability, A_l: Teachers can help students understand the difference between deep and surface learning styles, and use teaching strategies that promote the latter over the former. Some ways that teachers can encourage deep learning include using open-ended assessment tools, stating high expectations, and teaching for depth of understanding rather than breadth of coverage. Open-ended assignments such as essay questions, projects, or alternative assessments make students organize and process information. Setting high expectations means that students are always challenged and thinking. They cannot be passive and still "get by." Helping students develop improved listening and study skills is also a way of increasing students' abilities to learn with understanding – learning that lasts. Such practices might include any or all of the following: using active listening; conducting reciprocal reading and teaching; predicting outcomes on various tasks; comparing performance against a set of performance standards or stated objectives; completing practice tests and noting failures to understand; and conducting an analysis of one's study practices and explain what was done and why. Getting students to understand the processes of metacognition with its periodic self-assessments and self-regulation can also be powerful ways to raise learned ability.

Motivation, M: Students need to be motivated (as opposed to coerced) in order to effectively expend the time and effort needed to achieve academic success. Quay & Quaglia (2001) suggested a number of psychologically sound strategies that teachers can use to help build motivation and a sense of empowerment in students. These eight ideas are the following: provide a sense of belonging, familiarize students with heroes, provide students with a sense of achievement, make learning fun and exciting, use students' natural curiosity and creativity, provide a spirit of adventure, encourage leadership and responsibly, and build confidence in taking action.

Effort, E_1: Effort, while strongly associated with motivation, must not be confused with it. Motivation reveals itself in effort. Even though students might have the best learning abilities, the best learning situations, and even a high degree of motivation, they still will not be successful if they fail to exert the effort required for success. For instance, a student might have great personal motivation to learn how the play an electric guitar well – prestige, fame, and fortune – but unless that person actually expends the necessary time for practice, he or she cannot expect to learn to play the electric guitar well no matter how willing. Sometimes effort is not as much of a problem as is proper time management. Students who start the day with a list of prioritized tasks that need to be accomplished are often much more successful in getting things done well and on time than those who fail to recognize what needs to be done and when. In addition, effort must be sustained; students must spend an appropriate amount of time exerting the required effort to achieve academic success.

Environment, E_2: Environment plays an important role in student learning. Many students are immersed in "toxic" environments that are not always of their own choosing. Toxic environments might include the home where caregivers and/or siblings and/or friends can be a detriment to learning, study areas filled with any of a great variety of annoying and appealing distractions, or unengaging classroom conditions. Some distractions *are* of a student's own choosing such as watching TV, listening to loud music, or talking with friends on the phone while attempting to complete schoolwork that requires undivided attention.

Deploying *SAAMEE*

The model suggested by the author is nothing more than a way of organizing conventional information in order to make it more accessible and meaningful for students. The recommendations with regard to A_i, A_l, M, E_1, and E_2 are clearly in line with what common sense, craft wisdom, and research-base best practice appear to suggest. If teachers want to help students be more successful in class, then they might want to try promoting *SAAMEE* as a means for achieving that success. Readers are strongly encouraged to speak explicitly with their students about the model, and then provide them with and explain the practical implications of this model using a handout. Such a handout can be found following the references section of this article. This handout, which formerly was distributed by the author to students seeking academic help, has become part of the syllabus in each of his courses. The handout was originally patterned after work by Solomon and Nellen (1996), but has been extensively revised and extended. While *SAAMEE* is not the philosophers' stone of modern educational practice, it should go a long way toward helping students obtain what seems to be for some a very elusive goal.

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SAAMEE: A Model for Academic Success

Physics Teacher Education Program

SAAMEE is a hypothetical relationship that states that a student's academic success (S) is a function of innate ability (A_i), learned ability (A_l), motivation (M), effort (E_1), and environment (E_2). The proposed relationship between these factors is given in the following expression:

$$\boldsymbol{S = A_i A_l M E_1 E_2}$$

This relationship has not been tested empirically, but long experience suggests that these factors appear to be good predictors of academic success. Because success is a product of terms ranging from 0 (minimum) to 1 (maximum), a low "score" on any one of the terms will result in a low overall score for academic success no matter high the scores in other areas.

The following traits, behaviors, and conditions, while not mutually exclusive, tend to distinguish the typical "A" student from the typical "C" student in course work. The descriptors in the left column are characteristic of superior academic performance; they are not necessarily sufficient conditions that will guarantee success. Nonetheless, if students intend to earn a top grade, it would be best if the traits that describe them come from the left rather than the right column in the table below

A_i: Innate Ability

"A" or superior students…have special aptitude in a wide variety of areas. These skills might include creativity and organizational skills, or special insights. They are good problem solvers, and can see relationships where others often do not. They are confident of their innate ability; they have an inner strength that allows them to strive for success because they know that success is well within their grasp.	**"C" or average students…**vary greatly in natural aptitude. Some might be quite talented in specific areas, but their success is limited by a lack of having a broad range of pertinent abilities. They question their ability as learners; they have lost confidence due to prior failings. This deprives them of the emotional energy that they need. Sometimes it seems easier to just not try than to lose face by trying and then failing.

