

Implementing *Tutorials* Sustainably: Restructuring Undergraduate Recitations and Laboratories in Introductory Physics

This adaptation and implementation effort has sought to implement Tutorials in Introductory Physics in our large-scale introductory physics sequence and create a long-term solution by institutionalizing a unified, transformed course experience that ultimately demands no more resources of the university than presently allotted.

The approach has been to train undergraduates as learning assistants (LA's) in order to support their interest in education practice and research and to simultaneously provide institutional resources to increase the teacher to student ratio (required for implementing Tutorials) by supplementing departmentally appointed teaching assistants.

Intellectual merit: This grant addresses the problem of ill- and under-prepared students in physics. The grant activities have developed a cohort of advanced students (and faculty) in physics who are better prepared to teach and understand educational research in physics. Furthermore, this effort has developed a model for sustainable course-wide reform with minimal institutional demands. Finally, the grant activities have supported fundamental research on issues of adapting known effective programs (or secondary implementations) in a sustainable fashion.

The broader impacts and outcomes of this project have improved the education of the thousands of students, augmented the education and preparation of advanced undergraduate and graduate students for their future roles as teachers in the university and K12 system, and created the sustainable infrastructure and resources to insure longevity of the reforms. These reforms have impacted the other large service courses in the department. Finally, this grant has resulted in a model of course-wide, sustainable reform that will be disseminated broadly.

Research and Education Activities:

Our adaptation and implementation effort at CU Boulder has created a long-term solution to known pedagogical problems in introductory physics. We have institutionalized a unified, transformed course experience with minimal extra demands on the University and Physics Department, by successfully implementing Tutorials in Introductory Physics in our large calculus-based sequence. These Tutorials are among the most deeply researched and widely used effective reforms of traditional physics recitation sections. We have demonstrated marked improvement in students' conceptual mastery of physics and in students' expectations of what it means to learn physics. The transformations have been supported by coupling them with a new advanced course in teaching and learning physics, which was developed as part of this adaptation and implementation effort. They have also been tightly coupled with an ongoing development of an undergraduate Learning Assistant program.

It was the stated goal of our CCLI grant that we intended to implement Tutorials for both Physics I and II, create a sustainable infrastructure for them, couple the Tutorials to an upper division Teaching and Learning Physics course, and document the impact of the Tutorials on students in the class, as well as on the support staff (LA's, TA's, and faculties). We have successfully completed all the above goals, with publications (listed below) on all aspects of the project.

Some specific details regarding our Research and Education Activities:

- In the 2003 academic year, prior to receiving this grant, we ran a pilot version of Tutorials in Introductory Physics in Physics I (calculus-based) as a replacement for our standard recitations. At that time we used regular classrooms, and staffed the Tutorial sections with graduate TAs and undergraduate Learning Assistants (LAs) paid for through an external, multidisciplinary CU STEM-Teacher Preparation grant.
- Co-PI M. Dubson constructed dedicated Tutorial spaces in our basement lab area. We now have three "Tutorial bays" of dimensions 15' by 30', with tables and chairs for student groups, white boards, and storage cabinets. Tutorial equipment (particularly important for Physics II Tutorials) was purchased and constructed, with enough to support three simultaneous sections, which has been adequate to cover all sections of Physics I and Physics II at all times.
- Co-PI S. Pollock created Tutorial "instructor manuals" targeted specifically to the situation at CU. These have detailed weekly instructions and materials, provided in a hard copy format. These have been used by all the regular CU faculty teaching Tutorials, every term, and are continuously updated.
- Tutorials were implemented in Physics I (Mechanics) as a pilot in Fall 2003 and again in Sp 2004, taught by Co-PI S. Pollock. They were temporarily halted when the CCLI grant began, in order to focus our efforts on setting up Physics II (see below), and were reinstated in Sp06. They have run every semester since then, in all cases taught by regular CU faculty.
- Tutorials were implemented in Physics II (Electricity and Magnetism) starting in Fall 2004, and every semester since then. The first 2 terms (Fa04 and Sp05) the course was co-taught by S. Pollock and/or M. Dubson, but subsequently the course has been handed off to a sequence of only regular CU faculty.

