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The Epistemology and Pedagogy of Education in High School Physics and Physical Science

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The Epistemology and Pedagogy of Education in High School Physics and Physical Science

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Definitions

Conception – a constructed mental framework that can be either correct or not

Constructivism – an educational philosophy centered around the idea that students actively construct all knowledge they possess

Inquiry – an education concept where students through their own interest, direction, and thought processes use observation and experimentation to actively learn science

Inservice Teacher – a practicing teacher in a primary or secondary school system

Misconception – a self-created scientific belief divergent from those generally accepted by the scientific community

Preservice Teacher – a college student in an education program with the specific goal of being a certified, practicing teacher in the future

Transmission – the traditional education model where the teacher lectures to the students who passively absorb the information

Introduction

When asked what she thought of physics in general, a ninth grade student responded that she found physics boring and meaningless. “I don’t like being forced to memorize that something that falls down in a straight line has to be represented by a crooked line rising to the right” (Nachtigall, 1990, p.2).

This young learner is not alone in her feelings toward physics and physical science. These courses are normally taken by twelfth graders and ninth graders respectively in America, but are generally disliked by most Americans. To most people, the physical sciences are perceived as an “inert body of information to be memorized” (McDermott, Schaffer, and Constantinou, 2000).

Laypeople and high school students are not the only ones frustrated with physics and physical science. Over the past thirty years, as physicists and science education specialists have joined in, concern for the quality of physics education has steadily increased (McDermott & DeWater, 2000; Mestre, 1991). Concern has mounted to the point where some are claiming a “general crisis in physics education” (Nachtigall, 1990, p. 1). Many researchers cite inadequate teacher preparation as the root of the problem (Stein, 2001; Wilson, 1991; Nachtigall, 1990). Much research has been and is currently being conducted into the value and effectiveness of science preparatory programs (Adams & Krockover, 1997; Tibell, 2000).

Recognizing that there is a general discontent with the current status of physics and physical science education, it becomes important to investigate the ways that physics and physical science are learned and the ways that they are taught. This paper attempts examine the roles of learning and teaching in physics and physical science for students and their teachers. The ways physics and physical science are best learned often do not match up with the ways they are most commonly taught on the secondary level (Trumper, 2001; Mestre, 1991).

Misconceptions

Students are bombarded daily with new information wherever they go. Whether they are in the classroom, on the street, or at home in front of the television, students cannot help but have ideas and concepts thrown at them. Students must actively construct a personal understanding of this information in order to relate it to the rest of their world as they understand it (Trumper & Gorsky, 1996). As new information is received, students have to construct and deconstruct their current understanding so as to accommodate the new information (Gonzalez-Espada, 2003). Whether the information is scientific, pseudoscientific, or not particularly scientific at all, students will somehow choose to respond and attempt to make sense of the situations by applying them to their existing schemas. This construction of understanding is easily compared to Piaget's assimilation and accommodation concepts and is often quite creative and seemingly logical. Without proper scientific guidance, the frameworks constructed by student minds to account for scientific concepts often diverge from those commonly agreed upon by the scientific community (Gonzalez-Espada, 2003).

A list of commonly cited incorrect scientific concepts, created by the college students of Wilson J. Gonzalez-Espada (2003), at Arkansas Tech University, and gathered by means of a survey, includes:

- Seasons are created by the Earth's changing distance from the Sun.

- Meteors are falling stars.
- God and angels cause thunder and lightning.
- Batteries have “electricity” inside.
- The phases of the Moon are caused by the shadow of the Earth on the Moon.
- The pupil of the eye is a black object or spot on the surface of the eye.
- All metals are attracted to a magnet.
- All stars are the same size (or have the same brightness).
- Continents do not move.
- The Sun will never burn out.

(p. 37)

Similar lists can be found in many sources (Beaty, 2001; Olenick, 2001; Crockett, 2004) and can be quite informative into the thinking process of students.

These mental frameworks created with good intentions are often called preconceptions or misconceptions, the earlier being all self-created beliefs of students and the later being those beliefs that are generally accepted to be incorrect (Eryilmaz, 2002). Other names for these include naïve conceptions, naïve theories, alternative frameworks, alternative conceptions (Gonzalez-Espada, 2003), children’s scientific intuitions, common sense concepts, and spontaneous knowledge (Eryilmaz, 2002). Researchers cannot seem to agree on a name for these, but the biggest concern lies in their existence and the challenge of correcting them. The tendency for students to tenaciously hold on to misconceptions is especially worrisome (Bisard, Aron, Francek, & Nelson, 1994; Mestre, 1991; Harrison, Grayson, & Treagust, 1999). Misconceptions have been an area of much research in science education research. Studies concerning scientific misconceptions are well documented (Harrison *et al.*, 1999) and span back to the 1940’s (Blosser, 1987).

