Coordinating Science Education, Outreach, and Research

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ABSTRACT

This paper describes the development of a new university physics course which integrates physics education, research, and community outreach. The coordinated system of activities links the new course to local community efforts in pre-college education, university education, university outreach, and research on teaching and learning. The course was found to improve student understanding of physics and understanding of learning principles. Simultaneously, the course supported efforts in community outreach and created a rich environment for education research. The following narrative describes the motivation, structure, implementation, effectiveness, and potential for extension of this new model for science education.
MOTIVES

In science, a new vein of education research is emerging. Departments of science are now realizing the importance of developing a tradition of education research from within a discipline. In physics, much of the university reform is being led by physicists who have turned their attention to understanding how better to serve students. As a result, education research groups are beginning slowly to appear within these physics departments. The mission of such education research varies from empirical studies on how to revitalize undergraduate classes to cognitive research attempting to better understand how the mind works. Universally, however, faculty are beginning to realize that the traditional lecture-style physics course fails to impart a deep-seated conceptual understanding and framework of physics.[1] As a result, a new breed of physics class is evolving -- one that encourages student engagement. Additionally, the physics community is beginning to re-assess its purpose and the purpose of undergraduate courses in physics. One outcome of this reassessment is the realization that education research is an integral part of physics[2] Another outcome is that departments of physics and schools of education realize the need to better prepare teachers of physics.[3] Moreover, physics education research is a mechanism by which universities may coherently address their multi-faceted missions.

At an institutional level, the University of California, like many institutions of higher learning holds a tripartite mission of research, teaching, and community service. However, since the mid-Twentieth Century universities have emphasized research, and stand to gain from a coordinated set of activities which leverage local resources to enhance all three goals. Furthermore, in California and elsewhere a host of political initiatives and educational reforms have challenged the University’s ability to meet its charter commitment to serve all of the state’s population.[4] A significant response from both the legislature and the university system is to support community
service and outreach in an effort to better prepare potential students from traditionally under-represented populations. As the university seeks to develop stronger community-based programs, it often turns to research-based outreach activities which have been proven effective.

This research paper addresses these dual problems: 1. the improvement of student interest, understanding, and ability in physics, teaching, and learning, and 2. the creation of a sustainable system which addresses the multi-faceted interests of the university.

**COURSE STRUCTURE**

The seemingly disparate nature of these goals may also be seen as an opportunity given the right vantage point. In general, the goal is to achieve a sustainable system of activities which benefits each of the involved parties by serving undergraduates, addressing community outreach efforts, and providing a rich environment for educational research. Such an effort follows the work of Cole and others who create rich theoretically motivated environments for learning and fundamental research.[5]

In measuring the success of student learning, Cole cogently argues that assessment of cognitive ability is contextually dependent -- that is, the further an experiment or study is removed from the domain of use/application, the less applicable the results.[6] This same notion has been reported in a somewhat different form in physics. Studies, such as those using the Force Concept Inventory (FCI), report that while students may perform well in a traditional physics course, a course in which they have managed to master formulae and various mathematical manipulatives, the students miss the broader setting and conceptual basis for the discipline physics.[7] Either our conception of what constitutes physics has changed, or we have failed to accurately assess student ability in physics. In traditional lecture-style physics courses, the domain that we are newly assessing (conceptual underpinnings and structure of physics) is now only loosely correlated with
the domain of instruction. The creation of a new inter-related system of activities is designed to address this failure.

The focal point of this coordinated system of activities (that which links teaching/education, research and community outreach) is a new course composed of three elements: a study of physics content, readings in teaching and learning physics, and practical experience teaching physics. Each of the components is designed to complement the others by providing a varying perspective from which to view physics. Because the course draws upon and addresses questions for various disciplines (physics, education research, and community service), it sits on the interfaces between each of these communities. Star and Griesemer term such objects *boundary objects*:[8]

> [Boundary objects are] objects which both inhabit several intersecting social worlds and satisfy the informational requirements of each of them. Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites.