- Institutionalization of the Tutorials has been further fostered by shifting financial support for the LAs to almost entirely internal CU money (starting Fall 2007), coming largely from the provost, the Dean of Arts and Sciences, with small supplements from Physics Department and ongoing external research grants. We are currently able to support 18 LAs each term, enough to allow Tutorials in both Phys I and Phys II.
- Institutionalization of the Tutorials has also been supported by adapting a position known as "Lead graduate TA" (which has existed at CU for decades, supported by the office of Graduate Teacher Preparation). The physics department now allows (and encourages) the lead Physics grad TA to co-run Tutorial TA/LA training sessions, maintain supplies and infrastructure, and help train all our graduate physics TAs in the pedagogy of the Tutorials through workshops.
- Institutionalization of the Tutorials has also been supported within the physics department by means of an informal (though not entirely reliable) tradition of teaming up new (inexperienced) faculty with experienced faculty in the large introductory courses. This approach provides a systemic mechanism to transfer skills and knowledge about the implementation of Tutorials.
- We have established regular recruitment activities for LAs including classroom visits, a web-based application process, interviews, and an informational meeting every semester. We currently receive more than twice as many applications every term as we have available slots.
- We have established regular training activities for LAs including weekly meetings with faculty and TAs, a weekly pedagogy seminar for new LAs run in the school of education, and a pre-semester introductory/training meeting for all LAs
- PI N. Finkelstein created a new course, Phys 4810/7810 "Teaching and Learning Physics", which has been run every fall term since 2004, taught first by Finkelstein, and later by S. Pollock This course adopts a successful model of advanced undergraduate and graduate student preparation in physics education reform and physics education research. The structure of the three credit-hour course includes three core elements: pedagogical issues (cognitive, psychological, educational), physics content, and practical experience teaching. This course has provided LA support during the more tenuous early days of the project, and more importantly, has provided ongoing research data for our study. The course is now under review by the Physics department course committee, and should become an established departmental offering starting in Fall 2008.
- Extensive pre/post data collection has been run every term since the grant started in both Physics I and Physics II. This includes both conceptual evaluations (FMCE in Mechanics, BEMA in Electricity and Magnetism) and research-based attitude and belief surveys (CLASS). We have been able to compare performance in Tutorial and non-Tutorial courses, and observe the impact of different faculty practice and expertise in PER.
- Physics graduate students in the PER group have been involved in a series of experiments and measurements associated with the Tutorial implementations, including the impact of simulations on student learning in the Tutorials, the role of analogy in Tutorials, issues surrounding faculty change and faculty development, and (just recently) gender effects associated with the Tutorials and Peer Instruction.

Some relevant course details:

Physics 1110 (Physics I, mechanics). Enrollment typically 5-600 each semester. There are three 50 minute lectures a week (using Peer Instruction) and one 50-minute Tutorial section for ~24 students, led by a grad physics TA and 1-2 LAs

Phys 1120 (Physics II, E&M). Enrollment typically 350-500 each semester. There are three 50 minute lectures a week (using Peer Instruction) and one 50-minute Tutorial section for ~24 students, led by a grad physics TA and 1-2 LAs

Phys 4810/7810 (Teaching and Learning Physics). Enrollment typically 12-24, mixed graduate and advanced undergraduate. Meets twice a week for 75 minutes.

Current course syllabi can be found at

[http://www.colorado.edu/physics/phys\[1110, or 1120, or 4810\]](http://www.colorado.edu/physics/phys[1110, or 1120, or 4810])

For earlier semesters, the naming convention is e.g.

http://www.colorado.edu/physics/phys1110/phys1110_fa04

Findings:

Through the course of the CCLI program, we have found that these innovations:

- improve student content mastery in:
 - o mechanics (Physics 1)
 - o electricity and magnetism (Physics 2)
 - o teaching and learning physics (Phys 4810/7810)
- often succeed at supporting favorable attitudes and beliefs:
 - o there are some instances of degradation on the CLASS (phys 1), similar to other published work (See Adams, *Physical Review ST: PER*, 2, 010101)
 - o several of the implementations have seen no degradation on the CLASS, which we consider significant success
- provide lasting impact on content mastery
 - o in upper division physics we observe difference between those students have had Tutorials and those who have not
 - o there is differential positive impact for those students who were LAs
- depend upon which / how faculty implement these curricula.

A. Physics I:

FMCE (Force and Motion Concept Evaluation) given pre and post in Phys 1110 (introductory, calculus based physics) since the CCLI effort began:

1. Conceptual Learning: Learning Assistant data

(approximately matched: typically missing ~1 for pre and/or post)

Phys 1110, Sp 2007. For 7 LAs, pre ave was 87.4, post ave was 94.8, gain of ave = .59

Phys 1110, Fa 2006. For 7 LAs, pre ave was 88.7, post ave was 98.5, gain of ave = .87

Phys 1110, Sp 2006. For 5 LAs, pre ave was 98.3, post ave was 100.0, gain of ave = 1.0

(No LAs were used for the 3 semesters preceding, no data for pilot period before that.)