Research shows that students consistently embrace their misconceptions, even when exposed to observations and insights that seemingly conflict with their misconceptions (Mestre, 1991). Mestre accounts for this fight to maintain misconceptions by stating that students "either view events through the myopic eye of the naïve theory or make inconsequential modifications to their theories in ways that fail to resolve the contradictions" (1991, p. 57). Mestre's explanation parallels the assimilation and conceptual capture ideas of Harrison, Grayson, & Treagust in which students "simply capture or add new information to their previous conceptions" (1999, p. 56). Misconceptions, especially those grounded in everyday experience, seem especially resistant to change (Harrison *et al.*, 1999). Because of this, unlearning misconceptions can be exceptionally difficult, especially when the misconceptions "make sense" to the students. As students desperately cling to their misconceptions, the difficult task of unlearning these instead must fall on the teacher.

Studies have shown that physics and physical science misconceptions are not necessarily specific to any certain type of people. Eryilmaz found that physics misconceptions "show consistency across diverse samples of average students, honors students, and even physics teachers" (2002, p. 1003). This means that most people tend to have similar misconceptions, which may never be challenged, and if they are they may never be changed.

Adults and children alike hold similar misconceptions. Implied within the fact that adults often hold misconceptions is that science teachers can and do hold misconceptions as well. This realization is not incorrect. The misconceptions and the implications therein of preservice and inservice physical science and physics teachers are especially interesting topics. The misconceptions of these teachers have been studied in great detail for a variety of physical sciences topics.

A 2000 study by Trumper and Gorsky examined conceptions concerning force held by physics students in a preservice high school teaching program. It showed that physics majors, even into their fourth year of college, hold misconceptions worth noting and correcting (Trumper & Gorsky, 1996). For example, the preservice teachers studied held strong misconceptions concerning, and therefore did especially poorly when dealing with, forces in dynamic situations and when balancing forces in all situations.

A 2002 study examined college students, including preservice teachers, as well as inservice physical science teachers' understandings of heat and temperature (Jasien & Oberem, 2002). The college students were divided into groups according to how many physical science classes they had previously taken. The preservice teachers were separated from these groups to form similar groups of their own. There was also a group that separated out students in their second semester of organic chemistry. The inservice teachers formed their own group, but it should be noted that they self-selected to attend a summer enrichment physics course during which they were tested, and so, their results are not indicative of all inservice teachers. All of the participants took a test about heat and temperatures, and their scores were compared according to these groupings. The inservice teachers did the best of all the groups, with 43% of their population getting all of the questions correct, while their nearest competitors, the students who had taken four-or-more semesters of physical science, had only 22%. The preservice teachers scored the lowest in all the categories compared to their non-education college student counterparts, but only the preservice teachers who had taken only 1 semester of physical science did significantly worse than the non-education college students with the same amount of physical science coursework. The researchers note that the conceptions of the

> science students and pre- and in-service teachers examined in this study [were] lacking in the areas of thermal equilibrium, specific heat, and heat capacity. Even among practicing physical science teachers at the middle- and high-school level, the working knowledge in this topic [was] less than would be hoped for. (Jasien & Oberem, 2002, p. 893)

Despite the fact that the researchers proved that there appears to be no correlation between the number of physical science courses taken and performance on tests related to thermal equilibrium, the researchers were genuinely not satisfied with the performance of any of their participants.