This course borrows material and methods from each of the bordering disciplines. Upon observing the course, members of each of the bordering disciplines recognize familiar elements of the constructed environment, be they readings, activities, forms of discourse or even participants themselves. Not only do the course participants benefit from the variety of resources, but by acting at the interfaces between disciplines, the class provides a mechanism of communication and coordination of the disciplines themselves. For the departments of physics and education, the course serves as a catalyst and object of discussion and coordination. For the students, the class acts as a portal from physics into education and teaching. For the outreach program the course strongly links university efforts in science to community service. Figure 1 illustrates some of these relations. The figure depicts the three interacting components of the course at the vertices of a triangle. Each of these components necessarily interacts with the others, as will be described in
detail below. Furthermore, each of these components lies within varying disciplines. As a discipline, physics addresses physics content and issues in teaching. Education concerns itself with both the theory and practice of teaching and learning. Lastly, efforts in community outreach blend the practice of teaching (fieldwork) with content (physics) in community-based settings. Of course, the boundaries of these domains are not fixed, nor are they mutually exclusive.

In the new model of physics course, I tailor the environment to engage the students in activities which engender both broad-based skills (problem solving, analysis, meta-cognition, presentation) and specialized skills (physics content, knowledge and practice in theories of teaching). Additionally, the course is designed to be flexible enough to capitalize on the emergent nature of the activity. That is, because the participants, locales, and even the content are dynamic
in nature, the precise form of the activity system changes over time. This assertion does not claim that the physics itself is changing (though many may argue about the social construction of the discipline), but rather since facets of the system are fluid, and an open structure allows the coordinate system of activities to adapt to the local context. The arrangement of the components of this activity system may be thought to be skeletal in nature, and the actual content, interaction, and environment form the “flesh” that is placed upon the structure.

**COURSE IMPLEMENTATION**

Each of the three class components (physics content, theories of teaching and learning, and practical teaching experience) represents roughly one third of the course. One of the two weekly class sessions predominantly focuses on the study of traditional physics content. The other emphasizes readings in physics education, and cognitive theories of learning. At least once per week, students engage in the laboratory portion of the course, teaching. As much as possible, each component is integrated with the others. The lines between the activities are purposefully blurred. A student reading about theoretical difficulties in understanding the concept of electric field is encouraged to wrestle with his own understanding of the topic. Furthermore, as much as possible, there is a temporal alignment of the activities. The same week that students study about electric fields, they read about student difficulty understanding the concept of fields, and attempt to teach the concept to others.

*Physics 180/ TEP 105: Teaching and Learning Physics* was first offered Spring quarter 1999. As a pre-requisite for the course, students must have completed the introductory sequence in physics. The ten week class met 3 hours per week on the UCSD campus. Additionally, students performed 2-4 hours per week of fieldwork, teaching in local community centers and schools.
Each component of the course primarily addressed the domain of electricity and magnetism (E&M).

The physics content reviewed approximately two-thirds of an introductory course in E&M (using texts such as Halliday, Resnick and Walker [9]). While calculus was used in the analysis of problems, mathematics and symbol manipulation were not emphasized. Rather, each topic was introduced from a conceptual viewpoint, and placed within a broader context of other topics in E&M. Similarly, the physics segments shifted focus from symbolic representation and the coverage of text to an active engagement of the students in project oriented lessons. Students engaged in lessons which fostered active construction of mental models of physics. Most often these lessons focussed on the physical construction or public presentation of material.[10] These lessons varied from tutorials,[11] to discussion, to teaching and materials development. The topics were designed to have students confront traditional and demonstrated misconceptions in the domain.[12] The class was designed to encourage student learning during class hours, rather than after hours. Homework was assigned, but emphasized the conceptual understanding of content. For traditional text-book based problems, students were required to reflect on the solution process and critique the problem in addition to deriving answers. Other homework assignments included interviews of novices or teaching advanced concepts to novices, and subsequent write-up of the process and results. Each of these practices was designed to foster the dual development of mastery over the content and meta-cognitive skills such as reflection, regulation, and epistemological development.[13]

