

**Final Report:
CAREER: Physics Education Research
and Contexts of Student Learning**

**Noah Finkelstein
Associate Professor
Department of Physics
University of Colorado at Boulder**

*The goals of the Physics Education Research (PER) group
at the University of Colorado, Boulder (CU-B), are as big and bold
as the Rocky Mountains that loom over the campus*

- Jeffery Mervis, Science Magazine
Vol. 316 no. 5829 p. 1276, 2007

*The [Vice Chancellor of Faculty Affairs' Advisory Committee] voted to promote
Professor Finkelstein and to grant him tenure, with a majority of the committee
finding him excellent in research, teaching, and service*

Jeffery Cox, Chair, Provost's Advisory Committee
University of Colorado at Boulder
23 Mar 2008

Finkelstein leads one of the world-renowned research groups in physics education

- Faculty Evaluation Committee, Department of Physics
University of Colorado at Boulder, April 2009

*Dr. Finkelstein ... I want to express my sincere appreciation for your participation in
the 2010 hearing entitled Strengthening Undergraduate and Graduate STEM Education*

- U.S. Congressman, Daniel Lipinski, Chairman,
Research and Science Education, Committee on Science and Technology 2010

*PHYS is now a national and international leader in physics education research and in STEM (science,
technology, engineering, and mathematics) education reform...In addition to laboratory research, science
education research is taken seriously by PHYS. Not only has the unit become a leader in the field within a
single review cycle [7 years], it is, in fact, creating the field.*

- Academic Review and Planning Advisory Committee,
External Review of 8 Physical Sciences Programs for Accreditation Feb, 2011

Overview

This research program investigates the central role of context in the practice of physics education. That is, how and what students learn depends not only on traditionally conceived content but also upon the formation of tasks, class environments, and broader institutional structures in which the content is embedded. This project coordinates research studies on the role of context in student learning at two different levels: the individual, and the course. (The role of the department has been left for other studies.) Each of these levels (A. individual) and (B. course) is studied across three themes: (1) tools that are used, (2) practices using these tools, and (3) norms surrounding these practices. In particular these studies focus on: (A1) individual student use of tools, (A2) practices, how students use these tools, (A3) student beliefs about learning physics and how these influence practices. At the course level, research has focused on: (B1) the use of tools in courses, (B2) the construction of courses and practices which support student learning, and (B3) studies of replication and sustainability of educational practices. A Third level or frame of context rounds out my broader research efforts, but is not an explicit part of this CAREER award. However findings from this present research contribute to studies of departmental an institutional change, level C.

Theme	1. tools	2 practices	3. meta/ surrounding features
A. Individual	A1	A2	A3
B. Course	B1	B2	B3
C. Departmental/ Institutional			

The six years of this project have been spent making significant progress in these research areas and building my own career, the PER group at the University of Colorado (CU) as a national center of physics education research, the growth of efforts in other STEM departments (biology, astronomy, chemistry, engineering, and math) at CU that are engaging in education research, and the field of Physics Education Research at a national scale. Overall this CAREER grant supported the research behind 65 refereed articles, more than 200 talks (85 of which were invited, including testimony before the U.S. Congress, and many international plenary and keynote addresses). This grant has been instrumental in all my research, and directly supported 8 graduate students (seven of whom graduated, 1 MS and 6 PhDs), and several undergraduate senior honors theses.

The PER research group has established itself as a national leader, in significant part, due to NSF funding, particularly this CAREER project. Research from this CAREER award has been instrumental in obtaining a variety of other extramural grants.

An exciting extension of this CAREER effort has been an initiative running for the past two years, funded by the NSF I3: *Institutional Innovation through Integration grant: Towards a Center for STEM Education*. This initiative is led by the university Chancellor (PI), where I

serve as a co-PI. The efforts seek to build on the success of the PER group and this CAREER proposal, to seed efforts in other STEM departments. This program has started the process of building a Center for STEM Education at Colorado.

The intellectual merit of this CAREER proposal is to create a deeper understanding of the role of context in learning physics. This essential aspect of education complements existing physics education research. This work develops our understanding of tools, practices and surrounding frames of physics education at the levels of the student, the classroom, and the institution.