One study of common physical science and earth science misconceptions has proven to be quite interesting and citation worthy (Trumper, 2001; Trundle, Atwood, & Christopher, 2002). Bisard, Aron, Francek, & Nelson studied the misconceptions of a wide range of children and college students in their 1994 study. The sample included 180 middle school students, 157 high school students, 236 college freshmen and sophomores, 56 college juniors and seniors in upper-division science courses, 52 science majors in teaching methods classes, and 27 general-ed. majors in an elementary science methods class. Each member of this diverse group received the same test concerning seasons, temperature, moon phases, states of matter, light, and other commonly held misconceptions. As the span of the sample was large and diverse, it certainly led to interesting results. (See Figure 1.) As would be expected, older students generally did better than younger students, with the students in upper-division science classes doing the best with a score of 55.3% correct. The preservice teachers did not however do as well as their upper-division counterparts. The science education majors scored 51.4% correct, while the general education majors did significantly worse with only 37.3% correct. The researchers note that this is “approximately equivalent” (p. 40) to the score of the middle school students (34.6%) and go on to comment:

> This suggests that future general elementary teachers seem to have about as many misconceptions concerning the topics covered in this survey as do typical middle school students. . . . [The] tendency for middle schoolers to score similarly on this survey to future general elementary teachers is alarming.
> (Bisard *et al.*, 1994, p. 40)

Multiple studies have involved preservice teacher understanding of basic astronomy concepts. One study by Trumper (2001) of general astronomy concepts got a correct response rate of 38.4% correct of the 433 preservice high school teachers tested. This test was modeled after the Bisard *et al.* test described above, but with only the astronomy components. Comparing these scores to the Bisard *et al.* scores, these pre-service teachers did only a little better than the poorly performing pre-service elementary teachers and a little worse than the high school students.

Other astronomy studies specifically study misconceptions about moon phases. Moon phases are one of the most studied misconceptions, perhaps because moon phases are a targeted concept in the National Science Education Standards (National Research Council, 1996) clearly expected to be studied in grades K-8. They also might be studied often because their common misconceptions are easily distinguished from the scientifically correct conception. Misconceptions range from clouds blocking the light of the Moon to the Earth’s tilt to the Earth’s rotation on its axis, but the most common misconception is that moon phases are caused by the earth’s shadow being cast on the Moon (Trundle, Atwood, & Christopher, 2002). All of the above vary greatly from the generally accepted concept that as the Moon orbits earth, half is always illuminated by the Sun, but the relative position of the Sun, Moon, and Earth determines what part of that half we can see. Studies have found that no groups do particularly well at describing moon phases, but of most interest and concern are the science teachers who don't do well. Before the sample was ever given specific moon phase instruction, Callison and Wright (1993) found that of 76 elementary pre-service teachers, only 6.6% held a scientific concept of moon phases. A similar study found 18% understanding, while Trundle *et al.* (2002) had only 3.2 % of their preservice teachers answer scientifically before proper instruction . In summarizing all previous studies of preservice teacher misconceptions of moon phases, Trundle *et al.* had this to say:

> The results of these studies indicate that most pre-service teachers, like the students they are preparing to teach, do not understand the cause of moon phases.
>
> (p. 634)

The general conclusion from the above studies is that preservice and inservice science teachers at all levels lack a solid understanding of the concepts and tenaciously hold onto their science misconceptions. Herein lies a grave problem; the teachers are themselves holding misconceptions concerning topics that they are expected to teach to their students. The above can be inferred from the previously mentioned studies, but this topic deserves proper discussion. Trundle *et al.*, concerning their study and others reviewed in the introduction of their study, address this topic directly, saying:

> Because educators are charged with developing a scientifically literate society, a potentially serious problem is presented by preservice and inservice teachers who themselves hold alternative conceptions about concepts included in the textbooks they use or that are targeted by the national science education standards…. The potential for negative effects is clearly there.
>
> (2002, p.634)

Blosser (1987), in her research on science misconceptions, states "If teachers do not understand elementary physical science concepts, how can they teach their students"

(¶12)? To which Berg and Brouwer extend: “It is likely that some of those alternative conceptions have been passed on to students, as they were related to phenomena commonly discussed during a high school physics class” (1991). Bisard *et al.*, who led the study where the general education teachers did incredibly poorly, are especially bothered by what they call the “misconception cycle” (1994 p.42). As teachers either teach their students the misconceptions they personally hold or at least affirm the misconceptions that the students already hold, an endless circle of misconceptions starts. This “misconception cycle” has the potential to persist, unless colleges and teacher preparation programs appropriately address misconceptions to preservice and inservice teachers of science.

