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Why the Resistance to Inquiry-Oriented Science Teaching?

As a teacher educator I'm constantly fighting the good fight against the traditional mode of science instruction – teaching by telling. Plentiful PER research has shown that this mode of instruction isn't as effective as inquiry-oriented instruction, at least for the typical high school student. I regularly promote inquiry-oriented teaching among high school physics teacher candidates, while at the same time fending off bad habits developed by them in traditional university classroom settings – be it in science or any other discipline.

In the traditional teaching-by-telling paradigm, understanding is the goal and faith is the way. In such a mode of instruction, students are expected to have faith in what they are told and in those who are telling them. The traditional approach depends on an assumption of authority based upon the credentials of the teacher, "I have a degree in this area; therefore, I ought to know." Faith in an instructor and faith in a textbook leads to preaching – not teaching. The parallels are uncanny if you think about them.

The case for authority is not without merit. After all, verification labs often serve the purpose of showing that the faith we place in our instructors is not unreasonable. Besides, understanding often follows from reason. By following the lead of our teachers, we use our minds – reason – to understand. In other words, faith produces obedience that produces understanding. This understanding often leads to reward. Still, don't we want our students to think and reason rather than merely to exhibit rule-conforming behaviors? Shouldn't we treat our students more like Pascal's "thinking reeds" than as Pavlov's dogs?

While traditional teaching by telling focuses on the destination; inquiry teaching focuses on both the journey and the destination. Why settle for one when one can have both? Isn't science both a product and a process? Teaching only the facts of science is akin to teach history. Science consists of both product and process. Teaching the content without the process is to inculcate faith in an instructor, not the ways of science.

Teaching by inquiry – if our ultimate goal is to produce productive citizens who can identify an authentic, real-world problem and find its solution – should be our goal. Would we rather inculcate servile obedience or rule conforming behavior aimed at a reward that seems to be the natural outcome of teaching by telling? No, but this often seems to be the outcome of traditional teaching methods.

The resistance of traditional teachers to become inquiry-oriented teachers is consistent with the evolution of many forms of scientific thought and is neither surprising nor unexpected. The gradual changes in the thinking of a community of scientists over a period of several generations often leads to major paradigm shifts in that community's viewpoints by evolution rather than by revolution. If biological evolution can be used as a model for the way we think about how we teach, gradualism is more the case than punctuated evolution. We who promote inquiry-oriented instruction should expect resistance to change. It's only natural.

Gradualism can some time create tension between competing ideas and theories as data and evidence accumulate. Scientists are not prepared at a moment's notice to adjust their theories or thinking to facts in the light of new evidence, especially when that theory seems to work tolerable well. They are more likely to make minor changes in the ways they think in order to "preserve the phenomenon." So it is with educational paradigm shifts. Until major changes are affected, physics education researchers need to restate and validate their findings that show the good of inquiry-oriented teaching.

We all need to realize that there is some truth in a somewhat facetious claim that I make that often strikes my students as somewhat amazing when they first hear it, "Physics isn't all that important." Not long after a physics course concludes, most students will have forgotten the precepts of physics. What they might have learned in the process of studying physics through inquiry is that they can solve authentic, real-world problems using a modicum of information from physics and the experiences they have gained learning the processes of science. What they are left with when teaching otherwise is often of very limited and temporary value.

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Introduction to physics teaching for science and engineering undergraduates

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Recruiting and retaining highly qualified physics and physical science teachers is critical for maintaining America's global competitiveness. Unfortunately, many high school and middle school teachers are asked to teach science subjects they do not feel comfortable teaching and are not provided adequate guidance and support. Moreover, teachers often lack adequate pedagogical content knowledge to teach science effectively. Here, we discuss the development, implementation, and assessment of a course for science and engineering undergraduates designed to increase awareness and help them develop an interest and a deeper appreciation of the intellectual demands of physics teaching. The course focused on increasing student enthusiasm and confidence in teaching by providing well supported teaching opportunities and exposure to physics education research. The course assessment methods include 1) pre-test and post-test measures of attitude and expectations about science teaching, 2) self and peer evaluation of student teaching, 3) content-based pre-tests and post-tests given to students who received instruction from the student teachers, and 4) audio-taped focus group discussions in the absence of the instructor and TA to evaluate student perspectives on different aspects of the course and its impact.

Background

In the report "Rising above the gathering storm: energizing and employing America for a brighter economic future", a panel of experts convened by the National Academies calls for immediate efforts to strengthen our scientific competitiveness (National Academies Press, 2005). Indeed, educating students who are well-versed in science is critical for preserving our economic competitiveness and leadership. Physical science lays the foundation for later high school science courses and an understanding of physics helps students make sense of topics in other science fields. Therefore, many scientists have proposed a K-12 science curriculum with "Physics First" (Lederman, 2005; Hobson, 2005; Dreon, 2006; Bessin, 2007). If the ``Physics First'' idea is increasingly adopted in school districts nationwide, the need to recruit and retain well-qualified physics and physical science teachers will increase dramatically.

Recent data from American Institute of Physics (AIP) Research Center (http://www.aip.org/statistics/) shows that there are approximately 23,000 high school physics teachers nationwide. Approximately 1200 new teachers teach physics each year out of which approximately 400 have a major or minor in physics (http://www.aip.org/statistics/). The AIP Statistical Research Center 2000-2001 High School Physics Survey shows that 32% of high school physics teachers are "Specialists" in that they have a physics degree and also have physics teaching experience, 40% are "Career" physics teachers in that they do not have a physics degree but have extensive experience in teaching physics, and 28% are "Occasional" physics teachers in that they neither have a degree nor experience in teaching physics (http://www.aip.org/statistics/). At the middle school level, one third of the science teachers are asked to teach subjects they are not comfortable teaching (Tate, 2009). What is even more troubling is that the teachers often lack adequate pedagogical content knowledge to teach science (Shulman, 1986 & 1987). It is vital to enhance efforts to recruit highly qualified physics and physical science teachers and to carry out appropriate professional development and mentoring activities for in-service teachers in high schools and middle schools to ensure that the students they teach develop an appreciation and a deep understanding of science and scientific method and are well-prepared for a high tech workplace.

Research shows that content-specific professional development, especially when the teachers are provided guidance and support to implement the changes, has a greater impact on the quality of teaching and learning than any other classroom or teacher characteristics (Corcoran, 2003; Cohen & Hill, 2001; Desimone, Porter, Garet, Yoon, Birman, 2002; Kennedy, 1999). Several programs have been highly successful in providing professional development activities for in-service physics teachers. Since scientific inquiry is a sense-making endeavor, these approaches typically employ a research-based pedagogy in which students learn both science and scientific method simultaneously and are constantly engaged in the learning process (Singh and Schunn, 2009). These successful approaches attempt to bridge the gap between the abstract nature of the laws of physics and the concrete physical situations in which they are applicable. Hands-on and minds-on investigations are combined with appropriate use of technology and mathematical modeling to enhance student learning. Students work with their peers and the instructor acts as their guide to ensure that students build on their prior knowledge and get an opportunity to construct a robust knowledge structure.

For example, the Physics Teaching Resource Agents (PTRA) program (see http://www.aapt.org/Programs/projects/PTRA/) initiated by the American Association of Physics Teachers (AAPT) in 1985 with support from the National Science Foundation and the American Physical Society (APS) is a leading in-service physics professional development program. A professional development approach that has been used nationwide to train approximately 2500 physics and physical science teachers is based upon the Modeling Instruction (see http://modeling.asu.edu/). Modeling Instruction is a research-based approach for teaching science that was designated one of the seven best K-12 educational technology programs out of 134 programs in 2000 by the US Department of Education. Modeling Instruction in Physics was designated in 2001 by the US Department of Education as one of two exemplary programs in K-12 Science Education out of 27 programs evaluated. Another research-based approach that has been effective in preparing both the in-service and the pre-service teachers is based upon the Physics by Inquiry curriculum developed by the University of Washington Physics Education group (McDermott, 1996). The Activities Based Physics group has conducted joint professional development workshops for K-12 and college physics faculty members for more than a decade on a variety of pedagogical approaches related to physics teaching (http://physics.dickinson.edu/~wp_web/wp_resources/wp_workshops.html).

Numerous remedies have been attempted to alleviate the shortage of well-trained physics and physical science teachers. Remedies range from national to local policies and programs and include such approaches as emergency certification and out-of-field assignment to fill vacancies; alternative certification programs to hasten licensing requirements and job placement; tapping nontraditional candidate pools such as paraprofessionals, retired military, or career changers; providing scholarships, signing bonuses, or student loan forgiveness; and establishing partnerships between school districts and teacher preparation institutions to meet staffing needs cooperatively (National Science Teachers Association, 2000; American Association for Employment in Education, 2000; Gafney and Weiner, 19995; Shugart and Houshell, 1995; Clewell and Forcier, 2001; Clewell and Villegas, 2001; U.S. Department of Education, 1993-1994; U.S. Department of Education, 2000). Each remedy has certain costs and some degree of success. However, many remedies must resort to back pedaling to meet content knowledge qualifications, calling back to the educational fold those who have already left, or investing in populations who fail to complete licensing requirements.

One of the most accessible potential sources of recruits is science and engineering undergraduates who have not yet completed their degree. According to a longitudinal research study conducted by Seymore and Hewitt (1997), 20% of science, engineering and mathematics undergraduates at one time consider careers in math or science teaching, although less than 8% of them hold to the career interest.

In order to get the science and engineering undergraduates excited about K-12 teaching, colleges and universities must take responsibility for providing the undergraduates appropriate opportunity, guidance and support. A focus on the appropriateness of the curriculum and mentoring at all levels is important for success. One strategy to get more undergraduates interested in majoring in physics and in careers in physics teaching is revamping of the introductory physics courses (McDermott, 2006). These courses are taken by most undergraduates interested in majoring in science and engineering and can provide an opportunity to recruit more physics majors and more undergraduates with an interest in teaching physics. If these courses are not taught effectively, we are unlikely to produce a higher percentage of undergraduates with interest in majoring in physics and in a career in physics teaching (McDermott, 2006).

A solid partnership between science and science education departments is a positive move in this direction. Physics departments in some universities have taken a lead role in working with their Schools of Education to provide such opportunities to their undergraduates. For example, the UTeach program at The University of Texas at Austin has been successful in forging a partnership with the School of Education to provide a degree in science and a teaching certification simultaneously (http://uteach.utexas.edu/). Some member institutions of the PhysTEC program, which is a joint program of APS and AAPT, have been successful in increasing the number of undergraduates who go into K-12 teaching after graduation (http://www.phystec.org/). One feature of the PhysTEC program that has been promising is the Teacher In Residence (TIR) program in which a well-trained teacher acts as a liasion between the University and the partnering school district. Some of the PhysTEC institutions have a Learning Assistants program (Otero, Finkelstein, McCray, Pollock, 2006) that provides undergraduate students opportunities as teaching assistants in college physics courses to cultivate their interest in K-12 teaching. Recently, a partnership of a large number of institutions called "PTEC" has been formed which provides a forum for exchanging ideas about physics and physical science teacher preparation via a yearly conference and a website (http://www.compadre.org/ptec/). Other novel approaches such as involving science undergraduates as discussion leaders in museums is also being piloted to increase their interest in teaching and to recruit them as K-12 teachers (CLUSTER, 2007).

