

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, 1995; 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 liaison 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 entuse 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

Grades
9-12