Addressing Misconceptions

It is easy to say that science teachers must overcome the misconceptions that they have in order to be properly trained in the science content that they teach, but overcoming misconceptions is quite an undertaking. If misconceptions are not adequately addressed specifically, they are likely to persist. “Because misconceptions are so deeply ingrained, . . . merely giving the correct explanations in class is inadequate” (Bisard *et al.*, 1994). If they are only mentioned or slightly addressed, the subject is likely to listen to the new information but resort back to the old misconception in the long run. Current ideas for correcting misconceptions apply equally to both teachers and students. Therefore, teachers should learn to correct their own misconceptions just as they should help their students address their misconceptions. Considering the trend of teachers to teach as they were taught, properly addressing the misconceptions of teachers should adequately serve to help stop the "misconception cycle."

Conceptual change is a fairly popular model for dealing with misconceptions (Alparslan, Tekkaya, & Geban, 2003). The established conditions for conceptual change are attributed to a paper by Posner, Strike, Hewson, and Gertzog concerning the accommodation of scientific conceptions in 1982 (Eryilmaz, 2002; Harrison *et al.*, 1999). This method calls for the teacher to help the student break the misconception himself/herself (Posner, Strike, Hewson, and Gertzog, 1982). Conceptual change calls for dissatisfaction, intelligibility, plausibility, and fruitfulness in the following manner:

a) There must be some level of dissatisfaction developed for the old conception that cannot be remedied without radical changes in the conception.
b) The new conception must be intelligible and make sense to the student.
c) The new conception must appear plausible, in that it should be capable of solving problems that the old conception could not and it should cohesively fit other conceptions and previous knowledge.
d) Lastly, the new conception should be fruitful, opening new doors for further study and growth.

Nachtigall and Brouwer (as cited in Eryilmaz, 2002) provide a variation of conceptual change designed to give students the "cognitive conflict necessary to help them assimilate [new] conceptions into their everyday life" (p.1003). Their method calls for the teacher to:

a) help the students become aware of their misconceptions.
b) allow the students to define their misconceptions thoroughly and test them.
c) confront the students with situations where the misconceptions can not adequately be used to explain or solve
d) let the students realize this conflict

e) help the student accommodate new ideas and conceptions
f) apply the new knowledge to familiar and new situations to validate the power of the new conception over the old one.
g) give the students a feeling of progress and growth
h) test student understanding conceptually and quantitatively

(Nachtigal and Brouwer, 2002)

Eryilmaz used a variation of the above in a study of 396 high-school physics students. The aim of the study was to see if conceptual change discussions, like the Nachtigal and Brouwer model, and another concept called conceptual assignments, which were homework assignments specifically involving physical phenomena from real life instead of raw quantitative calculations, served to reduce misconceptions dealing with force and motion. All of the students participated in regular physics classes and were then divided into groups that did conceptual change discussions, conceptual assignments, both, or neither. The students took tests to measure their pre-instruction misconceptions, participated in the their assigned protocol for eight weeks, and were then tested for their misconceptions again. The study concluded that conceptual change discussion was the most effective means of reducing misconceptions and improving physics achievement. There was not, however, much evidence that the conceptual assignments or the combined protocol were particularly effective or in-effective in either regard. Despite their success, the teachers of the conceptual change discussions did report added difficulty in performing this protocol.

Bisard *et al.* (1994) offer another variation on Posner *et al.*'s conceptual change. Their method is rooted in the exposure of the misconception, calling for the teacher to specifically identify to the students that the conception of the students are misconceptions. After this, the students are directly offered the correct scientific concept in hopes of creating a “state of cognitive dissonance” (p.42). Class discussion furthers this dissonance, forcing the students to relate and evaluate the conceptions, with the intent of constructing “logical, coherent, and, most important, realistic knowledge of science” (p.42). It should be noted that this option differs greatly from the Nachtigall and Brouwer variation, because it does not allow for much, if any, personal discovery or experimentation. Though this option seems logical and plausible but as a specific option of its own it does not appear to have been tested.

Jose Mestre created his own method for helping students overcome misconceptions (1991). Although he admits that there is no tried-and-true method for such, he goes on to say that some approaches based on constructivism have shown to be quite effective. His method, based on these and sounding fairly similar to the Nachtigall and Brouwer method mentioned above, also claims to be constructivist, meaning that it allows the students to construct their own knowledge. He first states that students will accept a new conception over a misconception only if they fully understand the new conception, it is believable and compatible with other conceptions, and it is useful for interpreting and explaining other situations. Mestre’s method consists of the teacher:

a) helping the students probe for the misconception
b) asking questions to clarify the beliefs of the students
c) suggesting events that contradict the beliefs of the students
d) encouraging debate and discussion to further ideas
e) guiding the students toward constructing scientific conceptions either through synthesis or experimentation.