Introduction

Here, we discuss the development, implementation and assessment of a course called “Introduction to physics teaching” for science and engineering undergraduates so that they would consider K-12 teaching as a potential career choice. The course was designed to increase awareness and develop a deeper appreciation about the intellectual demands of physics teaching. The course attempted to increase student enthusiasm and confidence in teaching by giving them opportunity to design instructional modules in pairs and teach in authentic college recitation classes twice during the semester. We provided significant scaffolding support and guidance during the development of the modules but gradually decreased the guidance to ensure that students develop confidence and self-reliance. The course strived to improve students' knowledge of effective pedagogies, familiarize them with cognitive research and its implication for teaching physics, and included extensive discussions of physics education research including topics related to active engagement, effective curricula, student difficulties in learning different physics topics, affect and epistemology. Special attention was paid to helping students see the relevance of these discussions to actual classroom teaching and learning.

Course Details

The course has been taught twice with a total of 12 students. A majority of the students were science and engineering undergraduates (sophomores, juniors, and seniors), but also two Masters of Teaching students from the School of Education at the University of Pittsburgh. The cumulative grade point average for the students was between 2.5 to 3.5. At least a B grade average in introductory physics I and II was mandatory to enroll. The department of physics and astronomy imposed this requirement because each student pair was required to conduct two college recitation classes.

An initial survey administered in the first class period to the students enrolled in the class suggests that a majority of students had previously had some kind of teaching experience. The most common teaching experience was tutoring in high school. The survey responses suggest that students felt confident in teaching the subject matter they had tutored earlier. When asked to rank-order the main reasons for having taught in the past, the students cited “curiosity" followed by “a sense of being good at it", followed by “a desire to work with children", and “giving back to the community".

The class met for three hours per week for the semester and students obtained three credits for it. Students were assigned readings of one or two journal articles about teaching and learning each week. They submitted answers to the questions assigned about the readings and discussed the articles in class each week.

We used a field-tested “Cognitive Apprenticeship Model” (Collins, Brown and Newman, 1989) of teaching and learning, which has three major components: modeling, coaching, and fading. Modeling in this context refers to the instructor demonstrating and exemplifying the criteria of good performance. Coaching refers to giving students opportunity to practice the desired skills while providing guidance and support and fading refers to weaning the support gradually so that students develop self-reliance. In the modeling phase, students worked through and discussed modules from an exemplary curriculum, Physics by Inquiry (McDermott, 1996) in pairs. There was extensive discussion of the aspects of the modules that make them effective and the goals, objectives, and performance targets that must have lead to the development of those modules. In the coaching and fading phases, the student pairs developed, implemented and assessed two introductory physics tutorials and related pre-/post-tests with scaffolding support from the instructor, teaching assistant (TA) and peers.

Students were allowed to choose their partner and they stayed with the same partner for both tutorials. All student pairs designed two tutorials on the same broad topics: DC circuits and electromagnetic induction. Although all student pairs employed the tutorial approach to teaching, there was flexibility in how to design the tutorial. For example, one group successfully employed cartoons in their tutorials. Also, students were free to choose the focus of their 25-minute-long tutorial (10+15 minutes were spent on the pre-test and post-test respectively). Each student group determined the goals and performance targets for their tutorial, which was discussed during the class. This class discussion was very useful in helping students realize that they needed to sharpen their focus for a 25-minute tutorial instead of covering every concept in DC circuits or electromagnetic induction. A majority of the preliminary development of the tutorials and the accompanying pre-tests and post-tests took place outside of the class and students iterated on versions of the tutorials with the instructor and TA. Then, each pair tested their pre-tests and post-tests and tutorials on fellow classmates and used the discussion and feedback to modify their tutorial. The peers were very conscientious about providing comments on both the strengths and weaknesses of the tutorials.

In addition, we discussed the connection between the concept maps of concepts in physics and physical science that K-12 students should learn in various grades. Appendix A provides an example discussed in the class of a concept-map related to electricity and magnetism concepts that K-12 students should learn in various grades. We discussed how these concepts build on each other in various grades since physics is hierarchical. We also discussed the connection of the concept maps to research in physics education.

Course Evaluation

Evaluating Tutor Effectiveness

The content-based pre-tests and post-tests accompanying the tutorials were given to the introductory physics students during the recitation. The typical pre-test and post-test scores were 40% and 90% respectively with a Hake normalized gain of 0.8 (Hake, 1998). We note that the pre-test refers to the test given after traditional classroom instruction but before the tutorials.

Evaluating Impact on Tutors

We developed a teaching evaluation protocol based upon an existing protocol (see the RTOP at http://physicsed.buffalostate.edu/AZTEC/RTOP/RTOP-full/index.htm), which includes 15 questions on a Likert scale (five point scale ranging from strongly agree to strongly disagree with neutral in the middle) designed to evaluate different aspects of teaching. The students were given this protocol at the beginning of the course and told that their own teaching effectiveness will be evaluated on these measures. Thus, the students knew before they began preparing their lessons in pairs how different aspects of their teaching would be valued. The 15 questions in the protocol were further divided into two parts: the first 7 questions were related to content/lesson plans/class design and the other 8 questions dealt with the class activities during instruction. The following are some items:

- Class content was designed to elicit students' prior knowledge and preconceptions and build new concepts from there.

- The lesson was designed to engage students as members of a learning community: engaged in talk that builds on each other's ideas, that is based on evidence and responds to logical thinking.

- Instructional strategy included useful representational tools (for example, symbols, charts, tables, and diagrams).

- The activity actively engaged and motivated students rather than having them be passive receivers.

Each student was required to observe and critique the instruction of at least one other pair in each of the two rounds in addition to evaluating their own performance. All of the teaching recitations by the students were videotaped. After each round, we discussed the teaching evaluations of each group in class to stress the aspects of teaching that were good and those in need of improvement. We found that the student evaluation of other pairs were quite reliable and consistent with the instructor and TA evaluation. Students did a good job evaluating the positive and negative aspects of other group's instruction. However, self-evaluations were not reliable and students always rated themselves highly. Students were told that their grades will depend only on the evaluation conducted by the instructor and the TA and not on the self and peer evaluations and that the self and peer evaluations were to help them learn to critique various aspects of instruction. The fact that students rated themselves higher than others may be because they were worried that the evaluation may factor into their course grade.

There was a clear difference between different student pairs in terms of how effectively they helped the introductory physics students work on the tutorials in groups. There was a strong correlation between the extent to which group work was motivated and emphasized at the beginning of the recitation and its benefits explained and whether introductory students worked effectively in groups. After the student pair conducted the recitation class, there was explicit discussion about how they could have engaged students more effectively in-group work and each student pair obtained a copy of all of their evaluations. They were asked to pay attention to the instructor/TA/peer critiques of their performance. However, the second performance of each pair was not significantly different from the first. For example, pairs good at employing group work effectively the first time did it well the second time and those who had difficulty the first time had similar difficulties the second time. More detailed guidance is needed for improving students' classroom delivery methods.

We also conducted an anonymous survey in the absence of the course instructor at the end of the course. One of the questions on the survey asked students to rate how the course affected their interest in becoming a teacher. 56% reported a significant positive impact, 34% a positive impact and 10% no impact. Students noted that they learned about the intellectual rigor of instructional design from moderate to great extent. On a scale of 1 to 5, students were asked to rate different elements that contributed to learning. They provided the following responses:

- Preparing tutorials and presentations: 4.8/5

- Instructor's feedback on these: 4.5/5

- Class discussions: 4.3/5

- Rehearsals for their presentation: 4.0/5

- Instructor's presentations: 4.0/5

- Readings: 3.9/5

We also conducted an audio-taped focus group discussion to obtain useful feedback to evaluate and improve next offering of the course. The focus group was conducted on the last day of class in the absence of the instructor and the TA. The facilitator asked students pre-planned questions for one hour. The questions and some typical responses are presented below:

Question 1: What is the take home message of this course?

- S1: Teaching is more than the teacher's perception. How much of a two way relation is necessary to teach students.
- S2: Helped me understand that teachers have to learn from students.
- S3: Instruction is more about students. There are methods available to make instruction more suited to students. There is a mountain of cognitive research that is being developed as a resource for me as a future teacher...that was my biggest fear when we started talking about bringing instruction to student's level.
- S4: Increased enthusiasm. You have to take into account student's level.
- S5: Increased appreciation of teaching. Opened my eyes to the difficulty and different techniques for teaching students with different prior knowledge.
- S6: Figuring out different ways of making students active and structuring the lessons so that there is a lot of activity by students to learn on a regular basis.

Question 2: Do you take a different perspective during your own classes after you learned something about how to teach?

- S1: I think now that teachers who don't teach well could be trained but before the course I just took it for granted that there are good and there are bad teachers and that's all.
- S2: My college instructors ignore the work being done in how people learn.
- S3: Slightly, because I know how difficult it is. I give more respect to good teachers.
- S4: It gives you an idea about how a teacher cares about the students.

It is interesting that student S1 seems to have learned that teaching is not simply an inherent skill that an instructor possesses but an instructor can develop this skill and learn to be a good teacher. Moreover, student S2's remark about how college instructors ignore the work being done about how people learn is consistent with a recent editorial (Wenning, 2009).

Question 3: What did you learn from your K-12 teaching? How do you compare that to teaching at the college level?

A common response was that the students had not thought explicitly about what they learned from teaching in high school or till they took this course.

- S1: When I was a student I just took teaching for granted and did what they told me to.
- S2: I never thought about teaching when I was in high school.
- S3: At school most were educators; in college not.

Question 4: How did this course affect your interest in teaching? What about your plans for pursuing teaching?

All students except two said they will teach. A majority explicitly said they plan to teach in high school.

- S1: Reinforces my interest. Made me realize that I don't want to teach college because of the structure of college-lots of material, little support, under-appreciated...I want to have more time to engage students in the method learned in this course.
- S2: It helped me decide I want to go on to teaching right after college.
- S3: I want to be a teacher. This course affected me positively.
- S4: K-12. Good physics teacher in high school to give good base at young age...early

Question 5: How could this course be improved to enthuse more people to teaching?

One common discouraging response was that students felt they did not really get an opportunity to teach where the word "teaching" referred to frontal teaching. Despite the fact that the course attempted to bridge the gap between teaching and learning, students felt that moving around the classroom helping students while they worked on the tutorials that was not teaching. Common suggestions included a follow-up class with the following features:

- Observing, critiquing and delivering frontal teaching
- Observing and critiquing K-12 teaching
- Amount of reading per week can be reduced although students appreciated the readings

Summary and Discussion

To prepare future scientists and engineers for the demands of a high tech workplace, preparation of highly qualified K-12 science teachers is critical. The physics departments in colleges and universities must take responsibility to accomplish this important task. We have developed, implemented and assessed a course for science undergraduates to increase their interest and awareness about the rewards and challenges of teaching. In addition to extensive discussions about teaching and learning, student pairs designed and implemented two tutorials in college recitation classes. Assessment methods included pre-tests and post-tests of expectation and attitude about teaching, content-based pre-tests and post-tests before and after tutorials designed by students, critiquing peers and self-evaluation of teaching and focus group discussions. We find that the course had a very positive effect on students' views about teaching and learning. While the total number of students enrolled in the course was small, at least half of them went into K-12 teaching soon after finishing their undergraduate degree.

Earlier we discussed other models, e.g., the Learning Assistant or LA model (Otero, Finkelstein, McCray and Pollock, 2006) and the Collaboration for Leadership in Urban Science Teaching (CLUSTER, 2007) for getting the undergraduate science and engineering majors interested in K-12 teaching. In the LA model, undergraduates from large introductory physics courses are recruited as teaching assistants for college introductory science courses. They meet weekly with the course instructors and take a course about teaching and learning simultaneously. They are typically paid a stipend and are eligible to get scholarship if they commit to K-12 teaching in the future. In the CLUSTER program, the science and engineering undergraduates are discussion leaders at a science museum and meet weekly as a group to reflect upon what they have accomplished each week and how they can improve the learning of those visiting the museum.