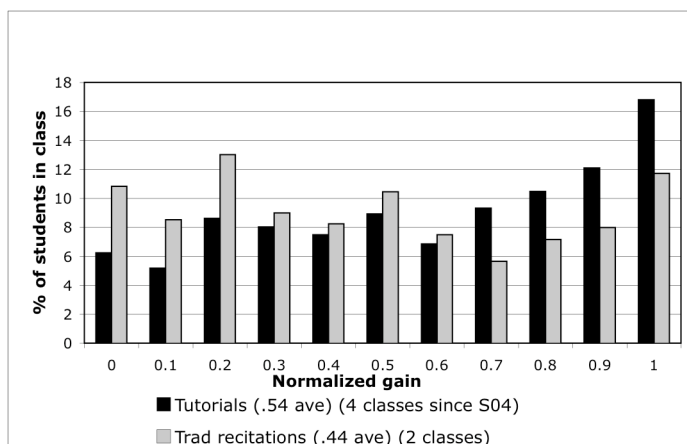
2. Conceptual Learning: Data for classes as whole:

Semester	N (# students) (matched only)	Pretest (%) ~ +/-1%	Posttest (%) ~ +/-1-2%	Ave norm. gain ~ +/- .02	Gain of averages
Sp 2007	363	28.6	61.7	.49	.46
Fa 2006	331	33.2	67.1	.53	.51
Sp 2006	278	26.5	59.5	.47	.45
Fa 2005 *	293	32.1	58.3	.42	.39
Sp 2005 *	213	28.4	58.5	.45	.42
Fa 2004 **	392	33.2	69.0	.59	.54
Sp 2004	335	28.2	73.9	.66	.64

* no Tutorials (*and no LAs*): traditional recitations, a "control" of sorts.

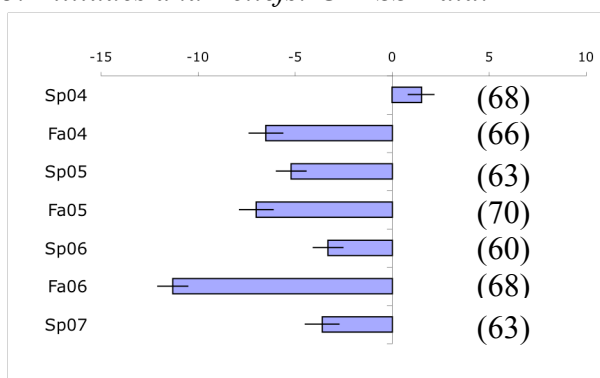
** no Tutorials (*and no LAs*) - but they utilized small-group recitations centered around research-based workbook materials.

All semesters without * used UW Tutorials and LAs developed in part with our CCLI support. (Sp04 was taught by one of the Co-PIs) Note that although all our courses demonstrate significant learning gains, the two semesters with traditional recitations show the lowest two normalized gains. The best terms show very high gains, nearly triple national averages for traditional classes (Hake (1998), "Interactive Engagement vs ..." *Am J. Phys* 66,1, 64)



In the figure above we plot a histogram of individual students' normalized gains, averaging over all 4 of our Tutorial courses, and separately, averaging over both of our traditional-recitation courses. As observed, the Tutorials have significant impact on conceptual learning gains.

3. Attitudes and Beliefs: CLASS Data:



Above graph shows *shifts* (Post - Pre) for "overall favorable" CLASS score in Phys 1110. (Scores to the right are pre-tests) Note that, after the first term, all these classes show overall *negative* shifts. (Sp04 was the only one shown here taught by one of the CO-PIs) These results are typical for attitude and belief shifts (as demonstrated e.g. by the MPEX, Redish, Saul Steinberg 1998) Note that Fa04 through Fa05 were non-Tutorial courses: it does not appear from these data that the curricular reforms in the recitation plays a significant role on CLASS shifts, in either direction.

B. Physics II:

BEMA(Brief Electricity and Magnetism Survey) given pre and post in Phys 1120 (introductory, calculus-based second semester physics) since the CCLI effort began:

1. *Conceptual Learning: Learning Assistant data* (not all matched, but close)

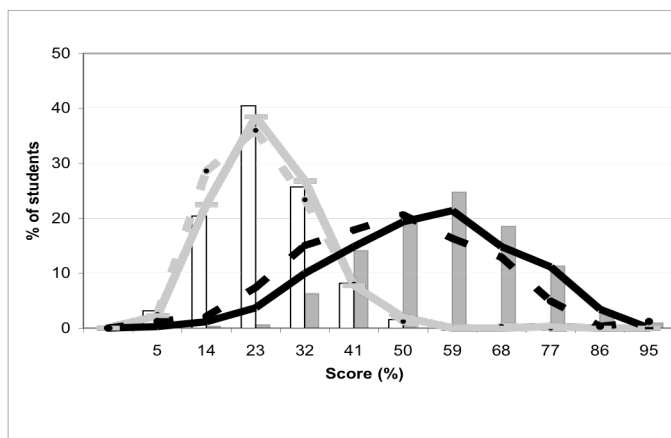
- Phys 1120, Sp 2007. For 4 LAs, pre average was .71, post average was .80 (g=.31)
- Phys 1120, Fa 2006. For 6 LAs, pre average was .64, post average was .71 (g=.19)
- Phys 1120, Sp 2006. For 5 LAs, pre average was .73, post average was .81 (g=.31)
- Phys 1120, Fa 2005. For 8 LAs, pre average was .66, post average was .76 (g=.31)
- Phys 1120, Sp 2005. For 6 LAs, pre average was .75, post average was .90 (g=.61)
- Phys 1120, Fa 2004. For 8 LAs, pre average was .54, post average was .73 (g=.42)