(Mestre, 1991)

In 2002, Trundle *et al.* decided to study a method of correcting misconceptions based on Physics by Inquiry (McDermott, 1996), an established progressive physics textbook. They state that their study used "an inquiry sequence of instructional activities and strategies" (Trundle *et al.*, 2002, p. 636). They used this method to counter misconceptions of moon phases in preservice teachers. The students were interviewed at the beginning of the study to determine their misconceptions, but after that their misconceptions were not discussed or mentioned. This is where this method varies from the others mentioned. Instead, the students did research that slowly put them at odds with their misconceptions. As the data came in, the students tried to justify their results by constructing new conceptual models. The misconceptions were thus naturally confronted by the students' desire to make sense of their observations. Much later in the semester terminology was added for greater understanding and the class completed exercises and tests to verify their new understanding. This study found that at the end of the course 68.3% of the students had full scientific conceptions of moon phases. It should be noted that their measure for determining scientific conception was consisted of an interview where the student explained the conception three-dimensionally using spheres and that this measure was quite stringent. As low as a success rate of 68.3% sounds, it is still significantly greater than all the other studies to correct moon phase misconceptions mentioned in Trundle *et al.*'s study.

Key to all the methods of correcting misconceptions described above is the concept that students must somehow be engaged with the thought that their initial conception was indeed incorrect. Teachers must understand that the previous knowledge of their students plays a major role in how they interpret and accommodate new information and must be adequately addressed and belabored if change is to occur. Teachers should examine and attempt to correct the misconceptions of their students, but this can go too far. Mestre makes a special note that we should not "turn science instruction into a witch-hunt for students' needs" (1991, p.57). This is an important concept, because misconceptions can easily steal time from laboratory investigation, problem solving, and other important science skills. There are so many misconceptions in so many areas of science that it can easily be overwhelming (Talanquer, 2002).

Constructivism and Inquiry

Based around an understanding of misconceptions is a contemporary view of learning often called constructivism. Constructivism's formal title might be the constructivist model of learning or constructivist epistemology, but central in all of these terms is construction. Just as laborers physically construct a building, students "actively construct the knowledge they possess" (Mestre, 2001, p.45). Constructivism argues that all of the knowledge an individual possesses is the result of having personally constructed it. Jose Mestre, one of constructivist science education's greatest supporters, contends that "constructing knowledge is a lifelong, effortful process requiring significant mental engagement from the learner" (2001, p. 45). At any given time, a person's body of knowledge is constructed in a way that makes sense to the current time and serves to predict relevant events (Mestre, 1991).

Whether dealing with established science misconceptions, that need to be deconstructed and then reconstructed, or science conceptions that students have never thought about, that need their own construction, constructivism places a lot of emphasis on the prior knowledge and sense making skills of the students. By taking advantage of the already established conceptions and skills of students, teachers can adequately help their students construct their own knowledge. Knowledge construction is often described as an active process, so constructivist science calls for active student-driven learning. "Hence," says Mestre, "instructional approaches where students are discussing physics and doing physics, teaching each other physics and offering problem solution strategies for evaluation by peers will facilitate the construction of physics knowledge" (Mestre, 2001, p. 46).

According to Haney, Lumpe, & Czerniak (2003), constructivist teaching includes five specific components. These are scientific uncertainty, student negotiation, shared control, critical voice, and personal relevance. Although these five are not directly mentioned in all constructivist descriptions, they do offer insight into the constructivist model of learning. According to Haney *et al.*, "Teachers who believe and enact these tenets of constructivism would present scientific knowledge as arising from human experience and values, evolving and insecure, and culturally and socially determined" (p.366). Students in a classroom like this would consider their ideas internally, listen to the ideas of their peers, and reflect on the relations and contradictions. Students would have shared control in the outcomes of the class. Most importantly, Haney *et al.* express that topics need to make use of the everyday experiences of the students and relate meaningfully to their lives.

One of the best ways for students to actively construct their own knowledge is through a process called inquiry. Inquiry has been around in various forms since the early

1970's, but is fairly unified in concept. Central to inquiry is the idea presented in the following quote by a student who was a part of an experimental inquiry-based classroom: "Don't tell me the answer, I want help in finding out myself" (McDermott, 1974). The National Science Education Standards, created in 1996 by the National Research Council, defines inquiry in this fashion:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (p.23).