The second component, readings in physics education research, occurred in a seminar format in which each session began with brief student presentations, followed by discussion. Students were encouraged to support or refute theories using evidence from the other components of the
course. Readings in physics education research fell into several categories: empirical research,[14] theoretical underpinnings of physics,[15] or cognitive science of the teaching / learning process more generally.[16] Students handed in weekly summaries and / or question relating to the readings. The informal notes insured that students read the assigned papers, and forced some level of reflective analysis. As will be discussed in the evaluation section below, reflections upon these readings showed up in the other areas of course-work.

The fieldwork component served to provide students with practical experience both in physics and in theories of teaching and learning. The teaching occurred at four sites, in and after school hours at the junior and senior high school level. Students were encouraged to develop and teach their own curriculum (within E&M); though in each instance, students were supervised by the university class and by a local coordinator. In this fashion, student fieldwork differs from more traditional service-learning models, because the students are guided and studying the process of teaching while engaged in the process itself. Each week students were required to write-up detailed fieldnotes describing their experiences, curriculum, interactions, and reflections. In addition to using the fieldsites as opportunity to refine and test theories, students used the sites as resources for research for their final projects and papers. Again, the final papers were a mechanism for students to reflect back upon the quarter’s activities.

EVALUATION

The success of the activity system is assessed in several ways: at the level of students, as a research venue, and finally as an organizing tool for institutional coordination. Predominantly, I focus on response at the student level. However, this reflects my current bias as a research site. No less significant is the analysis of this system as a research site, or the role that this activity serves in the coordination of various institutions.
Teaching / Learning -- student ability in physics

Of primary interest is the question of whether or not the course participants improved in the domains of physics, education, and teaching. Student ability was assessed by pre- and post-testing conceptual understanding of electricity and magnetism, by evaluating homework, from interviewing students, and from recording in-class performance. Through each of these measures students demonstrate improvement in understanding in physics. The pre- / post- test data are shown in Figure 2. The diagnostic test was a mix of thirty-five free-response and multiple choice questions drawn from the Conceptual Survey of Electricity and Magnetism, the Electrical Circuit Concept Evaluation, and material of my own design.[17] The independent axis list individual students, the left most being a student who has never formally studied the material. The right most student being a fifth year graduate student in physics. A dashed line indicates a division between physics majors and non-majors. The dependent axis plots student performance. The mean pre- and post-test scores are respectively 54% (standard deviation=25%) and 74% (s.d = 24%). The average of individual student gains is 51% (s.d.=30%; N=13).[18] Aside from demonstrating improved conceptual understanding of physics, a few points are worthy of note. No students show a complete grasp of the material at the beginning of the course. Furthermore, some of the students, even physics majors perform at levels equivalent to or below the unschooled student. Generally, those students who had a better grasp of the material upon entering this class made greater improvements than those who were weaker at entry. (The half of the class that performed best on the pre-test made average gains of 66%; whereas, the bottom half of the class made gains of 31%.) Perhaps this is due to the challenge of offering a class to such a diverse range of student backgrounds.[19] As noted the students background in physics spanned a range
of as much as eight years of exposure. On average, there was no statistically significant bias by gender.[20]

Observational notes written immediately following each class serve as a complementary tool for evaluating student understanding. My ethnographic observations are full of examples which corroborate the above data -- students do not begin the course with expected grasp of material:

*week 4:* I write of two students in class, “their conceptual failure was a very clear mark of not having learned / retained the physics from the prerequisites to my class. Furthermore their conversation revealed that they hadn’t done the reading ...”