The different models for getting the undergraduates interested in K-12 teaching have their own strengths. The LA model may be most suited for larger universities, which have large introductory physics courses with many recitations that are not run by the course instructors. The CLUSTER model may be better suited for urban areas where there is a museum close by. The model that we described in this paper can be adapted easily at both small and large colleges and universities. If a course like "Introduction to Physics Teaching" is offered as an elective, which can be taken by science and engineering majors to fulfill an undergraduate course requirement, the enrollment in the course can be increased. With suitable partnership with the School of Education at a particular institution, the enrollment can be increased further if the course can be used to fulfill a science teaching certification requirement. The reading assignments can be adapted to suit the instructor's goals and vision. However, the instructor must keep in mind that providing guidance, support, mentoring and encouragement to students throughout the course about teaching and learning is critical.

We note that we used a modified version of the RTOP as a rubric to encourage student pairs to plan their two lessons for the college recitation classes. Since the student pairs knew that the criteria in this rubric would be used to score their teaching, their lessons were interactive and involved introductory physics students actively in the learning process. An institution adapting this model may replace the teaching in college recitation classes with teaching in K-12 classroom or at least provide students an opportunity to observe a K-12 science classroom as a part of the course if logistics can be worked out. Visits to K-12 classroom would be particularly beneficial because it will provide students an authentic experience with the type of classroom they can expect if they become K-12 teachers.

Lastly, we wish to touch upon the importance of diversity in physics education. Recent AIP data shows that the percentage of men and women in high school taking at least one physics course is approaching 50% for each group (http://www.aip.org/statistics/). Moreover, more than two thirds of the Asian American high school students take at least one high school physics course but only 15% of the African American high school students take at least one physics course (Tate, 2009). The low percentage of African Americans taking high school physics could be due to many reasons including lack of physics teachers or lack of well-qualified physics or physical science teachers in the middle and high schools with African American majority, lack of guidance, support, and mentoring pertaining to the value of science in general and scientific career in particular, and inadequate parental encouragement and role models in this regard. Considering US demographics which projects that the percentage of Whites in the population will be less than 50% by 2050, it is particularly important to encourage African American and Hispanic students to focus on physical science and physics in middle and high schools to maintain America's global leadership. Robust education in physical science, physics and mathematics for all students is the key to ensuring that we continue to excel and deal with the challenges effectively.

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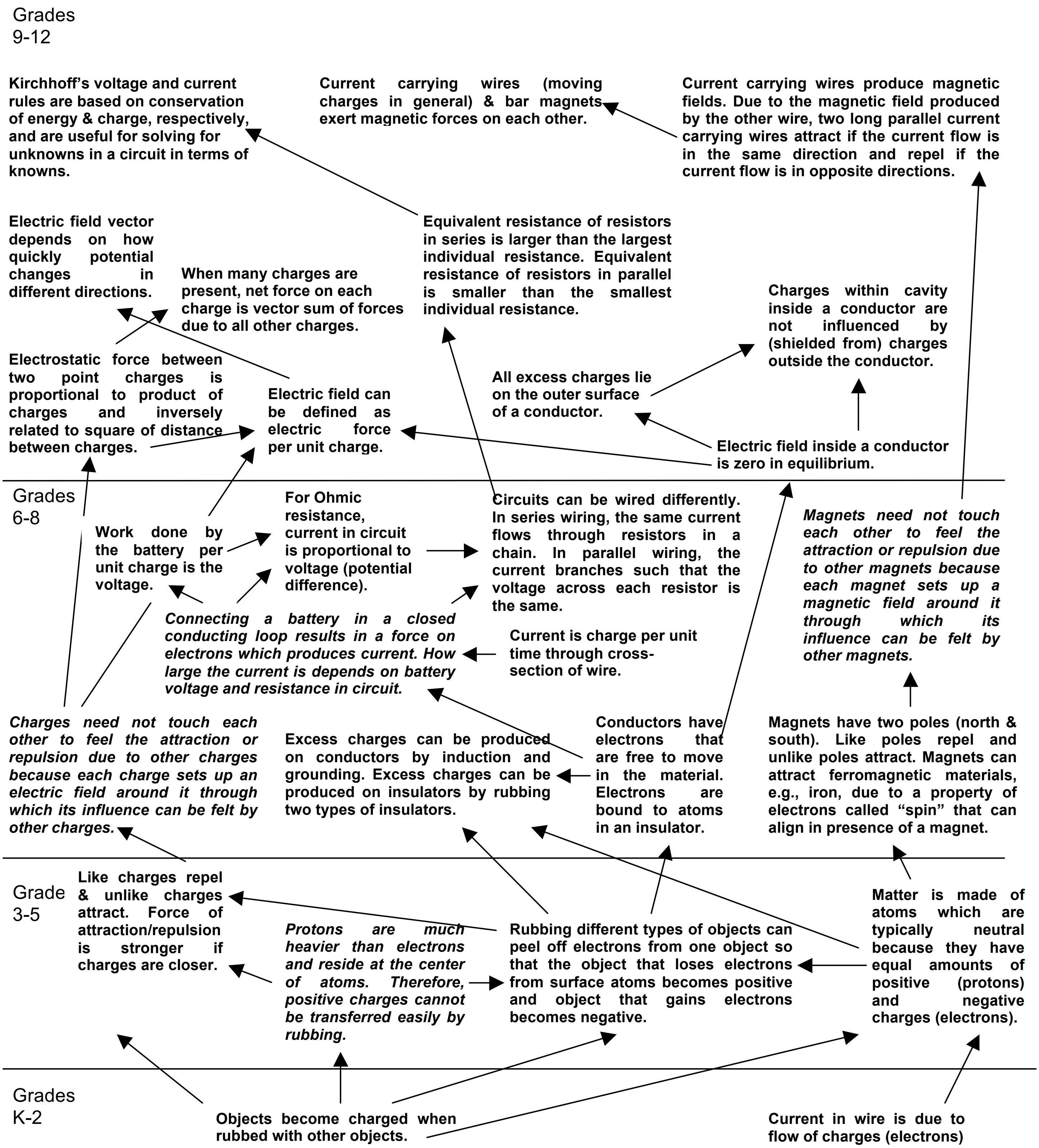
Appendix A: Conceptual Map of Electricity and Magnetism



Self-monitoring to minimize student resistance to inquiry

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A teacher faces resistance from students when converting a conventional physics program to an inquiry classroom (Reif, 2008; Wenning, 2005b; Wenning-Vieyra, 2007). This study investigated how the metacognitive process of self-monitoring helped minimize student resistance toward inquiry-based instruction in high school physics classrooms. A total of 50 high school students participated in this study. Two data resources were collected including weekly self-monitoring worksheet and end-of-study questionnaire. Findings indicated that students struggled with inquiry practices due to lack of problem solving skills and lack of motivation. In addition, evidence suggested the metacognitive practice of self-monitoring was effective at minimizing student resistance towards inquiry in the majority of the participating students. Implications were discussed in the paper.

INTRODUCTION

Inquiry has become a ubiquitous term in science teaching and learning. Although there are different interpretations of the definition of inquiry, most educators would agree that inquiry involves asking researchable questions, investigating and exploring, and providing explanations about national events based on evidence. The National Research Council (1996) defines scientific inquiry as a "multifaceted activity that involves observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; using tools to gather, analyze and interpret data; proposing answers, explanations, and predictions; Inquiry requires identification of assumptions, use of critical thinking, and consideration of alternative explanations" (p. 23).

In inquiry-based science class, the role of the student is to take an active position, ask probing questions, and to learn the concepts presented by a hands-on approach. However, implementing inquiry in physics class consumes a great deal of time, students face difficulties unique to an inquiry environment, and teachers often become frustrated. For instance, in a discussion on the Modeling Instruction Program Listserv – an online forum that links physics educators implementing an inquiry-based program around the globe – the topic of student frustration and resistance was brought up (Wenning-Vieyra, 2007). One frustrated teacher stated, "I have a student who has recently been making comments that "I am not teaching anything," and today the attitude turned class-wide. One more vocal student clearly supported the modeling method, but the few students who are failing (mainly because they want to be spoon-fed) and the students who are doing well (likely because they want more content) seem very angry." Another teacher on the same forum reported this as "a common experience." When implementing an inquiry-based program for the first time, difficulties are the norm rather than the exception. Wenning (2005b) classified several realms of resistance to inquiry that teachers may face which include resistance from students, parents, administrators, and teaching colleagues. He observed that some students resist inquiry if they perceive it as a threat to their grades. Students who have done well under a more conventional mode of instruction tend to find learning more challenging in classrooms where there is a strong reliance on inquiry. These students act out in many ways that disrupt the learning of others. Wenning reports that much of this resistance dissipates as students become more comfortable with inquiry practices of metacognition.

Metacognition refers to the ability of a person to anticipate performances on various tasks and to monitor understanding (NRC, 1999). Teaching practices can be classified as metacognitive if they focus on self-assessment and reflection on what is successful and what needs improving. These practices significantly improve a person's ability to synthesize information and to apply it to new situations. A student engaging himself/herself in the metacognitive practices will learn to monitor and control their own learning (NRC, 1999). This is by definition a self-regulated learner. Students need to be aware of what they know and what they do not know. The metacognitive technique of self-monitoring is an essential tool for developing competent learners (NRC, 2005).

This study primarily investigated how metacognitive practices in high school physics class helped students acclimate to inquiry learning. Many of the students tend to make statements of despair and quit before they get a logical answer when faced with cognitive dissonance. They need to work through this despair. However, little research has been done about acclimating students to inquiry teaching from a conventional style of teaching. This research gives insight into how to help frustrated students through times of despair by minimizing their resistance to inquiry to learn physics in a more meaning way.

LITERATURE REVIEW

Since the advent of the National Science Education Standards there have been significant efforts in the physics teaching community to change instructional strategies from conventional science teaching methods to inquiry-based science teaching methods. Lloyd (1996) compared the two methods of science teaching and found that teachers in the conventional setting did nothing to provide students with an understanding of how scientists think and inquiry teachers promoted integrating knowledge into their cultural background, thinking, and learning.

In a study of pre-service elementary education majors in an inquiry-based science course, the average increase in correct responses on the Introductory Thermal Concept Evaluation (TCE) was 33.4% (Yeo & Zadnick, 2001). In another effort to test the effectiveness of the inquiry method, Hake (1998) performed a study on 6,542 physics students of which approximately half were taught by conventional methods and the other half was taught by inquiry-based methods. The students taught through inquiry methods showed to have a much better understanding of the basic concepts of physics as compared to those taught through conventional methods. However, it is not always well received by the students. California Polytechnic State University introduced an inquiry-based physics class to freshmen. In an exit pole, they found that 2/3 of students preferred learning in a conventional classroom environment (Mottman 1999).

A student may form a negative attitude towards inquiry instruction because he/she is not equipped to deal with the challenges of an inquiry environment. Rop (2003) studied 16- and 17-year-old chemistry students in an inquiry class. He found that when students ask deep probing questions they are sometimes discouraged by their peers. When negativity comes from a peer, the teacher must immediately address this issue and not allow this type of discouragement so students feel safe engaging in inquiry activities (Reif, 2008). Peers are not the only source of discouragement. In several instances, Rop (2003) observed teachers becoming angry at the students because they felt threatened by the students' questions. He also observed teachers brushing off or not answering student questions so that they could meet the content requirement for the day. This discouragement can cause students to disengage from class activities, form a negative attitude towards inquiry, and resist the teacher's attempts at inquiry-based instruction. To avoid this problem, teachers need to slow down, listen for intellectual hunger in student questions, and encourage scientific thought patterns. In addition to this, inquiry instructors ought to offer sincere praise for student responses to help elicit deeper questioning in the classroom.