In simpler terms, students use observation and experimentation along with scientific reasoning and critical thinking to actively construct an understanding of science. Inquiry can occur in laboratory-type experiments, conceptual group discussions, or many other situations, but the key factor is always that the students evaluate and construct their own knowledge themselves.

The National Science Education Standards define the goals of inquiry by its ability to help students develop:

- Understanding of scientific concepts.
- An appreciation of "how we know" what we know in science.
- Understanding of the nature of science.
- Skills necessary to become independent inquirers about the natural world.
- The dispositions to use skills, abilities, and attitudes associated with science.

(National Research Council, 1996, p.105)

Understanding and skills, as mentioned above, are two key components of inquiry. By trying to figure out scientifically sound conceptions on their own, students utilize the skills and knowledge they already have to develop new skills that will help direct them towards a greater understanding of science.

One way often used to approach inquiry is the Five-E method (Colburn, 1998). Each of the five steps serves as a relevant path progression towards personal learning through inquiry:

- Engagement – teacher asks questions or gives statements, with very little explanation, to cause students to think about their personal knowledge.
- Exploration – students actively learn through self-designed experiments, activities, or discussions.
- Explanation – students attempt to offer explanations for what they have observed/studied, with teacher pointedly helping only when necessary.
- Extension – students attempt to apply their explanation in practical terms.
- Evaluation – teacher evaluates as desired, but should include a variety of methods to account for different learning styles.

(Colburn, 1998)

Inquiry, as a learner-centered educational experience, does not imply that the students do whatever they wish. It is much more complicated than that. Teachers of inquiry-based science have to do a lot of work. The teacher has to be more involved than just giving knowledge. The teacher plays the role of facilitator rather than transmitter, and therefore must be attentive and ready for questions with more questions and situations. The teacher probes student understanding and helps them resolve conflicts between scientific knowledge and their preconceptions. Thus, through inquiry and constructivism, students do not "discover" everything for themselves. Instead, the teacher must focus "on relating new knowledge both to previously learned knowledge and to experiential phenomena so that students can build a consistent picture of the physical world" (Mestre, 1991, p. 57).

Transmission vs. Constructivism

A teaching model in contrast to the constructivist/inquiry model is the prevalent transmission model (Mestre, 1991). In the transmission model, students experience learning through teacher-centered lectures, presentations, and readings. Assumed within this model of learning is that the student actually absorbs what the teacher is trying to transmit. Transmission is a teach-by-telling type of method, where student difficulties are often attributed to an unclear or confusing presentation. This causation places the teacher as the central player in the learning equation, as opposed to inquiry where the student is the focus.

When most Americans think about school, they picture students sitting in little desks in rows facing the front of the classroom, where the teacher stands at the blackboard giving a lecture (Haney *et al.*, 2003). This is the image of the American classroom that most people have, because this is what they experienced, and what their children are probably receiving. This is an image of the traditional classroom strictly following a transmission model of learning. The transmission model works for almost all subject areas, but is most easily associated with science and math classes. Conceptually heavy subjects such as physics are most often taught using a transmission model

(Harrison *et al.*, 1999), because of the perceived amount of content that must be learned by the end of the school year (Tretter & Jones, 2003).

Despite the prevalence of the transmission model, one must remember that frequency of use does not necessarily imply quality. In fact research shows that "students learn best when actively engaged" (Mestre, 2001, p.48) and when "concrete experience establishes the basis for the construction of scientific concepts" (McDermott & DeWater, 2000). Very little in the transmission model can be confused with being "actively engaging."

Often times the transmission model is defended by claims that its students often achieve high grades on standardized tests. Studies have shown that students taught physics problem-solving skills with the transmission model can in fact score quite well on exams, but can still manage to display little understanding of the concepts underneath (Mestre, 1991). There is no strong correlation between high grades and understanding (Harrison *et al.*, 1999). If the goal of science education is deeper conceptual understanding of scientific principles, then the transmission model seems like a step backwards.

When weighing transmission and constructivism, one really has to pick between memorization and understanding, between breadth and depth (McDermott, 1974). Transmission modeled classrooms often cover so many topics so quickly that little time can actually be spent acquiring a true grasp of underlying concepts (McDermott *et al.*, 2000). Transmission physics classes all too often focus on quantitative skills at the cost of qualitative reasoning.