These same notes are useful for catching moments of student learning, documenting students’ progress and evaluating the instructional process:

*week 6:* regarding the same students, “From this discussion it became very clear that H, whom I had asked to step to the board, didn’t really understand electric fields all that well (the topic had recently been covered in Phys 180, and the class pre-req.) ... it was clear that
the discussion helped 2 people in the room (S and H), was probably useful for M (whom I often caught guessing).

An integral part to understanding and learning physics is wrapped up in students attitudes about physics. By quarter’s end, in open ended evaluation of the course students report on their own understanding of material, and greater comfort and interest in the subject area:

“I’m finally enjoying this material [E/M ...] Overall, I’ve learned (understand finally) so much about E & M and I’m learning about techniques to teach it” - week 5

“I learned a lot about teaching, and even found a new interest in the subject of physics through this course” - week 9 [Biology major]

 “[The best part of the class was] discovering that I didn’t know what I thought I knew about physics” - week 10

I’m not good at [discussion]. This is really the first class where I have really had to talk about what I think” - week 10

These statements belie greater import than simply changing students’ attitudes. The goal for students in this course was not simply to improve their conceptual understanding of and attitude towards physics, but also their epistemological development (what it means to do or know physics) and their awareness of their own understanding.

Following Hammer’s metric of epistemological development in physics,[21] students are moving from a belief that physics is simply a mastery of disjointed formulae handed down by authority to a belief that physics is a coherently organized and related set of principles useful for an independently developed understanding of the world. Furthermore, it is evident from the above quotes (and those given later in the paper) that students are now more aware of their own knowledge, and able to control their learning process. In Schoenfeld’s terms of meta-cognition, they are self-assessing and regulating their knowledge of physics,[13]

The development of students’ abilities in physics, their conceptual mastery, their attitudes, their conceptualization of what physics is and how it is organized, implemented, and learned, and
their ability to monitor and modify their own level of understanding physics is all tightly coupled
to their teaching experiences.

**Teaching / Learning -- student ability in teaching**

As with student attitudes and images of physics, in open-ended evaluations of the course,
students report improved ability and interest in teaching:

“I got so excited [about teaching]” *week 10*

“I thought I had a pretty good grasp on how to teach physics, but I’ve learned enough to
revamp my whole style” *week 9* - Graduate Student TA in physics

“I loved fieldwork b/c I actually was able to observe the teaching theories involved in class
and even put them into practice” *week 10*

“This [fieldwork] really drove home some of the points made in our discussions and
readings” *week 10*

Again, students indicate changes in attitude about teaching. They report also that their
conceptions teaching have changed. In pre- and post- ‘statements of teaching,’ students reflect
upon what it means to teach: [22]

**DM: pre:** “... there seems to be two ways of going about [getting people to learn]. One
school of thought is that repetition is how one learns, and the teacher should focus on the
most important ideas and go over them repeatedly. The other methods is to saturate the
students with information... I have no opinion on which method works better...” - *week 1*

**DM post:** “I believe that teaching is less telling and more leading through interactive
experiences. It is important for a teacher to know the subject material and be able to convey
it clearly, but it is equally important for a teacher to be able to prompt students into learning
experiences through which students learn on their own, and in the process own the
knowledge themselves. ...Another important duty of a teacher is to provide an environment
for the student that is conducive to learning. This may include ... providing groups of
students for interaction and making sure the students are learning and not just memorizing
by getting involved in the learning process.” - *week 10*

**Pre:** “I think that the most important thing to do when teaching physics is to keep the classes
attention. This can be done by inspiring students ... making physics ... relevant to their lives,
by being humorous or animated ... Make physics class an inviting atmosphere and hold class
discussions.” - *week 1*