Reif (2008) identified several other forms of student resistance. Students who make easy grades in other more conventional classes may object to inquiry-based methods. Students asked to present their ideas in class may feel exposed, threatened, or unsure of their answer. Inquiry-based teaching involves the elicitation of student ideas and confrontation of student misconceptions. This causes students to face cognitive dissonance. When first exposed to teaching methods that build on cognitive dissonance, students do not have the appropriate mental tools to alleviate the dissonance (Kirschner et al., 2006). They do not know what to do when confronted with a misconception. In prior non-inquiry experience they were not required to deal with dissonance. As a result, they have no mental tools to deal with inquiry and as a result they sometimes give up.

Kirschner et al. (2006) also observed this phenomenon, "When students learn science in classrooms with pure-discovery methods and minimal feedback, they often become lost and frustrated and their confusion can lead to misconceptions." Zion, et al. (2007) likewise found that students often lack the necessary skills to succeed in an inquiry-based program. Learning does not occur in minimally guided instructional practices because the students that are being first introduced to these types of methods do not have the necessary experience and memories to piece together a solution. This is why modeling appropriate metacognitive skills will help students to succeed in an inquiry environment. Metacognitive practices help students to have the mental tools to successfully identify a problem, draw from potential solutions from the available resources, and solve the problem (NRC, 2005; Wenning, 2005b). The classroom instructor must model the appropriate mental processes so students become aware of the correct mental procedures that will enable them to solve a problem.

Guided problem solving worksheets or mental process worksheets have been shown to be an effective way to teach students these mental processes (Kirschner et al., 2006).

According to the designers of the Modeling Instruction Program for Physics (see reference), the premier inquiry-based instructional curriculum, the effectiveness of implementing such a program depends heavily on the pedagogical expertise of the teacher. It is difficult to cultivate such expertise among high school teachers (Lotter, 2004; Wells et al., 1995; Zion et al., 2007). Beginning teachers often do not have the necessary expertise and experience to deal with inquiry practices and so they struggle. Many of the problems teachers face when implementing inquiry for the first time are due to inexperience. Lotter (2004) studied about 13 pre-service teachers from a large Midwestern university, and all 13 of the teachers identified inquiry methodology as a good way to teach science but only 4 of them were observed using it. Two hundred and eighty six pre-service science teachers were surveyed about inquiry, and many of these teachers held major misconceptions about inquiry by believing that questioning or predicting was the complete inquiry process. The inability of a teacher to correctly implement an inquiry-based program leads to student resistance. Students form negative attitudes and do not give forth the effort if the instruction seems pointless causing them to give up or not try (Lotter 2004).

Duran et al. (2004) studied about pre-service middle school teachers being introduced to an inquiry-based physics class. The pre-service teachers were initially frustrated in the course because it was different than their other science courses. They became frustrated and anxious during the development of the physics concepts. They wanted the instructor to simply give them the answers. The pre-service teachers initially felt uncomfortable in an inquiry-based environment due to the amount of workload and time that it consumed. They felt like they did not get enough time to work on the variety of projects that were part of the course. Time as an inhibitor to inquiry seems to be a reoccurring theme. Not enough time or a restrictive time frame limits the effectiveness of inquiry (Felder & Brent, 1996; Lotter, 2004; Zion et al., 2007). The NRC (2000) suggests that a paradigm shift needs to take place in education from covering a breadth of information at the surface level to understanding a few concepts deeply. Veteran teachers, especially those that are dynamic lecturers often identify with this problem of time.

In 2000, Carthage College added an inquiry-based introductory physics course. Studies found that student attitudes towards physics improved as well as their ability to solve physics problems compared to their counterparts taking the conventional physics class (Arion et al., 2000). The most profound aspect to this finding is that it goes against what typically happens in an introductory physics class. Redish et al. (1997) found that student expectations and attitudes in introductory physics classes deteriorate rather than improve. Arion et al. (2000) showed inquiry to be effective at increasing student attitude toward physics that goes against what is typically observed in introductory non-inquiry physics classes.

So what else can teachers do to ensure a positive learning experience when attempting to use inquiry-based practices? According to Felder and Brent (1996), climate setting is a key to minimizing resistance. The teacher should convince the students of the effectiveness of student-centered learning at the onset. Schulz and Mandzuk (2005) suggest that the role of the teacher must be changed. Time must be spent clearly defining the role of the student and the teacher (Wenning, 2005b). The instructor needs to shift the way that they view learning by pointing out that students will not succeed by memorizing facts. When students have cognitive discrepancy, the instructor should tell them that even the best students will not understand at first but in the end it will all come together for a greater understanding (Reif, 2008). Climate setting is preventative by nature so many of the problems that students face as previously described will not occur. Wenning (2005a) suggests stair-stepping novice inquiry students from lower levels of inquiry to higher levels of inquiry. This gives students the opportunity to gain a schema that appropriately deals with dissonance that they face. At the lower levels of inquiry the instructor guides students through the inquiry process. As the year progresses the students are more acclimated towards inquiry thought processes and can handle a higher level of inquiry. This stair step progression gives students time to adjust to a different style of learning.

Felder and Brent (1996) offer some excellent advice to teachers struggling to implement and inquiry-based program, "Giving up is a mistake. Inquiry may impose steep learning curves on both instructors and students and the initial awkwardness and student hostility are both common and natural." Students will face problems and cognitive dissonance. Teachers must be aware of this and utilize metacognitive strategies that help guide them through the times when they do not understand in order to make science learning more meaningful and effective than conventional methods.

METHODOLOGY

Overview

The main objectives of this study were two fold: the first was to determine why physics students are resistant to inquiry based teaching and the second was to determine if implementing the metacognitive practice of self-monitoring was helpful at alleviating student resistance to inquiry. This study was performed on 50 students enrolled in 2 different first year inquiry-based physics classes at a high school in a Midwestern area. The students received self-monitoring worksheets on a weekly basis as an intervention to decrease student resistance to inquiry. Data were taken from self-monitoring worksheets (see Appendix A) and a post survey questionnaire (see Appendix B) at the end of the study.

All of the students selected for the study were 16 to 18 years old and had been taught science mainly through conventional methods. The large majority of the students were Caucasian. The ratio of female to male was 2:3. This was their first inquiry-based science class so the results gave insight into how to minimize resistance that students face when introduced to an inquiry-based class when they have been formerly taught by conventional methods.

Context and Instrumentation

There were two data collecting instruments that were used in this study: a self-monitoring worksheet and a post survey questionnaire. At the beginning of February 2009 students completed a weekly self-monitoring worksheet for 5 weeks. At the end of the 5-week period the students were given a follow-up questionnaire.

The instructor's lessons dealt with electrostatics and circuits. The curriculum used was from Modeling Method of Instruction units on electric charge and electric field, electric potential, and circuits (Lotter 2004; Wells & Hestenes 1995). The instructor was properly trained in a Modeling Method of Instruction workshop and had been using the curriculum for 5 years at the time of this study. During this time a variety of Modeling Method activities were completed. Each unit began with an inquiry lab in which the students mathematically and graphically derive models for the unit. The students worked in cooperative learning groups of 3 or 4 and they presented and defended the results from the lab. Worksheet problems were designed to allow students to determine how to deploy their models in a variety of contexts. This forced the students to confront common difficulties in the context of their experimental results. The groups then whiteboarded their solutions and presented to the class defending their method conclusion. Socratic dialoguing by the instructor is used to address misconceptions (Wenning, 2005c). See the following website for more information http://modeling.asu.edu/modeling-HS.html.

Self-Monitoring Worksheet. This study proposed that the practice of metacognition might help high school physics students more quickly adjust from conventional science teaching practices to inquiry-based science teaching practices. The difficulty with implementing metacognition as an intervention that will minimize student resistance is that the internal nature of the skill is not easily observed. Because of this, a self-monitoring worksheet was developed for the study. This worksheet was developed from the book *How Students Learn: History, Mathematics, and Science in the Classroom* by the National Research Council (2005). The self-monitoring worksheet gave students the questions they should be asking themselves to successfully diagnose problems they are facing in the physics class and then leads them into designing a plan to remediate the problems that they have identified. This process of self-evaluation is metacognitive in nature. In the weekly self-monitoring worksheet, the students were required to look at the previous week's plan and evaluate whether or not they were successful in eliminating their self identified problem. Implementing the self-monitoring worksheet was a necessary step because it showed that students were using metacognitive practices. The data collected from this section was used to answer both of the research questions.

Questionnaire. The questionnaire was designed to probe deeper into the thoughts of the students involved in this study. This activity allowed the researcher to answer both of the research questions that focused on why the students feel resistant to inquiry-based teaching, it elicited their opinions of the effectiveness of self-monitoring as a technique to minimize resistance to inquiry, and it obtained responses on how to further reduce resistance to inquiry.

Results

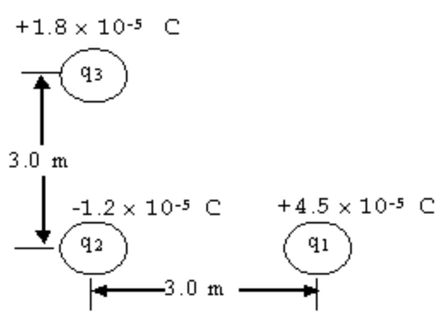
Responses from Weekly Self-Monitoring: Areas of Struggle for Research Objective 1.

There was a diversity of responses dealing with area of struggles. These were taken and classified under two major themes: *Struggles with Problem Solving* on the Modeling Method worksheets and *Struggles with Motivation/Complacency.* It is important to note that many of the students did not identify areas of struggles. For example, Dillante (Pseudonym) wrote that, "I actually didn't struggle. I thought I would do bad on the test and I ended up getting a B+!! I think I am starting to understand everything." Another student wrote, "I didn't struggle with much this week." Another note of interest is that the students enjoyed the inquiry labs and found them to be helpful. Angie (Pseudonym) states, "Hands on activities always make class better and easier to understand."

Struggles with Problem Solving.

Problem solving in an inquiry classroom requires students to take the information gained from the labs and generalize the information in the form of word problems. Often they need to use previous units' concepts and reasoning skills. This often causes frustration. The following is an example of a word problem that the students were given in a worksheet.

Three charges are placed as shown below. Determine the magnitude and direction of the net electrostatic force on charge q1. As part of the solution, include a force diagram.



What further frustrated students about the word problems is how the instructor responded to their questions. The instructor rarely answered a student on whether they are right or wrong but rather directed them down the most logical path. The idea is to get the students to synthesize the information and to understand the content at a greater depth than what is provided by memorizing all possible solutions. The responses from the weekly self-analysis showed that students had the greatest trouble with problem solving. Within this category there are three categories of subheadings: lack of mathematics skills, confusion of variables in context rich problems, and generalization problems.

Lack of Mathematical Skills. Several students diagnosed their weekly problem as not having the necessary mathematics skills to solve the problems. Jenny stated, "I struggled most with Coulomb's Law because it uses math I was not familiar with." Mark stated, "The formulas we learned blew my mind." Lin stated, "The scientific notation is just confusing to me."

If the students do not understand the mathematic principles behind a word problem it is easy to see why they cannot solve the problem. There are certain mathematical requirements to get into physics at the junior and senior level. If they pass the required math classes then they can get in. This means all of the students should know enough about mathematics to complete any of the physics problems. Unfortunately, this is not always the case. Some students took their frustration in mathematics and turned it into an excuse to not solve the problems or even try. Anne stated, "It had math in it so it didn't keep my attention."