Transmission model classrooms focus on algebraic formalism and definition memorization, but their students can rarely relate these facts to real-life applications (Nachtigall, 1990). Very few children can actually learn well this way. Except for the fewer than one percent of high school students who might become physicists, one class in physics is all most high school students will ever learn of physics, and such a teaching style can actually have negative results (Nachtigall, 1990). Students do not need elegant derivations and equations; they need relevance to their own lives and experiences. Rushing through basic concepts can wear students out and turn them away from the joys of science and physics. On the other hand, when students participate in creating their knowledge, science can become an activity as opposed to a useless body of knowledge (Etkina, 2000), and perhaps more than 1% of students will like physics enough to try it in college.

Concerning standardized testing, a 2003 study in North Carolina found that there was no significant difference in state proficiency exam scores between physical science students who learned by a textbook-oriented approach and an inquiry-based approach (Tretter & Jones, 2003). It should be noted that the standardized test studied and most others are still aimed toward transmission-type learning, so it can be assumed that inquiry-based learners might do significantly better if the tests were aimed towards understanding instead of fact recitation. The researchers for this study also noted that the inquiry group students had higher attendance rates and were more motivated.

The advantages of constructivism and inquiry-based learning seem to far outweigh those of transmission. By this means, constructivism and inquiry have gained much credibility in the eyes of science education specialists as viable frameworks for teaching and learning models. Constructivism and inquiry, generally linked together, have "become an intricate aspect of current educational reform and [are] included in many of the national science education reform recommendations" (Haney *et al.*, 2003). Inquiry plays an integral part in both Project 2061: Science for All Americans, an initiative of the American Association for the Advancement of Science, and the National Science Education Standards, written by the National Research Council and supported by the National Science Teachers Association. The National Science Education Standards believe so highly in inquiry that they go as far to say:

> Inquiry is a critical component of a science program at all grade levels and in every domain of science, and designers of curricula and programs must be sure that the approach to content, as well as the teaching and assessment strategies, reflect the acquisition of scientific understanding through inquiry. Students then will learn science in a way that reflects how science actually works.
> (National Research Council, 1996, p. 214)

All formality aside, perhaps the best endorsement comes from a group of secondary science teachers. After taking a course in inquiry physical science, the nine in-service teachers had this to say: "The best opportunity for establishing long-term conceptual understandings in science lies in using the inquiry approach" (Kleine *et al.*, 2002, p. 39).

"Teachers Teach as They Were Taught"

Despite all the evidence in support of constructivism and inquiry, little is done in real classrooms to conceptually change misconceptions or to introduce inquiry and constructive learning. Inquiry may be the better method than transmission, but most science teachers do not use inquiry as an educational method (Kleine *et al.*, 2002). There are several reasons why most science teachers don't practice inquiry in their classrooms, including fear that content moves too slowly and unwillingness to put forth the extra effort, but the biggest deterrent from getting inquiry into all science classrooms is a lack of teacher understanding of inquiry because few of them learned using inquiry.

Research verifies the cliché, “teachers teach as they were taught” (Stein, 2001; McDermott, 1990). Whether intentional or not, teaching methods are learned by example (McDermott & DeWater, 2000). Teachers tend to imitate their instructors in both style and content (Nachtigall, 1990; McDermott, 1974). The transmission model thus pervades classroom instruction mainly by default, because for most teachers it is the method by which they were taught (Mestre, 1991). Having never seen an instructional method that differs, secondary science teachers all but have to follow the transmission method. Thus it persists with little theoretical justification, carried on the shoulders of tradition.

The pervasiveness of the transmission method in high schools can therefore be attributed to the college science departments and education departments for not giving preservice teachers opportunities to learn about inquiry or participate in inquiry. It is common belief in physics departments that the quality of a high school teacher is determined by the number and difficulty of physics courses taken (McDermott & DeWater, 2000). By this measure, high school physics teachers might know conciderable amounts of theoretical physics, but will not be able to convey it to their students in a way that the students can understand. Although content knowledge is important, it does not insure that a teacher will be able to teach as described above.