**Post:** “My teaching strategy this quarter in class and at site has focused on creating a solid
foundation of physics concepts for the students through hands on activities ... I’ve made a
conscious effort ... not to make previous assumptions about one’s knowledge ... I think that
group work and project based learning is a more successful way to go than just lecturing” -
*week 10*
Post: “I have gained invaluable experience in (and learned the main underlying principles of) teaching, both in general, and as it relates to physics. I think this experience has helped me to refine my goals, strategies, and implementation for teaching. ... I also was able to see just how important it is to keep students actively involved with the lesson, participating in through-provoking projects, thinking, answering questions, asking questions, explaining, and discussing ... These activities are where the real learning takes place, not half sleeping through a lecture on the finer points of proving the Shrödinger equation” - week 10

It may be clear to the reader that the class holds a heavily constructivist bent, which seems to have seeped its way into the students’ consciousness.[23] A significant effort was made, however, to insure that students wrestled with the theoretical underpinnings of their convictions and teaching experiences. Again some of these theories and tools for understanding the teaching / learning process begin to re-cycle through the course as demonstrated by an increased use of technical language from the course readings in student fieldnotes, for example one student writes:

of pre-college students failure to grasp a lesson, “This might be a consequence of the fact that they were not forced to confront many of their pre-conceptions, come upon a conflict, and resolve it” - Posner’s notion of accommodation

the fieldnote continues, “knowledge ... never really became integrated as a system,” - diSessa’s notion of knowledge in pieces/ Reif’s knowledge structures.

Students adopted strategies from the readings and reflected on their own success and failure to implement these strategies in the teaching environment.

In summary, because of the coordinated activities of the course, students demonstrate a greater grasp of both physics and teaching. It is worth emphasizing that student improvement in each of these areas is broad and multi-faceted. Students demonstrate an improved grasp of content and application of content. Furthermore, they are better able to place their understanding and efforts in a broader context, both in terms of fields in which they study, and within their own understanding of the world and education.
Research

As research venue, this course provides valuable insight into the process of learning of physics. While a host of research opportunities exist, here I focus on undergraduate learning. Data from student work, interviews, audio taped classes, and fieldnotes suggest some significant themes for analyzing student learning and the importance of context in the learning process. The sections above strive to answer the question: do students learn and benefit from this environment? This preliminary study appears to indicate in the affirmative. The next stage of study is to examine why this proves to be an effective environment for students. What about the context of this program -- the interplay between the study of teaching / learning and the re-examination of physics-- is useful. Although there are many conclusions, one is that teaching a topic forces an added level of reflection both upon the content and about an individual’s own mastery of the subject. Current studies examine the correlation between teaching a topic and learning it deeply. Does one indeed best learn a subject when teaching it? What is the role between the teaching process, the added level of reflection, and the development of epistemological and meta-cognitive tools? Finally, I am examining the role of context on the learning process, which includes identifying the conditions under-which students are willing to revisit material that they believe they already know. This research explores a critical link between meta-cognitive understanding and local context.

Institutions

The institutional response is yet another level of analysis for determining the success of this class and surrounding system of activities. Institutionally, the program has met with success. The Department of Physics has adopted the course as an upper division restricted elective in the sequence of classes required bachelor’s degree. The Teacher Education Program offers the class
as part of its certification program. Additionally, this class is the first course cross-listed between physics department and the education program. In establishing and maintaining this course, an inter-disciplinary team has gathered to critique and help shape the course. The Director of the education program and the Vice-Chair of Physics have and continue to hold collaborative discussions. Foremost among these conversations is the proposal and development of a new undergraduate physics and education major, in which Physics 180/TEP 105 will be a required course.

As described above, fieldwork is an integral component of the course, and as such, has required the development and strengthening of ties with community partners. The community host agencies, such as the local schools and Boys and Girls Clubs, have indicated great interest in the continuation of collaborative efforts. The community partners greatly value the added human resource of student-experts participating in local activities, and in several cases used these added resources to develop new educational programs. Meanwhile the community-based programs serve as necessary resources for the university students and researchers who use these environments as laboratories for studying pre-college student learning. In this way, it is not simply a matter of the university delivering outreach and programming, but rather a collaborative arrangement whereby both partners develop and benefit from the interaction. Community-university partnership programs using this model continue to expand both in size and scope (into more schools and at more educational levels, including elementary). In the past two quarters, without the involvement of the undergraduates in the outreach process, two of the four community-based programs would not have operated.