Confusion of Variables. One of the difficulties with solving context rich word problems is that the students need to be able to read through the problem and assimilate the information by identifying known variables, unknown variables, and throwing out variables that are not necessary to solving a problem. This is a high level problem solving skill and some of the students struggled with it. Johnny stated, "I didn't understand what the questions were asking." Veronica likewise struggled, "I didn't understand where to plug stuff in at." Having multiple step problems also confused students. Pat illustrated this, "Figuring out the new magnitude and force was difficult. I would get to a point where I didn't know what to do next."

Generalization Problems. Generalization is using observations from labs, previous knowledge, and mathematical skills to solve a problem that has never been seen by a student. Completing a problem like this requires mastery level knowledge and is the main indicator of how well the students learned the information. The following examples show that the students struggled with problems they have never seen. Mohinder stated, "I don't do good without being told exactly what you need to use in the problem. I have a *thinking outside-of-the-box* problem." Ryan stated, "The in-depth thinking and problem solving were the hardest this week." Another difficulty the students faced was connecting the question with previous unit's materials. Jordi stated, "I struggled with the last problem on worksheet 4 because I failed to connect ideas from previous units to this unit."

Struggles with Motivation/Complacency

The results show that lack of motivation and a general complacency towards school was a big contributor to many of their identified problems in the physics classroom. It seemed to be a daily struggle for many of the students. As a result they were not asking questions, paying attention, studying, or doing homework outside of the class. The following examples further illustrated how this affects their learning.

Several students had trouble paying attention. A student indicated that, "I can't remember what we did this week because I did not pay attention. Now I don't understand anything." In the following example the student's complacency caused her to be inactive and miss the main purpose of the lab. Janesha stated, "I have been struggling with section two and I think it is because I didn't take an active part in the lab." Kim showed her complacency with the following statement, "I struggled getting my homework done. I am so unmotivated it isn't even funny." Darin stated, "I had trouble staying awake. I need more sleep."

Another problem with a lack of motivation is that it affects their problem solving ability. An expert problem solver will not give up when faced with difficulties but will keep working at it until they get it. Several students did not show this kind of persistency. Some students gave up when they faced problems instead of asking for help. Allison illustrated this by stating, "I really didn't get the one we had to make a triangle on, so I gave up and stopped paying attention because it makes no sense to me."

Effectiveness of Weekly Self-Monitoring for Research Objective 2.

The weekly self-monitoring sheets were analyzed to find improvements or changes in the student identified struggle areas. This would be an indication that self-monitoring reduced the amount of student resistance thus answering research question 2. The students' responses were classified into four categories: students that implemented a plan for a *change in behavior*, students that had a plan for improvement but had *no change in behavior*, students that *did not specify* a plan for improvement, and students who *shifted blame* for problems they faced. It is important to note that when tracking a student through 5 weeks, rarely did a student have the same category all five weeks. This is shown by Table 1 below. The responses were taken from question 1 and question 3 of the weekly self monitoring guide. Question 3 had the students write a plan to remediate self identified deficiencies and question 1 of next week's guide questioned the students on the success of the previous week's plan.

Table 1: Student Behavioral chart

Week 1 Responses		**Week 2 responses**		**Week 3 responses**		**Week 4 responses**	
classification: *change in behavior*		classification: *no change in behavior*		classification: *change in behavior*		classification: *no plan specified*	
Plan for improvement	Was it implemented?	Plan for improvement	Was it implemented?	Plan for improvement	Was it implemented?	Plan for improvement	Was it implemented?
I'm gonna study better and ask for help next time.	Yes it was. Studying helped out helped out a lot	I'm gonna I do well tomorrow	No I didn't study but I wish I had.	I will study until test day	yes but we have a test yet	I will keep going what I'm doing!	I didn't struggle with anything on last week's worksheet.

The student responses represented by Table 1 contained 3 of the 4 classifications: 2 of the responses were classified as *changes in behavior*, 1 was marked *no change in behavior*, and 1 was marked *no plan specified*. Forty students participated in the weekly self-monitoring activity and all of their responses were analyzed and classified as was done in Table 1. However, many of the students did not complete all 5 weeks due to absences or lack of participation. Out of a possible 200 responses, 135 were classified. The results of this are shown in Table 2.

Table 2: Type of responses from weekly self-monitoring

	Change in behavior	no change in behavior	Did not specify plan	Shifted blame	Total
No. of responses	71	29	26	9	135

Students indicating a change in behavior

The majority of the responses showed that the students came up with a plan for improvement, implemented the plan, and documented a change in behavior. This indicates that they used metacognition and it helped them improve as a learner. The depth at which they responded is shown in Table 3. A pattern developed from their responses showing two categories: *Simple suggestions* and *In-depth suggestions*.

Table 3*:* Student suggestions for improvement

Simple suggestions	**In-depth suggestions**
I should try harder.	I need to actively build concepts by connecting what I know to previous units.
I should not give up.	
I need to keep trying.	I am going to work on my problem solving technique.
I need to reprioritization my life.	
I need to pay attention.	I will study for understanding instead of memorization.
Do my homework.	
Make up missed work.	I should ask peers questions when I do not understand.
Get along with my group.	
Get sleep.	Ask the teacher questions when I do not get it.

The majority of the responses fell under the simple suggestion category. These responses were often one step fixes like get more sleep or pay attention. The responses for this category did not show a high level of thinking as opposed to the *in-depth* category. The responses in the in-depth category show that they are thinking about how they learn and how they think which is metacognitive in nature (NRC 2005).

Students indicating no change in behavior

As shown by Table 2, many of the responses on the weekly self-analysis showed that a plan was put into place but they did not implement their plan. Even though they did not change their behavior, they could still be engaged in metacognitive ways of thinking. They may not have had the opportunity to follow through with their suggestions. The following is an example of this:

> **Lu's week 3 suggestion:** I am going to study harder on my own time for the next exam. I will maybe even stay after school and ask Mr. L questions.
> **Lu's week 4 analysis**: I have not been able to implement my plan because we have not had any exams.

Some had opportunity but chose not to implement their plan. The following example illustrates this point:

> **Mark's week 2 suggestion:** I'm going to actually study and look over my objectives tonight to make sure I do well tomorrow.
> **Mark's week 3 analysis:** No. I did not implement the plan but I wish I had. I did terrible on my exam.

Mark may have failed to follow though with his plan in week 2 but he used his failure to succeed later in the study as shown in the next example.

> **Mark's week 3 suggestion**: I will study for at least 15mins every night until test day so I am not overwhelmed the night before the exam.
> **Mark's week 4 analysis:** Yes I implemented my plan but I will not know if I am successful or not until the next exam.

Metacognitive practices forced students to confront their weaknesses and remediate their deficiencies as was illustrated by Mark.

Students who did not specify a plan

Table 2 shows that a significant amount of the responses were categorized as *not specifying a plan* for improvement. The following is an example of a student's response that was classified under this category.

James's week 3 suggestion: I did not really have any issues this week.
James's week 4 analysis: I did not have any difficulties. I achieved success in everything this week.

A response like this is difficult to determine the extent of the self-analysis. Students like James either don't struggle in physics thus not needing to remediate any deficiencies or they did not take the time to complete a more in-depth analysis of their thought processes.

Shifting Blame

While the majority of the student responses fell under the other three categories, it is significant to note a few of the responses fell under the *shifting the blame* category. A student response was categorized as this if the identified problem was with an external factor as opposed to an internal factor. An external factor is one that is not controlled by the student. The following is an example of a student who put blame on the group she was in.

Rachael's week 1 comments: I struggled with the group activities because other people in my group aren't the ones I am friends with.
Rachel's week 2 analysis: I didn't have a plan to remediate deficiencies because I can't change my partners.

This example is of a student that put blame on the teacher.

Cory's week 1 comments: We didn't have time to work in class on our worksheet with a group so I didn't understand what was going on until we whiteboarded. The example problem in the notes was nothing like the problems in the worksheet. The teachers should give more class time to work in groups. He should also give more examples that relate to the homework we will be given.

Not able to classify

There were a small number of responses that were not classified because they made no sense. This occurred only a few times but it is prudent to take note of these. The following is an example of this type of response.

Jennifer's week 2 suggestion: I am going to sing the batman song incessantly and out of tune to annoy people.
Jennifer's week 3 analysis: Yes I did.

Responses from the Questionnaire for *Research Question 1*:

As aforementioned in the introduction of this study, students often have trouble transitioning from a non-inquiry-based class to an inquiry-based class. The questionnaire (see Appendix B) directly addressed objective 1 by asking the students, "What are some things the instructor could do to help transition you from a non-inquiry-based class to an inquiry-based class?" The student responses to this question gave insight into why they were resistance to inquiry and how the instructor could help eliminate this. The suggestions for improvement were broken down into two categories: *climate setting* and *general administration tips.* Example responses are shown in Table 4.

Table 4: Improvements as presented by students

Climate Setting	General administration tips
Compare and contrast the way the class should be done and how it should not be done so that students understand what to do and not to do.	Slowly move from traditionally based class to inquiry instead of instantly…like over a months time.
Spend a day teaching inquiry and how to be successful at it.	Slowly leave the books and slowly give us more inquiry. Don't just jump in and say you have to do this worksheet and I am not giving the answers.
Have a class discussion over how to improve in certain areas.	I like how we keep the notebooks because its like we have our own book and notes all the time.

Tell us from the start how untraditional class would be and explain things more until we understand the basics. Once we have these concepts down, allow more inquiry learning/teaching.	Make problems that you have to ask about, make students want to ask questions.
Explain that answers will never be clearly given and that you might feel lost at times.	They could use some bookwork.
	Fewer notes and more hands on activities.
	Start by teaching and walking through the first couple of worksheet at the beginning of the year and then slowly give control to the class.
	If a student is trying to prove a solution wrong, you should stop them so that the rest of the class doesn't become confused.

Questionnaire Response 1a for Research Objective 2:

Question 1a on the questionnaire stated, "Was this (self-monitoring) a successful technique in helping you to succeed in this class?" Table 5 shows the results of this question.

Table 5: The helpfulness of self monitoring

	Yes	No	No opinion	total
Frequency of responses	28	8	5	41

Yes. This is a helpful technique. The "yes" response indicated that self-monitoring worked to minimize student resistance in many of the students. While not every student explained why this was a good technique, many of them did. Three trends were identified from the student responses. The first trend is it was successful because it indicated where their weaknesses were. The following examples illustrate this.

> **Pavarti's response:** It helps me point out the weaknesses I had.
> **Kallie's response:** It made me admit to myself that I was failing.
> **Joe's response:** It helped me find out what I needed to work on.

The second trend is that it was successful because it gave the students ways to improve.

> **Mindy's response:** I thought of ways to help myself.
> **Denny's response:** It got me to think about what I could do to improve my performance as a student.
> **Mel's response:** It opened my eyes to what I needed to do in order to improve and it gave me incentive to do it.

The third trend is that it kept some of the students from giving up. It was a good motivational tool.

> **Dan's response:** It was helpful because it required me to actually think about the homework instead of getting frustrated and giving up.

No. This was not a helpful technique. 8 of the 41 responses indicated that self-monitoring was not a helpful technique. Many of the "no" students felt that it did not actually help their problems. Suzy stated, "It didn't work. I always have the same problem every time." These students did not find self-monitoring a useful technique at minimizing resistance to inquiry.

No opinion. A small number of responses were classified as no opinion. Several of the responses indicated that it would have been useful if it were during a more difficult unit. Barry put it like this, "It was useful at first when the content was difficult to understand but then it got really easy, so I never struggled with anything. It then became useless." Answers like this show a depth of response. They were thinking metacognitively but they did not have any problems so there was no resistance for them to overcome.