A_l: Learned Ability

"A" or superior students…are always prepared for class, and are rarely if ever surprised by due dates or exams. They are always well prepared for tests, and complete their assignments on time. They always respond when called on in class discussions, and actively contribute even when not called upon. Their attention to detail sometimes results in catching text or teacher errors. Successful students are critical thinkers. Critical thinking is characterized by a set of attitudes more than anything else: trying to be well informed, staying focused, seeking precision, proceeding in an orderly manner. They show evidence of "deep learning" rather than "surface learning." They carefully read textbooks, seeking to understand each passage and paragraph; they can readily state with understanding what they have learned. They are active listeners, and good communicators. They are very concerned about learning with understanding. More successful students learn concepts with understanding rather than memorize details so that they are better able to connect past learning with present material. They can readily apply knowledge to a variety of new situations. Their written papers show a high degree of professionalism including empirical research findings. They exhibit test-taking skills such as an ability to budget their time and to deal with test anxiety. They put considerable effort into class projects that show a strong, consistent desire to exhibit the best possible performance.	**"C" or average students…**are not always prepared for class, and are often surprised by due dates or exams. They might not have fully completed an assignment, have completed it in a careless manner, or hand in their assignments late. They rarely contribute to class discussions unless called upon. When they do say something during class discussions, their answers often indicate a cursory understanding rather than a mastery of the material. Less successful students are rarely critical thinkers. They tend to "go with the flow" and follow the path of least resistance. They show evidence of "surface learning." They tend not to question and accept things on the basis of authority, often without understanding. They read textbooks without understanding and rarely can indicate what they have learned through reading. They are poor listeners – often listening without comprehension – and are poor communicators. They are more concerned with learning enough to pass a test than with understanding. Less successful students memorize details rather than learn concepts. Because they usually cram for tests, they perform relatively better on short quizzes than on more comprehensive tests such as the final exam. Written papers show lack of insight and are filled mostly with random opinion rather than detailed research findings. Less successful students obtain mediocre or inconsistent scores. They often do not budget their time well on exams and might not deal well with test anxiety.

M: Motivation

"A" or superior students…show strong initiative. Their desire to excel makes them do more work than is required just to get by. They are dedicated to their work and like the work that they do. They are visibly interested during class and display interest in the subject matter active through active participation. They often volunteer thoughtful comments and ask interesting questions. They make effective and regular use of the instructor's office hours; they benefit from insights provided by the course instructor. They take all course assignments seriously, and work diligently to achieve their goals. They are confident in their abilities, and are unlikely to give up at the first sign of resistance. They depend on themselves for answers to their questions.	**"C" or average students…**seldom show much personal initiative. They are more responsive to coercion. They never do more than required and sometimes do less. They often exhibit a low level of personal dedication. They participate in class without enthusiasm, with indifference, or even boredom. They show little, if any, interest in the subject matter. Their comments in class, when made, show lack of interest generally. They rarely if ever take advantage of the instructor's office hours. They often lack self-confidence, believe they cannot do the work correctly, and give up at the first sign of difficulties. They often expect to glean information from the solutions of problems provided by others.

E_1: Effort

"A" or superior students…maintain a regular study and homework schedule. They regularly prepare for each class no matter what the assignment. They average one to three hours of study for every hour in class; they work diligently and regularly on their course projects. They do not procrastinate. The attend class. Their commitment to the class resembles that of their instructor. Missing even a single class is not an option without a major reason. They think carefully about what they know and don't know. They use such practices as reflective reading and teaching, take inventory of their own knowledge, administer self-tests, reflect on and learn from failings. They have good conceptual understanding, and seek to comprehend the "big picture." More successful students see learning as a sustained effort and all learning activities as important to a comprehensive understanding.	**"C" or average students…**study or do homework only under pressure. When no assignment is due, they do not review or study ahead. They average no more than a few minutes of study for every hour in class. They cram for exams, and procrastinate on regular course assignments. They periodically miss class and/or are late. They place other priorities such as a job, ahead of class They are generally unaware of what they know, don't know, and need to know. They do not reflect on their intellectual state of affairs and fail to take an intellectual inventory. They tend not to seek or develop a broad conceptual understand-ing. They tend to focus on a myriad of details, and rarely see the "big picture." Less successful students fail to see learning as a sustained effort, and study only from time to time – usually under the threat of an exam. They tend to value only that work which contributes significantly to course grade.

E_2: Environment

"A" or superior students…are careful about the time and places they choose to study. Study spaces are generally conducive to learning. Study spaces are rarely filled with few if any distractions. More successful students tend to sit close to the front in class to avoid distractions. More successful students regulate and limit their relationships so that they don't become a major disruptive influence on their lives. They often have jobs, but rarely ever exceed more than 10 hours per week so as not to allow a job to interfere with their education.	**"C" or average students…**are careless about their learning environments, and often study under unsuitable conditions. Study spaces are often filled with annoying and/or appealing distractions. Less successful students typically sit in the back of class where their attention can be distracted by any of a number of people or events taking place between them and the instructor. Less successful students have personal problems that limit their success. They sometimes work many hours that often interferes in the educational process.

JPTEO