Because of the unique blending of university-community partnerships surrounding physics education, this activity is supported and used as one type of model for the university’s centralized
outreach office, the Center for Educational Equity Assessment and Teaching Excellence (CREATE). As the university begins to extend its efforts in community partnerships, the CREATE office has yet another tool for developing programs that enhance both the university and the community partners.

**Crossing Boundaries**

As important as the success of any individual component is the recognition that none of these components stands separately from the others. For example, as alluded to in the research segment, the data suggest that student learning is bolstered by involvement in community outreach and teaching. Learning and community outreach are coupled. Furthermore, by working within a coordinated system, it becomes possible to research the effects of social factors in physics education. Research and course structure are coupled. By blurring the lines between these various disciplines and programs, new questions and opportunities arise. This class exists at the interface between a host of disciplines and may be regarded as the interstitial webbing between these various academic pursuits.

As such, by layering the various disciplines and institutions atop one another in a coordinated fashion, the possibility of creating a sustainable system becomes more likely. Though the interests of each of the involved institutions may vary, each has a vested interested in the success of the program as a whole. Each is willing to support the program in (necessary) ways that other programs may not. Also, since these systems are invariably dynamic, the level of involvement of any particular participant may shift, and yet, necessarily, other programs adapt in a dynamic manner to accommodate. Hence, at some level, this system becomes an organism which may develop over time.
CONCLUSION

I have presented a new university physics course which intertwines physics education, research, and community outreach. By substituting content, this model for coordinated activity may be adopted more broadly within the science education community. There is nothing particular to physics, nor undergraduates in this model. The class and activity system provide a rich opportunity for science education research which is tightly coupled with and informed by educational reforms. Because the class addresses the multiple motives of the physics, education, and outreach communities which support the activity, each develops an authentic interest in maintaining this program.

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NOTES


The anti-affirmative action debates have received wide-spread publicity and response both at the state level and at the University of California level. The passing of California Proposition 209 in 1996 was the culmination of many of these debates.


[17] The Conceptual Survey in Electricity and Magnetism (CSEM) is part of the TYC Physics Workshop Project. Curtis Hieggelke, Natural Science Department, Joliet Junior College, Joliet Ill. The Electric Circuit Concept Evaluation (ECCE) is part of the Real-Time Physics project at the University of Oregon.

[18] The measured gain is similar to the gain Hake reports in reference [1]: (post-pre)/(100 - pre). However, here, the average of individual gains is reported rather than the gain of the class average. Inverting the order of operations (averaging and measuring gain), shifts the statistical weighting of individual students.

[19] The class was designed for students who had some familiarity with the material at the outset. As a result, the course was better suited for those students who performed higher on the pre-test. However, this is not to say the class model could not be used for an introductory level, or for the lower performing students, but rather the class could not equally well address all of the students who spanned a range of 8 years in terms of exposure to formal physics.

[20] The * near the students indicates female students. The two greatest improvements in absolute score (Pre-Test - Post-Test score) were both women (MA & JH). In this case, there is some suggestion that while there may be some correlation between gender and class performance (MA&JH show 63.5% gains), it is masked by familiarity with the material (S). See prior note.


[22] Though only three statements are presented here, these responses are representative samples, rather than extra-ordinary student statements.

[23] It may be argued that students were parroting discussions from class rather than shifting epistemological and pedagogical view-points. However, from students’ discussions in class, their fieldnotes, and final papers, it is evident that the students constructed a rich framework of inter-related ideas about teaching and learning.