The broader impacts of this program improve educational practices for students, instructors and potentially institutions. We are developing a better understanding of how to make these practices sustainable and scalable. These efforts develop and promote this sub-discipline of physics, has built a new research line in PER at the University of Colorado, and has established a long-term career path. Many of the studies of broader context also impact educational reform in other disciplines. Finally, this program reaches thousands of students at the University of Colorado and establishes models for reaching students at all large-scale research universities.

Findings:

Following the framework of *themes* ((1) tools, (2) practices, (3) norms) and *levels* ((A) individual and (B) course), this project has made contributions within each of the six areas, described below. The following seven classes of studies are conducted across at least two segment areas (across either theme or level), which allow me to understand the nature of the interplay among these different contexts of student learning. More extensive summaries of findings from each project are presented in 1-page summaries in the Appendix, along with a listing of detailed articles with findings.

Representational Competence and Learning Physics

with Pat Kohl Ph.D., Physics 2007.

Contextual units: *A1-2; B1-2 – characterizing individual and course tools and practices*

In these studies we document that different representations affect student performance. For example, a problem given with the same statement and answers but with different representations (mathematics, graphs, pictures or words) yielded remarkably different results for matched students. (This result calls into question the validity of many of the standard measurement instruments used to assess physics competence.) We also noted that the same students varied dramatically in their abilities to use representations (sometime performing much better on mathematical representations than graphical ones, and other times just the opposite), which suggests that the coarse and absolute framing of learning styles may not be sensitive to contextual variation (of environment or problem statement). In this effort we begin to characterize the mechanisms of individuals' uses of representation (representational competence), their abilities to regulate and understand their use of representations (meta-representational competence), and the impact of instructional environment. We find that courses that explicitly model and those that explicitly use a broad range of representations support student use of representations. Finally, in this project we find distinct differences between experts and novices in use of representations and begin to explain these differences.

Analogy and Representation Use in Instruction and Learning Physics

with Noah Podolefsky Ph.D., Physics 2008.

A1-2; B1-2 – characterizing individual and course tools and practices

Related to and building on the project on representation, we introduce a new model of analogy and present a series of experiments that test and confirm the utility of this model to describe and predict student learning in physics with analogy. This new model, Analogical Scaffolding, explains empirical results and demonstrates the limitations of current models of domain mapping (from base-to target domain). We demonstrate that representations (e.g., diagrams) play a key role in students' use of analogy and meaning making. These findings provide key insights into how to use representations to cue student reasoning in productive (or unproductive) ways. This model of analogy use, while focussed and tested in physics, holds the potential to be generalizable and serve as a tool in education more broadly.

Characterizing and Improving Students Interpretations of Quantum Physics

with Charles Baily Ph.D., Physics, 2011.

A2-3; B2 – individual beliefs/norms and course practices

While we may be increasingly successful at teaching content (conceptual framing) of physics, increasingly we are paying attention to student interpretation in our courses. We have developed a framework for understanding and characterizing student perspectives on the physical interpretation of quantum mechanics, and demonstrate the differential impact on student thinking of the myriad ways instructors approach interpretive themes in their introductory courses. In our studies we find that instruction in classical physics reinforces a deterministic (and incorrect) view of quantum phenomena. How instructors approach teaching modern physics differentially impacts student abilities in interpretation—those classes that do not address interpretation (the predominant model espoused by ‘shut up and calculate’) lead to students incorrectly interpreting quantum phenomena. Those classes that specifically address modeling and interpretation in quantum mechanics lead to more sophisticated views. Furthermore we find that a transformed curriculum (one developed as part of this project) can positively impact student interest in the subject.

Student Attitudes and Beliefs in Physics

with Wendy Adams Ph.D., Physics 2008 and other colleagues in the PER group

A3; B2 – individual beliefs/norms and course practices

In addition to the traditional content within any course, there are extensive sets of attitudes and beliefs about science that we teach to our students. The way we conduct our classes sends messages about how, why, and by whom science is learned. Some of these messages are beneficial (e.g., that science is a coherent representation of the world) while others are detrimental (e.g., the notion that women cannot be strong scientists). In this early vein of research, supported by CAREER, we develop a new instrument, the Colorado Learning About Science Survey (CLASS) to reliably and validly assess this so called ‘hidden curriculum.’ We document that, traditionally, courses lead students to regress from more expert-like beliefs to more novice beliefs. In follow-up research we find that students recognize the difference between expert-like beliefs versus their own (that is, while students know what we may seek to promote in our classes, they do not personally believe these.) Women and men show differential impact of our classes, with women being differentially more negatively impacted. We also find that those students who are more likely to stay as physics majors begin freshman year with preferentially favorable views (that is, we differentially select rather than develop students’ beliefs in physics.)