Physics and physical science teachers tend to learn their physics content completely separate from instructional methodology, which decreases the effectiveness of both (McDermott, 1990). Prospective teachers need to learn their elementary physical concepts in depth for a sound understanding and the ability to explain the underlying reasoning (McDermott, 1990). This requires a lot more time per topic than traditional introductory physics classes allow, and would probably call for a separate class for prospective teachers, delving deeply into a smaller number of topics (Zollman, 1994; McDermott, 1990; Mestre 1991).

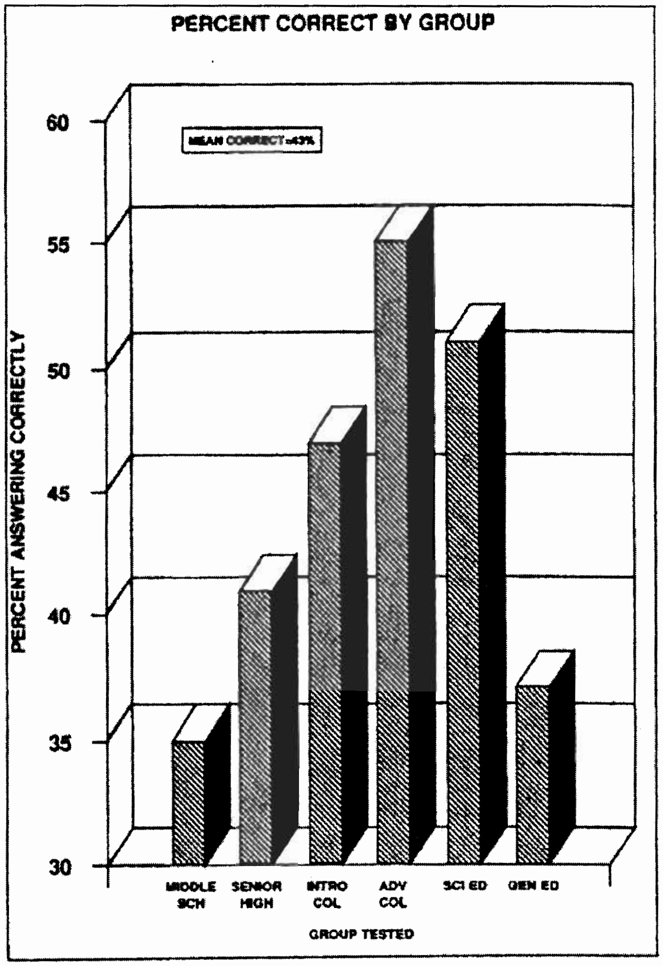
Just as science instruction for students has proven to be most effective when real experiences are used to construct scientific thought, the same holds true for adults. Much like the correction methods for dealing with misconceptions, studies have shown that adults, including preservice and inservice teachers, learn best in the same situations that are best for children (McDermott & DeWater, 2000). This means that not only would teachers benefit pedagogically from an inquiry-based class, but that their content knowledge would also dramatically benefit. To really be able to teach using inquiry, it almost becomes a necessity that teachers participate in inquiry-based content specific class.

Such a course should "emphasize the content the teachers are expected to teach" (McDermott, 1990, p. 737), should present topics "in a way that is consistent with how they [the preservice teachers] are expected to teach that material" (McDermott, 2000, p. 412), and should certainly be hands on and laboratory based (Wilson, 1991; McDermott, 2000). To make this class truly inquiry-based and meaningful to future teachers, the college professor would have to teach as he/she was probably never taught and put in the extra work to provide proper examples to challenge the teachers' misconceptions without giving any of the answers away to the class easily, just as the teachers will have to do in the high schools.

The only way to stop the misconception cycle and the transmission cycle is for preservice physics and physical science teachers to be taught their physics content and physics pedagogy in the same manner that science reform movements call for them to do. Science Education faculty often swear by the National Science Education Standards and Project 2061: Science for All Americans, but they rarely hold their students accountable for the content of these. The content of these texts, being the proper pedagogy for both students and teachers, should therefore be used in all levels of education. Science and Science Education departments of all colleges should embrace The Standards and Project 2061 in their science classrooms to ensure that all future teachers receive the training they will need to be better teachers. After taking classes that involve true inquiry and discuss inquiry and pedagogy, teachers should be able to utilize the cliché. "Teachers teach as they were taught" can actually take on a proper dignified meaning if tomorrow's teachers are taught properly using the concepts of constructivism, inquiry, and conceptual change for misconceptions today.

Figures

Figure 1:



from Bisard, Aron, Francek, & Nelson, 1994

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