Questionnaire Response 1B for Research Objective 2

Questionnaire response 1B asked the students if self-monitoring should be implemented again. Their responses to this question indicated whether or not this was a successful technique at minimizing resistance. Table 6 shows the distribution of their responses.

Table 6: Recommend using this technique again

	Yes	No	No opinion	total
Frequency of responses	33	6	1	40

Yes. The teacher should use this again. The overwhelming majority of the students recommended using self-monitoring again. This shows that it was helpful at minimizing student resistance. The following responses gave insight as to why it was successful.

Sue's response: While doing the weekly self-monitoring, I felt more interested in the material we were learning.
Alex's response: I would recommend it for motivational purposes.
Shanice's response: It helped you to know what your problems are and how you can solve them. This is helpful to everyone.
John's response: I felt more interested in the material we were learning.
Pat's response: It works because students would identify areas they need to improve and come up with a way to do it.

Many of the responses gave suggestions on how better to implement the weekly self-monitoring activity.

Morgan's response: It should be done every couple of weeks until a student can learn to do their own self-monitoring.
Ashley's response: It should be implemented either during hard material or only to students who frequently struggle.
Lisa's response: This would have been helpful at the beginning of the year.

No. The teacher should not use this again. A small minority of the student population did not recommend using weekly self-monitoring. For this group, it was not successful at minimizing resistance to inquiry. Several of the students indicated no because they did not struggle with inquiry thus not needing the technique. Paula stated, "I don't think the teacher should use it again. This is something that the students should decide to do on their own." Eliah put it like this, "Nope, I didn't need the help, it was a waste of time." The other students who responded no indicated it did not help them through their struggles.

DISCUSSION

Objective 1: Areas of Resistance

Many of the responses from the weekly self-monitoring activity indicated that there were no weekly struggles as shown in Table 2. The questionnaire confirmed this observation showing that many of the students stated that they, "liked inquiry teaching methods." This brings us to the first limitation of the study, since this study was done after the half-way point in the school year, many of the problems that that the students faced had been resolved resulting in a good attitude. The other reason for such a good attitude is the population is lacking students that were unsuccessful in an inquiry environment. Often students drop at the start of the 2nd semester if they dislike a class.

Even though the general feeling towards inquiry is positive, two areas of struggle presented themselves in the results. The most common difficulties that students faced were *problem solving* in the inquiry environment and a *lack of motivation* or a general sense of complacency.

Problem Solving.

The responses from the weekly sheets show that the students often struggle with problem solving because of three things: lack of mathematical skill, variable identification is confusing in context rich problems, and poor generalization skills. The results showed that in each of these cases if the problem was not alleviated then the students used this as an excuse to give up. Kirschener, Sweller, & Clark (2006) found that once students feel despair, they feel lost and frustrated often leading them to give up.

Lack of mathematical skill. As a result of self-monitoring the students themselves came up with several remedies to their own problems. For the lack of mathematical skills, they suggested using bookwork as shown in Table 4. For novice problem solvers, going over worked examples is key to achieving success (Kirschener, Sweller, & Clark 2006). A book would show example problems going step-by-step through the math. For an instructor with limited time, this would be an excellent resource to aid the students with mathematical deficiencies

Variable identification. For the problem of variable confusion in context rich problems, students suggested that the instructor should lead a discussion in which they compare and contrast how an expert problem solver approaches a problem as opposed to a novice as shown in Table 4. They need to look at how it is supposed to be done and how it should not be done. Wenning (2005b) recommended the same pointing out that instructors need to model the correct thought processes.

Generalization Problems. As a response in the weekly self-monitoring activity, Kathy stated, "It would be nice if the teacher said if what I was doing was right or wrong so I can learn stuff quicker." Students like Kathy want a simple yes or no to a problem. This was in reference to a problem that she had not seen before. This shows that she was not confident enough to generalize the information to a new problem. A solution to this as shown in Table 4 is the teacher should explain that the answers will never clearly be explained and that students might feel lost at times. Not understanding this leads to much student frustration. Felder and Brent (1996) point out that, "Students do not appreciate having their support suddenly withdrawn. It's like a shock to their system."

Students are conditioned in conventional classroom settings that the only answers that will be discussed are the correct answers. Rop (2003) observed that students lose confidence when questioned by a teacher or peer. They just assume they are wrong and allow another's response to overwhelm their own. In the questionnaire (see Table 4), the students again offered a solution, "Tell us from the start how an untraditional class would be and explain things more until we understand the basics. Once we have these concepts down, allow more inquiry learning/teaching." This may mean "stopping a student from proving a solution wrong so that the rest of the class doesn't become confused." Another viable solution to preventing this would be to start with low-level inquiry and move to higher levels of inquiry as the students mature as inquiry learners (Wenning 2005a).

Lack of motivation.

Many students identified their weekly problem as the lack of motivation or a general sense of complacency towards school. They did not want to do their homework, they wanted to sleep, they did not want to solve the problems, and they resisted intellectual depth. This is one of the greatest challenges that teachers face. How does one motivate the unmotivated? Mottman (1999) observed, "With increased exposure to physics, students like physics less." The profound thing about the self-monitoring activity is that many students identified motivation as their problem and gave solutions to overcome this problem. Results from the questionnaire illustrated that complacency leads to poor problem solving ability and a desire to resist depth of learning. A student with poor motivation will look for excuses to give up. The weekly self-monitoring activity worked to expose their lack of motivation. Instead of giving up because a problem was too hard, it gave them direction to where they needed to improve. It put the responsibility of learning on the students. It gave them tools to deal with despair and kept them from giving up. Because of this, self-monitoring can be used as a motivational tool. Darin responded on the questionnaire, "It was helpful because it required me to actually think about the homework instead of getting frustrated and giving up."

Objective 2: The Effectiveness of Self-Monitoring

As aforementioned in the discussion of objective 1, each of the problems identified by the students was given a remedy. It important to point out that each of the student-identified remedies was exactly the same as what top inquiry researchers recommended. When given opportunity, most of the students showed they can successfully diagnose their problem and can effectively remediate the problem. This provides evidence that self-monitoring is a good technique to minimizing student resistance to inquiry. The results for research question 1 were not the only evidence to support this claim. Part two of the results likewise confirm the effectiveness of self-monitoring.

Weekly self-monitoring sheets

Observing behavior change is the primary indicator to whether learning took place. The results showed that the large majority of the students reported a behavior change as a result of their plan as shown in Table 2. This indicates that the intervention was successful at reducing resistance to inquiry. Some of the plans were simple showing behavior changes in general student practices like, “keep trying” and “get along with the group.” Some of the plans offered more in-depth responses towards inquiry practices like, “I will study for retention instead of memorization” (see Table 3).

A significant number of the students reported no change in behavior as a result of their weekly intervention. Many of the responses in this classification showed intellectual honesty and provided evidence that they were engaged in metacognitive thought processes. It forced them to confront problems and remediate the problems they faced showing it was effective at reducing resistance for student responses classified as “no change in behavior.”

A small number of responses showed that self-monitoring did not work. These students either already succeeded and had no problems with inquiry practices or have already given up trying to improve. Despite this, the evidence supports the claim that self-monitoring is effective at reducing resistance to inquiry teaching in the majority of the students.

Questionnaire

When asked about the effectiveness of self-monitoring, the strong majority of students indicated that it was a helpful technique as shown in Table 5. An even greater majority of students recommended implementing self-monitoring again as shown in Table 6. They explained that it was effective because it indicated their weaknesses, it gave ways to improve, and it kept them from giving up. Only a few indicated that it should not be implemented again. In some cases they did not need the help and in other cases it did not remediate their problems. With only a few exceptions, the results from the questionnaire confirmed previous results that showed self-monitoring to be effective at minimizing resistance. However, these results are not entirely conclusive. More research needs to be done due to the following limitations: a small sample size, the study was performed for only 5 weeks, and the study lacked empirical data. Follow up research should be done with a larger population of inquiry students, it should start earlier in school year, it should span a greater time period of the semester, and needs to be performed on an experimental and control group.

CONCLUSION & IMPLICATIONS

Engaging students in metacognitive practices like self-monitoring is necessary when transitioning a group of students from a conventional science class to an inquiry class. The results indicate that self-monitoring helped minimize resistance to inquiry in most of the students. When using self-monitoring to transition students into an inquiry class, it would best be introduced at the beginning of the school year during the initial climate setting discussion. As the instructor discusses how to deal with cognitive dissonance, they should introduce the self-monitoring worksheets. The self-monitoring worksheets model the necessary thought processes for novice, non-inquiry problem solvers to blossom into expert problem solvers.

In this way, the teacher can guide the thought processes of the students when they feel helpless. Once the students learn how to deal with cognitive dissonance then learning through inquiry becomes a less stressful and more enjoyable process. As the students pointed out in the results section, “This is something that the students should decide to do on their own.” Eventually, the instructor should not look over their responses. The goal is to empower the students to become independent learners. The students also gave the following advice concerning the administration of the activity, “It should be done every couple of weeks.” Issuing the activity every week was burdensome and redundant. It would be more effective every couple of weeks so that the students have time to implement their interventions.

It is observed that the students that are most stubbornly resistant to inquiry often look to undermine the teacher and disrupt the learning of the class. As the instructor is reading over the responses of the students, he or she should make a note of students that are not acclimating to inquiry and focus on helping them on the individual level. If these students can be helped early on, then much of the teacher’s stress concerning disciplinary issues would be resolved and the students may never reach a point of despair.

The results of this study showed that some students had already given up on learning through inquiry by the time the intervention was enacted. More research should be done on the effectiveness of this instrument at the beginning of the school year. It may prevent these students from giving up and help them to have a positive experience with inquiry. Another possibility for further research is on how to deal with students that have had a negative experience in a prior inquiry class.

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APPENDIX A

Name ______________________________ Date ____________ Period ________

Week #2 Self Monitoring Sheet

Instructions: Answer the following.

1. Look at last week's struggle from your previous "Self Monitoring Worksheet." Did you implement your plan to remediate your deficiencies? Did you achieve success in these areas?

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2. Identify concepts or activities with which you struggled this week? Why did you struggle in these areas?

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3. Write a plan to remediate any deficiencies you identified in the previous question.

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APPENDIX B

Interview Questions for the end of the experiment follow up discussion

1. Give me some feedback concerning the self-monitoring worksheet.
    a. Was this a successful technique in helping you to succeed in my course?
    b. Would you recommend implementing this on a regular basis?
2. What are some other things I could do to help transition you from a non-inquiry-based course to an inquiry-based course?

Classroom layout in a technology-enhanced physics teacher education course

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This research investigates the pedagogical decisions involved by a physics teacher educator involving the physical layout of a classroom during different portions of a graduate-level physics teacher education course. Throughout the progression of the semester-long course, 16 graduate-level inservice and preservice physics teachers investigated concepts in kinematics and dynamics in an inquiry-oriented approach with high levels of technology integration (real-time data collection and analysis). Depending on the physics concepts under investigation (distance, velocity, acceleration, forces, etc.), the instructor chose a different physical classroom layout regarding the tables and chairs, and the directions that the students were facing. Data indicated that the physics teacher educator utilized different collaborative and grouping methods, Socratic tutoring technique, and interactive lecture demonstrations (ILDs) where he deemed appropriate. Implications from this study include an affirmation for modeling effective and appropriate secondary teaching methodologies in physics teacher education, with a specific emphasis on the pedagogical decisions involving physical classroom layout.