2. *Conceptual Learning: Data for classes as whole:*

Semester	N (# students) (matched only)	Pretest (%) ~ +/-1%	Posttest (%) ~ +/- 1-2%	Ave normalized gain ~ +/- .02
Sp 2007	260	N/A	52.8	N/A
Fa 2006	351	26.3	55.7	.40
Sp 2006	196	26.4	53.4	.37
Fa 2005	325	25.2	49.5	.33
Sp 2005	232	27.4	58.7	.43
Fa 2004	319	26.2	58.9	.44

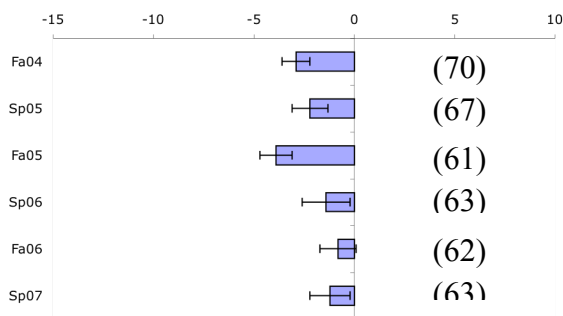
The Table above shows remarkable consistency of pretests from term to term.

Fa04 and Sp05, with the highest gains, were taught by Co-PI's on the grant. Histograms for pre and post data look relatively normally distributed, and are not plotted for all semesters.



In the figure above, we illustrate an interesting faculty development effect. The histogram (barred) data show pre- and post- distributions for the two terms (averaged) taught by co-PI's. In the foreground, plotted as lines, we show Fa05 data for Prof. X (dashed, pre on the left, post is clearly shifted to the right) and again for the same Prof. X, teaching again in Fa06. Prof X is traditional faculty member (non-PER), Fa05 was his first experience teaching a large introductory class. The second time he had some support (from a Co-PI) in running Tutorials, but otherwise ran the class himself. His class' average post-BEMA score has improved by 6 points, an improvement of over 12%.

3. Attitudes and Beliefs: CLASS Data:



Above graph shows *shifts* (Post - Pre) for "overall favorable" CLASS score in Phys 1120.

(Scores to the right are pre-tests at the start of the term)

Note that these shifts are all negative, but smaller than many we observed in Phys 1110 (and not always significantly negative) CO-Pis taught in Fa04 and Sp05.

C. Physics 4810/7810:

We have matched pre-post BEMA scores for the start and end of the terms in which students took our new upper division course on Teaching and Learning Physics.

Some of these students were explicitly engaged in LA activities in Physics II as the "practicum" component of the course, others were *not* 1120 LA's (their teaching activities were in other environments, primarily high school tutoring or mechanics Tutorials)

For N=8 (over 2 semesters) who served as LAs in E&M Tutorial environment:

BEMA pre ave was 72%, post ave was 85% , gain of ave = .46

For N=13 (over 2 semesters) who did *not* serve as LA's:

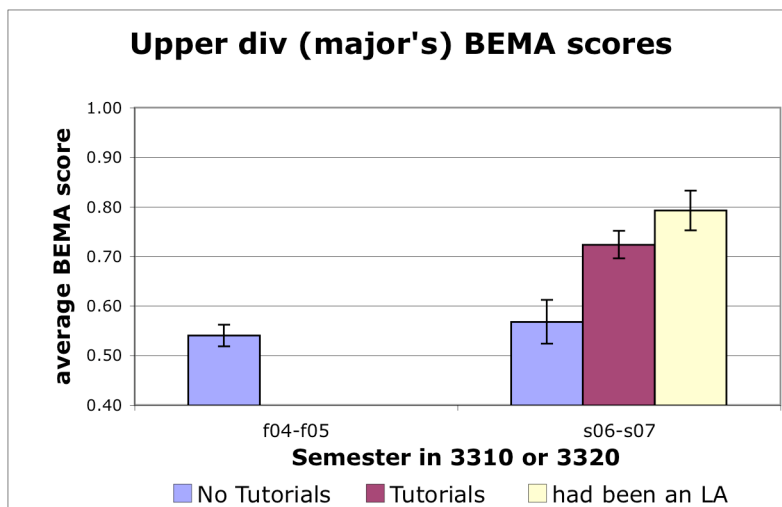
BEMA pre ave was 70%, post ave was 77% , gain of ave = .24

The above results combine graduate and undergraduates - although our graduate students average considerably higher on the BEMA pretest (77%, compared to 53% for the undergrads), and compose about 2/3 of this sample.