Documenting and Addressing the Gender Gap in Introductory Physics

with Lauren Kost, Ph.D., Physics, 2011.

A3; B2-3 – individual beliefs/ norms and course practices

The underrepresentation and underperformance of females in physics is well documented and has long concerned policy-makers, educators, and the physics community. This line of research as sought to understand and address these issues. In studies of over 8000 students in introductory physics, we document measures in which we find gender differences. Females are less prepared coming into Physics I than males: females have lower math and physics pre-test scores and less expert-like physics attitudes. Students’ survey responses indicate that females have lower self-

confidence related to succeeding in Physics I and are less likely to report seeing themselves or being seen by others as a “physics person.” We find that these differences can largely be accounted for by background factors other than gender (i.e. mathematics and physics preparation.) Finally, we have preliminary indication that a simple 15-minute writing exercise on values affirmation may account for the remaining gender-gap in performance that is not accounted for by background.

Instructional Choices and Student Perceptions of Educational Reforms in College Physics
with Chandra Turpen, Ph.D., Physics 2010

A3; B2-3 – individual beliefs/norms and course practices

Despite widespread use of reform-based instructional practices, little work has been conducted on the choices faculty make in implementing these reforms and how students perceive the use of these reforms. In a detailed case study of one such reform, Peer Instruction, we document the variation in pedagogically relevant choices that faculty make. We demonstrate that these choices aggregate to establish classroom norms that signal to students what this activity is about. Finally we show that that students perceive differences between the various norms in different classrooms. In short, we find dramatic variation among faculty engaged in the “same” practice—for instance during a class poll (clicker question), faculty may or may not leave the stage, may or may not discuss reasoning with students and may or may not solicit student answers. These repeated moves send signals that students pick up on. For example, students learn whether they should be reasoning or just answer-making, whether they should be discussing reasoning with the faculty or just their peers or not at all.

Physics Graduate Teaching Assistants in Transformed Environments: Developing Teaching Knowledge.

with Benjamin Spike, Ph.D. Physics anticipated 2012.

A3; B2-3 – individual beliefs/norms and course practices

As Research-based instructional strategies become more widespread, increased attention is being paid to the role of graduate Teaching Assistants (TAs) in transformed environments, as well as the impact of the teaching experience on the instructors’ own pedagogical development. In this study, we begin to characterize the specialized knowledge TAs draw upon when teaching, and demonstrate whether and how this knowledge is stable across multiple contexts. We have developed a framework for characterizing knowledge of teaching physics, and demonstrate: TAs differ in how they talk about their own teaching, and understand their roles and purpose of reform-based instruction differently. This suggests that TAs develop from teaching in reformed environments and that we might do well to better prepare TAs for teaching in these environments.

This collective work allows me to make patchwork of the 6-cell framing of context and its influence on student learning and our educational practices. This synthetic work is ongoing and the focus of this coming year.