Introduction

The call for teachers to find out what their students know and teach them accordingly (Ausubel, 1968) must also ring true for science teacher educators. Yet, teacher educators are often caught between a rock and a hard place in terms of the amount of background knowledge that their students (current and future teachers) bring to the education classroom. Many teachers often bring the content knowledge to their classrooms that they learned as successful students in their particular subject matter area of expertise. Teacher educators are faced with the dilemma of educating their students about student learning. Often, this is done primarily through the use of classroom discussions and educational literature (Hoban, 1997). While integrating these techniques for learning about teaching and learning are crucial aspects in becoming a practitioner, teacher educators must also present some models of teaching that bring into account these different ideas of student learning, classroom environments, and constructivist theory. The question is: how do teacher educators bring all of these factors, which are so crucial to becoming a successful teacher, into teacher education programs?

A critical component of the pedagogy of teacher educators is the notion of pedagogical content knowledge (PCK). PCK can be loosely categorized as the intersection of appropriate combinations of pedagogy and content that will allow for the optimal teaching and learning of particular concepts (Shulman, 1987). It is the goal of teacher educators to strive to develop an awareness of PCK within their students. The integration of pedagogical-appropriate technology within an already existing framework of PCK is the goal of this investigation – aptly named Technological Pedagogical Content Knowledge (TPACK). TPACK has recently gained traction as a schema of categorizing teachers' professional knowledge of teaching their content area with appropriate technology integration (Baldwin, 2004; Baldwin & Sheppard, 2003; Mishra & Koehler, 2006). Figure 1 illustrates the relationship of pedagogical knowledge, content knowledge and technological knowledge with the resulting intersection of TPACK.

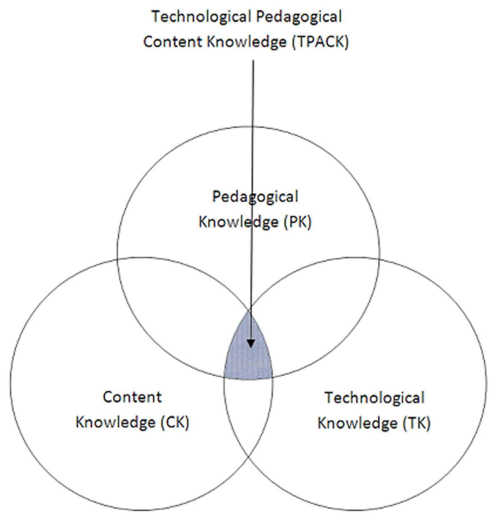

Figure 1: Technological and Pedagogical Content Knowledge (TPACK)

One accepted method of teaching teachers to teach is the use of modeling (Faison, 1996; Munday, Windham, & Stamper, 1991; Pope, Hare, & Howard, 2002). In fact, Russell (1997) posits that how teacher educators teach teachers is more important than *what* teacher educators teach teachers. Other pedagogical methods that teacher educators often employ include helping their students become reflective practitioners (Schön, 1983), and helping their students become advocates for social transformation (Ginsburg, 1988).

This study investigated specific pedagogical techniques resulting in modifications in room layout that one physics teacher educator used in order to introduce his students to what he considered to be proper techniques for developing technology-enhanced PCK in the prospective teachers.

While there has been an increasing body of research that investigates the impact of technology within K-12 classrooms, there seems to be a shortage of research into *how* technology is integrated by science teacher educators into *their* classes. Some notable studies focus on the development of TPACK skills during student teaching internships (Niess, 2005), yet there is little agreement on integrating TPACK strategies within science methods courses. One camp argues for technology integration within methods courses (Angeli, 2005; Li, 2005), while others call for stand-alone educational technology courses, often not subject matter specific (Hargrave & Hsu, 2000). Previous research on attitudes, beliefs, and self-efficacy regarding teaching with technology has shown that the quantity and quality of teaching with technology in both K-12 and teacher education classrooms is directly related to these factors (Vannatta, Beyerbach, & Walsh, 2001). Yet, the studies fall short of determining how these attitudes are related to both educational philosophies and teaching behaviors specifically related to technology (Mullen, 2001). Further, prior research does not focus on specifically on pedagogical decisions involving room layout when teaching courses with a heavy infusion of technology (Stetson & Bagwell, 1999). This study seeks to remedy that gap.

Changes in appropriate and affordable technology have made technology widely available and pedagogically a potentially powerful tool in teaching and learning science, especially physics. Many school districts have taken the initiative to integrate technology hardware into their schools, unfortunately often without appropriate training for the teachers in its effective use. Science teacher educators should be aware of contemporary technology tools with which to prepare current and future physics teachers. This requires of them knowledge of the hardware, software, and pedagogical skills needed for effective use within the K-12 setting. Further, it also requires knowledge of how technology can be effectively integrated within the teacher education setting, especially as the ever-increasing call for qualified science teachers has led to a changing population of teaching candidates in colleges of education.

Prior research on the role of science classroom layout has focused the role of collaborative learning (Biehl, Motz, & West, 1999; National Research Council, 1996; Veal & Jackson, 2006) by providing student workstations large enough to accommodate small groups. While collaboration between students while learning science concepts is a noble goal, there is often not one single method of collaboration that would serve this need. Hence, the call for a flexible science classroom that can be easily modified to fit the space requirements of the curriculum in general, and of the lesson in particular.

Conceptual Framework and Research Question

This research set out to address the following question: What are some of the ways that a physics teacher educator modified the classroom layout when instructing a semester-long graduate-level course for prospective and novice physics teachers while integrating technology throughout the course? A secondary interest centered on specific features of the classroom that limited the instructor's choices in modification of the learning environment, namely non-movable tables, dimensions of the room, and locations of the walls. The qualitative approach of utilizing a case study was chosen to address this issue.

Case studies have been used in education research in many different ways. Providing for the need for the rich descriptions required by case study analysis, each class session of the course was observed and notes were taken in a field journal about the concepts that were covered in each class session, as well as the pedagogical methods that the instructor utilized in order to present the material. These observations included field notes and interactions between the students, as well as between students and instructors during the courses. The field notes for each class were taken in a journal, and were used as an additional source of triangulation for data that were obtained via other methods (namely, interviews with the instructors and students). Semi-structured interviews were conducted with the instructor and students throughout the course. The interviews were audio-taped, and transcribed for later thematic analysis. The interviews progressed and continued throughout the duration of the entire semester in which the course was offered. Introductory interviews with the instructor and students were conducted to obtain self-reported descriptions of their beliefs, attitudes, philosophies, and experiences in teaching and learning. Follow-up interviews throughout the semester focused on the development of these attitudes and beliefs as a function of the progression of the course and the impact of technology. Sixteen semi-formal interviews were conducted with the CIP instructor. The interviews commenced the afternoon prior the first class session, as the instructor was finalizing the syllabus for the course. This introductory interview focused on some of the underlying educational philosophies of the instructor, his views on science teaching and learning, as well as his background on technology in education. This initial interview was pre-structured and semi-formal with a protocol of questions that the interviewer had prepared for the instructor to answer.

Subsequent interviews with the instructor were conducted throughout the semester, normally during the afternoon of the day following an evening class session. These subsequent interviews often touched upon issues that arose in previous class sessions, attempting again to triangulate data from field notes written during classroom observations with his rationale and/or explanation for events that took place during the class. These interviews had two or three guiding questions that were generated by the researcher from review of the videotape and observations from the previous class session.

The final interview with the CIP instructor also took place during the afternoon of the day following the final class session. This interview, like the initial interview, was also pre-structured and semi-formal. A major topic of this interview included the instructor's overall analysis of the course and his thoughts on the impact of technology on the course. Additional topics included the instructor's rationale for assessment of student work for the semester, as well as a continuation of his philosophies about science teacher education and technology integration.

All of these interviews were conducted by the researcher, audio-taped using a digital voice recorder, and transcribed by the researcher within a format utilizing Microsoft Word built-in styles. When all styles and formatting had been applied to the interviews, the raw interview transcripts were saved in Rich Text Format (RTF) for subsequent analysis using the NVivo software package (Gibbs, 2002).

This study focuses on the technology integration practices of one physics teacher educator at a well-known graduate school of education on the east coast of the United States, with special emphasis on the pedagogical decision making on classroom layout that he employed in his conscious decision to integrate technology throughout the course. The semester-long course was entitled Concepts in Physics (CIP), a graduate education course which, for purposes of state certification, counted as a content area course. CIP met a total of 16 times throughout the semester for a total instructional time of 1500 minutes.

Data and Analysis

In reality, CIP was a pedagogical content knowledge (PCK) course in which the students (consisting of 16 pre-service or in-service secondary science teachers) investigated different aspects of kinematics - the branch of physics dealing with motion and its graphical and mathematical representations. Toward the end of the semester, the students began investigations in dynamics (forces and momentum). The instructor selected a research-based curriculum entitled Real Time Physics (Sokoloff, Thornton, & Laws, 1999). The experiments and lessons in this curriculum were research-based to incorporate student misconceptions, as well as based on cognitive theories of how students learn. The material in the curriculum was targeted at a high school physics class, or an introductory level college physics class. The lessons in this curriculum incorporated real-time data collection devices with real-time graphical analysis, utilizing the hardware and software mentioned above. Computers were used in all class sessions, and extensively within each class session.

For the purposes of this course, the word *technology* was operationally defined as pertaining to the use of computers and their peripherals (i.e., data collection input and output devices) to aid in the pedagogical activities within the classroom. Technology was a "fully integrated" component of the learning environment, meaning that it was used in each and every class session as a tool with which the students investigated both concepts in physics and physics pedagogy. In today's education vernacular, "technology" is often synonymous with internet applications. However, in this course, the use of the internet was minimal (in the instructor's view) in aiding the students' understanding of the concepts taught in the course. The introductory interview with the CIP instructor revealed much about the nature of the technology to be used throughout the course, as well as the instructor's thoughts for its usefulness. Throughout every class session, real-time data collection devices (Vernier probes and sensors) were used in conjunction with real-time data collection and graphing software (Vernier Logger Pro software). In other words, the instructor downplayed the use of pre-made interactive tools for learning physics concepts, and focused more on the authentic experience of his students collecting and analyzing their own data in real time.

Grouping. The classroom organization of students into different groupings was an integral component in terms of pedagogy and content. In the first part of the course, the students worked in small groups of two or three students. In the second part of the course, the instructor led two whole class sessions in a series of interactive lecture demonstrations. The final part of the course was characterized by students working in groups consisting of four students. In each of these parts of the course, the use of the technology by the students varied, as did the pedagogy exhibited by the instructor. The intricacies of the technology usage and the instructor's pedagogy are described below.

Small Groups. During the first four class sessions, the students worked in two- or three-person groups, investigating the concepts of distance and velocity versus time. There were six student groups spread throughout the room, and the tables and chairs were moved to accommodate the need for ample, unimpeded space so that the students could walk in front of the motion detectors and produce a graphical display of their motion. Figure 2 shows a schematic of the setup of the motion detector, interface device, and laptop computer for graphical display, while Figure 3 shows an overview of the room with each of the different workstations.

Figure 2: Technology setup consisting of sensor, interface and laptop computer connected via USB connection

Each station in Figure 3 contains a set of the equipment shown in Figure 2. The walking areas highlighted in figure 3 (the shaded areas) are the areas that the students walk back-and-forth in relation to the motion detector. The setup worked in the following manner: the motion detector emits a series of ultrasonic pulses (sound waves) at regular intervals (usually 20 pulses per second, but customizable by the user). As the pulses hit an object, they are reflected back towards the motion detector. The time interval between the initial emitted pulse and the reflected pulse is calculated by the software, enabling further calculations on the distance that the wave traveled before it was reflected from the object (the person). A graph is displayed on the computer screen with different variables (defined and customizable by the user), as distance vs. time, and/or velocity vs. time. The group members were rotating between two different roles: one who was walking in front of the detector, and one who was initiating the software on the computer.