Here we conclude the following: The pretest scores of undergraduates students in this upper division course are typical, comparable to what we see from other upper-division physics majors (see next section). All students engaged in this course post gains on the BEMA, but those directly involved with teaching the particular material being tested by the instrument show significantly higher gains.

D. Upper Division Physics

Associated with this project, we have conducted a longitudinal study to investigate the long-term effects of these introductory reforms on our upper-division majors. Below is a plot of BEMA scores measured for physics majors *after* completing upper-division Electricity and Magnetism (either I or II, data is combined).



For the 1st three terms of data collection (Fa04-Fa05), *none* of the students had themselves taken a freshman physics class with Tutorials, since those were just starting up. This is our "control group", shown in the first bin in the figure, labeled "No Tutorials". (Total N=75 unique students, average is 54 +/- 2%) In the following three terms, from Sp06-Sp07, *some* of the students had come from other freshman experiences and had not had Tutorials when they were freshmen (again labeled "No Tutorials". This bin has N=23, average is 57 +/- 4%, please note this is not significantly different from this same category in the earlier bin.) Next we see students labeled "Tutorials", this indicates students in these *same* classes (Sp06-Sp07 combined, once again), but who had themselves taken their Freshman physics II several terms earlier at CU in a class using Tutorials and Learning Assistants. (This group contains N=33 students, average = 72 +/- 3%) The final bin is for only those students who had been an LA at some point in their career for the Physics II course, this has N=7 unique students, average = 79 +/- 4%) We thus see evidence that the Tutorial experience in freshman year translates to significantly improved BEMA scores at the upper division level, and that being an LA moves scores up to levels comparable to what we measure for incoming *graduate* Teaching assistants whose average BEMA score (before teaching) is 80 +/- 4% (N=15)

Training and Development:

As described in the sections above, a sizable fraction of the CCLI effort was directed at training and development.

At the level of LAs and TAs (those teaching the Tutorials), we have implemented:

- regular training activities for LAs including weekly meetings with faculty and TAs,
- a weekly pedagogy seminar for new LAs run in the school of education, and
- a pre-semester introductory/training meeting for all LAs

At the level of practicing faculty, those teaching the associated courses:

- We have created a local Tutorial instructor's manual and resource guide to delineate local practices, tips and step-by-step weekly activities
- The department has assigned additional faculty to teach these courses, making a dedicated faculty member to "back-up" the course, including running the Tutorials
- We have a lead TA guiding these activities
- We have a TA workshop at the beginning of each semester to introduce new TAs (and faculty) to the sorts of pedagogical practices used in the Tutorials.

Additional training and development:

- The Teaching and Learning Physics course has impacted roughly 45 students in its three years of offerings. This class has improved student understanding of physics, and of education and increased the likelihood that students engage in educational activities.
- This program has also supported the development of graduate researchers who are in the PER group

We originally hypothesized that Phys 4810/7810 would provide a steady and significant supply of LAs for the Tutorials. Although enrollment in 4810/7810 has been solid, it is only offered once per year, and many students have chosen to do their "practicum" teaching experience in environments other than the Tutorials. Thus, we find that this course has not been able to become a long-term supply of "free" LAs. However, this has also turned out not to be a problem, as we have been able to find and support more than enough LAs for all Tutorial sections.

Outreach:

Synergies of the grant:

The achievements listed above cannot be attributed solely to our CCLI-A&I grant, because in the same time period we have had additional support, first from the NSF STEM-TP grant, then an NSF LA-TEST (DRL0554616) grant, both of which have financially and logistically supported the LAs, as well as an NSF/AIP/APS Colorado PhysTEC grant, which has supported LAs and LA mentoring, two years of high school Teachers in residence, who have considerably helped build the Tutorials infrastructure, and additional partnership support for research and dissemination of the Colorado LA model, which has been influential in the successful implementation of Tutorials.