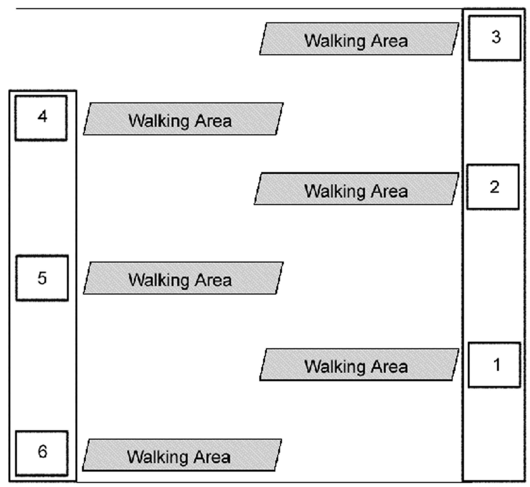

Figure 3: CIP room setup, Class sessions #1-4

During these initial four class sessions, the pedagogical techniques that the instructor used all had the effect of requiring all the students to slow down in their investigations and to think critically about the subject matter under investigation. The instructor rationalized this as follows:

> Everybody who has been through science education and lab knows that there is a premium to speed. One must get through the curriculum fast, got to get this worksheet filled out in time. This was my means of slowing them down. They had to get a check-out and I made sure that they had everything I think that is important before they go on to the next one. That was the strategy behind that, and that comes from my understanding of what they're going to do. They're going to just blast through this, fill in all the blanks real quick, and feel satisfactory that they get it done before the end of the period. That's just an attitude that some have. I want to get them to go into depth. I want to slow them down, and basically I do that with deeper questioning to make them think a little harder about it. No curriculum teaches itself. You need to have a teacher there to give them this curriculum, it doesn't mean that they benefit from it or actually learn from it. You need a teacher there who understands it forwards and backwards, who knows the critical moments to ask just the right question. Sometimes its successful, and sometimes its not. Sometimes it's more successful than just going through the curriculum. So, that's my attempt to slow them down.
>
> Interview with CIP Instructor, February 2

One method that the instructor used to ensure that students progressed at a slower pace was to incorporate a sign-out sheet on the front board at the completion of each activity in the curriculum. An activity normally included a prediction, a written description of the motion, graphing of the data, followed by analysis and short-answer questions. Each of these activities required 20 to 30 minutes of classroom time. As the groups finished an activity, one group member would write the group name on the board so that the instructor would come to their groups and ask them some additional questions based on the activity. The instructor's rationale for this method was to force the students to slow down, as his experience told him that students tended to rush through the material in the curriculum without each group member having an opportunity to both have their motion graphed on the computer screen and allowing a kinesthetic experience of relating the movement of muscles with particular intricacies of the graphs produced.

After a couple of class sessions, the instructor dropped the check-out list, and simply rotated from group to group, interjecting comments and asking questions of each of the group members. The instructor stated, "I think eventually I could just kind of drop that thing and just go around and around and know if they got what they should before they go on to the next thing. I may not always do that though." (Interview with CIP instructor, February 3) In this manner, each class session progressed in a more interactive nature with the instructor's interactions with the students incorporated throughout the investigations, as opposed to functioning solely as a method by which to slow students down. Dealing mainly with the kinesthetic movement of the students in front of the motion detectors, the students were able to graph and analyze their own motion.

In summary, the CIP instructor had many different foci when selecting the instructional techniques used in the class. First of all, he wanted them to experience the material as students would. Secondly, he wanted them to progress at a slower pace, which was initially accomplished by the sign-out sheet, and eventually by his integrated questioning strategy. Thirdly, he wanted the students to implicitly learn some pedagogical techniques based on his modeling of effective teaching techniques and questioning strategies.

Interactive Lecture Demonstrations. Interactive lecture demonstrations (ILDs) were performed by the instructor with a set of the technology equipment on the demonstration table at the front of the classroom, with the results of the demonstration projected onto a screen, as noted in Figure 4. Students are asked to make predictions about the upcoming demonstration and then the demo is carried out. Building on the topics that were investigated during the initial small group work, the instructor led the students through a series of demonstrations that involved a low-friction track and cart, with the motion detector attached to measure the different parameters of distance and velocity, with an introduction to the concept of acceleration.

The chairs and tables were brought back into the room, and the students were arranged in different four-person groups by the instructor. Each group of four students sat at one of the lab tables during the interactive demonstrations. For each different demonstration, the instructor instituted a specific set of steps that he wanted the students to progress through. The first step involved a prediction about the graph that would be produced by the movement of the cart. Depending on the particular demonstration, the graph could be distance vs. time, velocity vs. time, or acceleration vs. time graph. The students sketched the predicted graphs with a dotted line on a blank graph sheet. The next stage of the ILD was what the instructor deemed the "convince your neighbor" phase. During this phase, lasting 30 seconds to one minute, the group members shared their predictions and attempted to attain consensus about the shape of the graph after the experiment was run and the data was collected. After each group had reached a consensus, the instructor ran the experiment and the data was collected and displayed on the screen in real-time. Finally, the instructor led a short class-wide discussion about the particular demonstration. During the two class periods that ILDs were used, the instructor completed approximately ten different ILDs, using each of the steps as outlined above. These steps follow previously documented steps in effective ILD usage in a classroom (Sokoloff & Thornton, 1997).

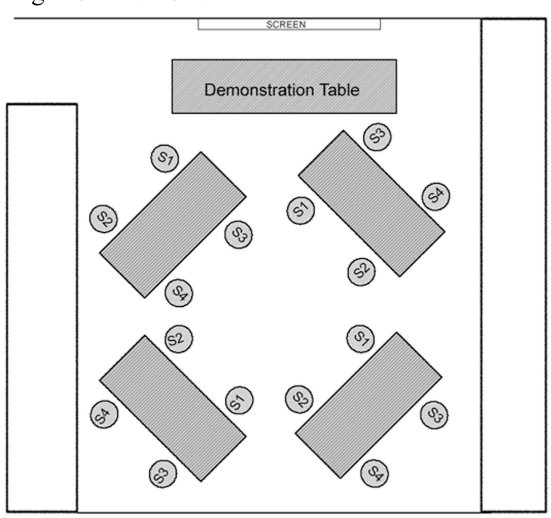

Figure 4: Room setup during ILD class sessions

<u>Four-person groups</u>. During the remaining six class sessions, the students remained in the same four-person groups assigned for ILD class sessions. In these class sessions, students worked through a series of activities investigating more (traditionally) difficult areas of motion, leading to the concepts of acceleration, forces, and momentum. Each group had their own laptop computer, motion detector, force probe, low-friction track, dynamics cart, as well as a fan accessory to investigate external forces. A setup of the new room arrangement is provided in Figure 5.

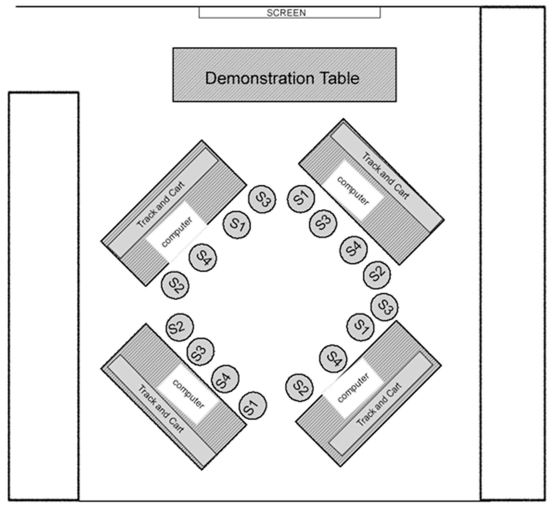

Figure 5: Room setup during four-person groups

In this new room arrangement, the instructor required all students to sit on the "inside" of the tables, so that all group members could see both the movement of the cart on the track, as well as the computer screen showing the real-time display of the data. According to the instructor, this was all part of his plan for modeling appropriate pedagogical strategies for his students:

> This technology and this way of teaching and learning suggests a different arrangement for the learning environment. You need an interactive setup. The students have computers which face towards the center of the room, so the teacher can be at the center, although this is not really a teacher-centered environment. The teacher is at the center of the room. They can simply see what is happening on every screen, simply by rotating in place. They can go over and ask students questions at the appropriate moment when the timing is right. It also allows students to see what other groups are doing, and where they're at. It gives them confidence, gives them ideas. Plus, it encourages the idea of the group effort in some sense. They're all working on the same problem, and trying to sort them out. Hopefully it's modeling a way of arranging the classroom when you use computers. Instead of having aisles and rows and files, where the computer screens all face to the back of the room with the teacher standing at the front, the teacher never knows what is going on with the computer screens. In fact, you had to come from the back of the room to see what was going on. This way, the teacher can see what each group was up to, and see it as a means of getting the right amount of Socratic tutoring and to see what is going on in the classroom.
>
> Interview with CIP instructor, April 1

Conclusions

In summary, the CIP course used real-time data collection technology with motion detectors, force probes, and computers. The pedagogical methods that the instructor used in the different sections of the course was mostly manifested in the different groupings of the students: small groups, ILD class sessions, and large groups. The instructor also engaged in questioning strategies which enabled the students to build on the knowledge that they were forming through the curriculum that was being followed throughout the class sessions. In answering the research question, the instructor utilized real-time data collection through the use of computers and motion detectors. The pedagogical strategies that he used included the division of the class into groups, ILDs, and his own questioning strategies when circulating among the groups.

Implications

The CIP instructor's beliefs about PCK within the teacher education classroom focused on learning the science content. He believed that in order for teachers to teach differently, they must first learn the content differently. He demonstrated this in his own actions by choosing to focus primarily on the teaching and learning of the physics content, as opposed to spending large amounts of instructional time dedicated to either pedagogical strategies or technology outside of the context of the physics concepts under investigation. He truly believed (as stated in both interviews and classroom observations) that with this approach to physics teacher education, he was able to successfully model PTACK for his students.

As stated above, the instructor focused predominately on the physics content. However, a point must be made of the purposeful pedagogical decision to *not* focus on the teaching of the pedagogical strategies (inclusive of teaching with technology). By arranging the room according to the learning needs of the students, he simply modeled what he felt to be appropriate physics teaching practices and left it up to the students to realize that he was trying to convince them that his pedagogical methods were successful in enabling them to learning *both* the concepts and pedagogical strategies in teaching secondary physics.

Capitalizing on the flexibility within the classroom, the instructor was able to mold the classroom to meet the needs of both the curriculum and his vision for the most beneficial physical learning environment for his students. This point cannot be overstated. Far too often, little effort is expended by instructors both at the level of teacher education or in the secondary level to physically modify a classroom in order to meet the needs of a curriculum, or of individual lessons. In this case, the physics teacher educator was able to model for his students different room arrangements which benefitted their learning styles based on the physics concepts under investigation. In order for any technological enhancement to occur in a classroom (physics or otherwise), attention is often not given to changes in room arrangement to account for the technology. Handing out computers to students to discover new concepts and refine their own knowledge was only one small part in this physics education classroom – the real benefit to the prospective teachers was to learn both the physics concepts and the pedagogical skills associated with being a successful physics teacher. These skills were effectively modeled by the instructor.

The physics teacher educator profiled in this study applied his practical classroom experience as a former K-12 teacher into a meaningful education course for preservice and inservice physics teachers. Yet the true test of the technology integration itself rests ultimately on student achievement in the different science disciplines. While this study does not predict that students will greatly and immediately improve scores on standardized exams, there is hope that with technology integration will become an increased knowledge of the processes of conducting a scientific investigation, as well for the ownership of learning different conceptual ideas. As standardized tests eventually incorporate more of these scientific process ideas into their format, the payoff will be realized for the integration of inquiry-based techniques within K-12 science courses.

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