Several synergistic efforts support community partnerships: the Physics Frontier Center at JILA, the High Energy Laser Center (E-UV Center), and the CIRTL graduate network. By collaborating with other programs focused on education, we leverage resources, provide new learning and teaching opportunities for future teachers, and support the general culture of valuing education within the sciences

As part of a collaboration with JILA's Physics Frontier Center, Laurel Mayhew has been hired in a post-doctoral position which focuses on outreach efforts. She has been given field experience information and we anticipate that she will put forth focused effort in developing this aspect of our program by building on our prior efforts (CU STOMP / summer camp and afterschool programs) and with other efforts in the school of education.

more information can be found at:

<http://per.colorado.edu/STOMP>

Publications:PEER REVIEWED PUBLICATIONS:

"No Single Cause: Learning Gains, Student Attitudes, and the Impacts of Multiple Effective Reforms", S. Pollock, Proceedings of the 2004 PERC, AIP Press. Melville NY, 790, (2005) p. 137

"Transferring Transformation: Learning Gains, Student Attitudes, and the Impacts of Multiple Instructors in Large Lecture Classes", S. Pollock, Proceedings of the 2005 PERC, AIP Press. Melville NY, 818, (2006) p. 141

"Evaluating a Model of Research-Based Practices for Teacher Preparation in a Physics Department: Colorado PhysTEC" N.D. Finkelstein, , C. Turpen, S. Pollock, M. Dubson, D. Iona, C. Keller, and V. Otero, Proceedings of the 2005 PERC, AIP Press. Melville NY, 818 (2006) p. 3

"Assessing the effectiveness of a computer simulation in conjunction with Tutorials in Introductory Physics in undergraduate physics recitations," C.J. Keller, N.D. Finkelstein, K.K. Perkins, and S.J. Pollock, Proceedings of the 2005 PERC, AIP Press. Melville NY, 818 (2006) p. 109

"Sustaining Change: Instructor Effects in Transformed Large Lecture Courses", S. Pollock and N. Finkelstein, Proceedings of the 2006 PERC, AIP Press. Melville NY, 883 (2007) p. 109

"Reducing the gender gap in the physics classroom: How sufficient is interactive engagement?", S. Pollock, N. Finkelstein, L. Kost, Phys Rev. ST-PER, 3, 010107 (2007).

"Preparing Graduate Students to be Educators" E. Price and N.D. Finkelstein, *Am. J. of Physics*.(in press)

"Who is Responsible for Preparing Science Teachers?" V.Otero, N.D. Finkelstein, R. McCray, and S. Pollock, Science. 313(5786), 445-446 (July 28, 2006).

"Replicating and Understanding Successful Innovations: Implementing Tutorials in Introductory Physics" N.D. Finkelstein and S.J. Pollock, Physical Review, Spec Top: Physics Education Research, 1, 010101 (2005).

"Teaching and learning physics: A model for coordinating physics instruction, outreach, and research" N.D. Finkelstein, J. of Scholarship of Teaching and Learning, 4(2), 1, (2005).

POPULAR PUBLICATIONS:

"Graduating Educated Graduate Students", E. Price and N. Finkelstein, APS Fed Newsletter Spring 2006

"The Learning Assistant model for Teacher Education in Science and Technology", Valerie Otero, FED newsletter, summer 2006

"CU Physics Education, Recruiting and Preparing Future Physics Teachers and the Teacher Advisory Group.", Noah Finkelstein, Michael Dubson, Christopher Keller, Steven Pollock, Steve Iona, Valerie Otero. APS Fed Newsletter Spring 2005.

RECENT TALKS: (Spring 06 – present).

V. Otero, N. Finkelstein, S. Pollock, P. Wolf, C. Fogle, "Transforming undergrad physics: the Colorado Learning Assistant program", Poster, PhysTEC conference spring 2007

S. Pollock, N. Finkelstein, "Sustaining Educ. transformation in physics", Poster, PhysTEC conference spring 2007

N. Finkelstein, S. Pollock, M. Dubson, "Addressing Gender Disparity in Introductory Physics Courses: Are existing reforms enough?" A21.00003, talk at APS March Meeting, Denver CO 2007

S. Pollock, N. Finkelstein, "Sustaining Educational Innovation: engaging traditional faculty in transformed practices", A21.00004 talk at APS March Meeting, Denver CO 2007

Noah Finkelstein & Steven Pollock, "Keeping a Good Things Going: What does sustaining reforms in physics mean?" poster at Winter 2007 AAPT meeting, Seattle WA

N. Finkelstein, S. Pollock, "Replicating of Reforms in a Large-scale Lecture Environment", talk at Winter 2007 AAPT meeting, Seattle WA

V. Otero, S. Pollock, N. Finkelstein, P. Wolf, C. Fogle, "Transforming Undergraduate Physics: The Colorado Learning Assistant Program " poster for the NSBP (Nat'l Society for Black Physicists) in spring 2007

N. Finkelstein, "Educating Scientifically: Advances in Physics Education Research," Fermi National Accelerator Lab Colloquium, Batavia, IL, May 2007. [invited].

N. Finkelstein, "Applying Physics Education Research to the next generation of classroom practice" Department of Physics Colloquium, Emory University, Atlanta, GA, Apr 2007. [invited]

N. Finkelstein, "Advances in PER: New Directions and Findings in Physics Education" Physics Colloquium, University of Northern Colorado, CO, Apr 2007. [invited]

N. Finkelstein, "Student Learning in Physics and the role of representation analogy and context," Institute for Cognitive Studies Colloquium, University of Colorado at Boulder, Mar 2007. [invited]

N. Finkelstein, "The Role of Representations and Analogies in Solving Physics Problems," Joint Mtg of the Nat'l Society of Black Physicists and Nat'l Soc. of Hispanic Physicists, Boston MA, Feb 2007. [invited]

N. Finkelstein, "A Science of Science Education: studies of transforming undergraduate physics," Department of Physics Colloquium, Rutgers University, New Brunswick, NJ, Feb 2007. [invited]

-----2006:

C. Turpen, N. Finkelstein, and S. Pollock, "Sustaining Reform: A Qualitative Study of Professors Beliefs and Classroom Practices." AAPT National Meeting 2006. Poster

S. Pollock, N. Finkelstein, "Sustainable and Scalable Reforms in Physics Education: Research Studies from Colorado PhysTEC". Invited Talk, March APS meeting, Texas, 2006

S. Pollock, N. Finkelstein, "Educational Reforms in Introductory Physics at Colorado: Replicability? Sustainability?", poster for the International Society for the Scholarship of Teaching and Learning, Nov 2006

S. Pollock, "Building on a Base: Applying Physics Education Research to Physics Teaching", colloquium for CSU physics department, Fort Collins, Mar 2006

S. Pollock, "Building on a Base: Applying Physics Education Research to Physics Teaching", colloquium for Kansas University physics department, April 2006.

S. Pollock, "Replication and Sustainability of Reforms in Introductory Physics at CU", Poster: for AAPT conference on Achieving Systemic Changes in Physics Teaching at Leading Research Universities, College Park MD June 2-3 2006.

N. Finkelstein, "Colorado PhysTEC: improving undergraduate education and the future of K12 physics teaching," APS Executive Board Meeting and Capital Campaign, College Park, MD Nov 4. 2006. [invited]

N. Finkelstein, "Learning Assistants, Course Transformation, and Discovery Learning in Physics," College of Natural Sciences New Faculty Teaching Conference, University of Texas, Austin, TX, Oct 2006 [invited]

M. Cole and N.D. Finkelstein, "The Design of Out of School Educational Activities" National Academy of Education, Fellows Retreat and Annual Meeting, Boulder CO, Oct 2006. [invited]

N. Finkelstein, "Researching Reform: studies of transforming undergraduate physics," Departmental Colloquium, Department of Physics, University of Arizona, Tucson, AZ, Oct 2006 [invited]

N. Finkelstein, P. Kohl and N. Podolefsky "Representation, Analogy, and Solving Physics Problems," Am. Assoc. of Physics Teachers Annual Meeting, Syracuse, NY, Jul 2006 [invited]

K. Perkins and N.D. Finkelstein, "Assessing Virtual Environments," Am. Assoc. of Physics Teachers Annual Meeting, Syracuse, NY, Jul 2006 [invited]

M. Dancy and N.D. Finkelstein, "Breaking the Paradigm: Working from a Sociopolitical-Critical Perspective," Am. Assoc. of Physics Teachers Annual Meeting, Syracuse, NY, Jul 2006 [invited]

N. Finkelstein, "Learning Virtually: examining the potential of computer simulations in learning E/M," Gordon Conference on Phys. Educ. Research, Mount Holyoke, MA, Jun 2006. [invited]

N. Finkelstein, "Colorado PhysTEC and The Learning Assistant Model for Transforming Undergraduate Science Education," AAPT Annual Chair's Meeting, Washington DC, Jun 2006. [invited]

N. Finkelstein, " Reconsidering Tools and Contexts of Student Learning" NAS/NSF Invitational Workshop, Reconsidering the Textbook, Washington DC, May 2006 [invited]

N. Finkelstein, "New Tools, Traditional Contexts: Examining the potential of computer simulations for undergraduate education," PER Sem. Series, The Ohio State University, Columbus, OH, May 2006 [invited]

V. Otero & the STEM Colorado/PhysTEC Team. "Who is Responsible for Recruiting and Preparing Science Teachers?" Presented at Texas State University, San Marcos, December, 2006 [invited].

V. Otero & the STEM Colorado/PhysTEC Team. "Who is Responsible for Recruiting and Preparing Science Teachers?" Presented at the Northwest regional meeting of the American Association of Physics Teachers, Seattle WA, November 2006 [invited].

V. Otero "The Colorado Learning Assistant Model: A multidisciplinary approach to teacher recruitment and preparation." Presented at the annual meeting of the National Academy of Education, October 20-21, 2006 [invited].

V. Otero & The STEM Colorado/PhysTEC Team (2006). "The Colorado Learning Assistant Model: A multidisciplinary approach to teacher recruitment and preparation." Presented at the annual meeting of the American Physical Society, Dallas, TX, March 2006 [invited].

Recent Workshops

Nuts and Bolts of Designing a Pedagogy Course for Learning Assistants. V. Otero and S. Iona. At the annual meeting of the Physics Teacher Education Coalition, Boulder, CO. March 1-3, 2007.

The University of Colorado Learning Assistant Model. V. Otero and S. Pollock. At the annual meeting of the Physics Teacher Education Coalition, Boulder, CO. March 1-3, 2007.

"Attending to More than Content Mastery: assessing student Attitudes and Beliefs in our classrooms" Noah Finkelstein, Wendy Adams, Katherine Perkins, and Steven Pollock, PhysTEC conference spring 2007

"The role of data in systemic change", S. Pollock, K. Perkins, Workshop for the International Society for the Scholarship of Teaching and Learning, Nov 2006

"Reconceptualizing Recitation", "Clickers in the Large Classroom", "CLASS: Attending to more than Content Mastery", S. Pollock, Set of 3 workshops for the Center for Teaching Excellence, Kansas University, April 2006.

"Attending to More than Content Mastery: Assessing Student Attitudes and Beliefs in our Classrooms", S. Pollock, workshop presented for the ASMCUE (American Society of Microbiologists: Conference for Undergraduate Educators)" conference:, May 19-21 2006 (Orlando, FL)

"Undergraduate Learning Assistants: A Powerful Way to Improve Student Learning and Recruit Future Teachers." V. Otero, G. Stewart, and S. Vokos. At the annual meeting of the Physics Teacher Education Coalition, Fayetteville, AR, March 24-25, 2006.

"STEM Colorado Workshop for K-12 Teachers, Noyce Fellows, and University Faculty." V. Otero, S. Iona, S. Pollock, N. Finkelstein, M. Dubson. Held annually (since 2003) at the University of Colorado at Boulder, June 14-16, 2006.

"Physics for Elementary Teachers: A workshop for physics faculty." V. Otero, Presented at the Annual Meeting of the American Association of Physics Teachers, Syracuse, NY, July 22-26, 2006.

Contributions to within the principal discipline(s) of the project

As described in the sections above we have:

- improved student understanding of physics (at the introductory level)
- demonstrated that it is possible to replicate the success of curricular materials developed elsewhere
- developed a greater understanding of replication and sustainability (applying our models of student learning in context)

Furthermore we have increased the number of students going into teacher and the number of students trained in physics education research.

Contributions to other disciplines of science or engineering

We contribute to what is known about implementing reforms that are developed elsewhere. Through a contextual constructivist analysis of our implementation of the Tutorials we identify some of the obvious and not-so-obvious critical features of implementing educational reforms. A thorough description of this can be found in Finkelstein and Pollock, *Physical Review*, 1,010101.

Additionally the model by which we engage in educational reform, the Learning Assistant model, has significant impact on other science disciplines and is being replicated by many institutions across the nation. For recent descriptions see:

Mervis, J. *Science*, 316. no. 5829, p. 1276 (2007).

and

V.Otero, N.D. Finkelstein, R. McCray, and S. Pollock, *Science*, 313 no. 5786, 445-446 (2006).

Contributions to the development of human resources;

Through the CCLI program we have impacted 4100 students over 8 terms of Phys 1 and Phys 2. We have had 56 undergraduate Learning Assistants and 36 graduate and postdoctoral TAs. 2 PER graduate students have been supported in this program.

A total of 7 physics faculty have participated in transformed class practices. We like to think that this has had a positive impact (and we can demonstrate improved teaching performance, as evidenced by student learning gains, for at least one faculty member, Prof X above).

Contributions to the physical, institutional, or information resources that form the infrastructure for research and education

We have reorganized the infrastructure of introductory physics sequence so as to institutionalize these programs. These changes have included dedicating physics space to run the Tutorials. Furthermore we have secured internal funding to continue running the Learning Assistant program which provides the added instructional resources necessary to teach Tutorials.

Contributions to other aspects of public welfare beyond science and engineering, such as commercial technology, the economy, cost-efficient environmental protection, or solutions to social problems.

This work contributes to studies of change in higher educational systems. It also contributes to the advancement of student understanding in the sciences, which ultimately is considered one of the major challenges facing society today.