Reviewed Journal Articles/Book Chapters

1. A. Mikaye, L. Kost*, N.D. Finkelstein, S. Pollock, G. Cohen, T. Ito, "Reducing the Gender Achievement Gap in College Science: A Classroom Study of Values Affirmation" *Science* **330**(6008) pp. 1234-1237 (Nov 26, 2010)
2. C. Turpen* and N.D. Finkelstein, "The construction of different classroom norms during Peer Instruction: Students perceive differences," *Phys. Rev. ST Physics Ed. Research* **6**, 020123 (2010).
3. C. Baily* and N. Finkelstein, "Refined characterization of student perspectives on quantum physics," *Phys. Rev. ST Physics Ed. Research*, **6**, 020113 (2010).
4. L. Kost,* S. Pollock and N. Finkelstein, "Gender disparities in second-semester college physics: The incremental effects of a smog of bias," *Phys. Rev. ST Physics Ed. Research*, **6**, 020112, (2010).
5. V Otero, S Pollock, and N Finkelstein, "A physics department's role in preparing physics teachers: The Colorado Learning Assistant model," *American Journal of Physics*, **78** (11), pp. 1218-1224, (2010).
6. C. Baily and N. Finkelstein, "Teaching and understanding of quantum interpretations in modern physics courses," *Phys. Rev. ST Physics Ed. Research* **6**, 010101, (2010).
7. C. Henderson, N. Finkelstein, & A. Beach A. "Beyond Dissemination in College science teaching: An Introduction to Four Core Change Strategies." *Journal of College Science Teaching*. **39**(5), 18-26, (2010).
8. N. Lasry, N. Finkelstein, E. Mazur, "Are most people too dumb for physics," *Phys Teacher*, **47**, 418-422 (2009).
9. C. Turpen* and N.D. Finkelstein, "Not all interactive engagement is the same: Variations in physics professors' implementation of Peer Instruction," *Physical Review ST: Phys Educ. Research* **5**, 020101, (2009).
10. C. Baily*, and N.D. Finkelstein, "Development of quantum perspectives in modern physics," *Phys. Rev. ST Phys. Educ. Res.* **5**, 010106 (2009).
11. L. Kost*, S.J. Pollock, and N. Finkelstein, "Characterizing the gender gap in introductory physics," *Physical Review ST: Phys Educ. Research*, **5**, 010101 (2009).
12. S. Pollock and N. Finkelstein, "Sustaining Educational Reforms in Introductory Physics," *Phys. Rev. ST Physics Ed. Research* **4**, 010110 (2008)
13. P. Kohl* and N.D. Finkelstein, "Patterns of multiple representation use by experts and novices during physics problem solving" *Phys. Rev. ST Physics Ed. Research* **4**, 010111, (2008)
14. E. Price and N.D. Finkelstein, "Preparing Graduate Students to be Educators", *American Journal of Physics*, **76**(7), pp. 684-690 (2008).
15. N. S. Podolefsky* and N.D. Finkelstein, "Analogical Scaffolding and Learning Abstract Ideas in Physics: empirical studies." *Physical Review, Special Topics: Physics Education Research*, **3**, 020104, 16 pgs, (2007)
16. N.S. Podolefsky* and N.D. Finkelstein, "Analogical scaffolding and the learning of abstract ideas in physics: An example from electromagnetic waves" *Physical Review, Special Topics: Physics Education Research*. **3**, 010109, 12 pgs, (2007).
17. P. Kohl,* N.D. Finkelstein, D. Rosengrant "Strongly and Weakly Directed Approaches to Teaching Multiple Representation Use in Physics," *Physical Review, Special Topics: PER*, **3**, 010108, 10 pgs, (2007).
18. S. J. Pollock, N.D. Finkelstein and L. Kost* "Reducing the Gender Gap in the Physics Classroom," *Physical Review, Special Topics: Physics Education Research*, **3**, 010107, 4 pgs, (2007).
19. N.D. Finkelstein, W. Adams,* C Keller,* K Perkins, C Wieman and the PhET Team, "High-Tech Tools for Teaching Physics: the Physics Education Technology Project," *Journal of Online Learning and Teaching*, **2**(3), 109. 11pgs, (2006).
20. N.S. Podolefsky* and N.D. Finkelstein, "The Perceived Value of College Physics Textbooks: Students and Instructors May Not See Eye to Eye" *The Physics Teacher*, **44**(8), 338-342, (2006).
21. V. Otero, N.D. Finkelstein, R. McCray, and S. Pollock, "Who is Responsible for Preparing Science Teachers?" *Science*. **313**(5786), 445-446 (2006).
22. N.S. Podolefsky* and N.D. Finkelstein, "Use of analogy in learning physics: The role of representations" *Physical Review, Special Topics: Physics Education Research*, **2**, 020101, 10 pgs, (2006).
23. P.B. Kohl* and N.D. Finkelstein, "Effect of representation on students solving physics problems: a fine-grained characterization" *Physical Review, Special Topics: Physics Education Research*, **2**, 010106, 12 pgs, (2006).
24. P.B. Kohl* and N.D. Finkelstein, "The effect of instructional environment on physics students' representational skills," *Physical Review, Special Topics: Physics Education Research*, **2**, 1,010102, 8 pgs, (2006).
25. W.K. Adams,* K.K. Perkins, M. Dubson, N.D. Finkelstein, and C.E. Wieman, "A new instrument for measuring student beliefs about physics and learning physics: the Colorado Learning Attitudes about Science Survey" *Physical Review, Special Topics: Physics Education Research*. **2**, 1,010101, 14 pgs, (2006).
26. K.K. Perkins, W. Adams,* N. D. Finkelstein, M. Dubson, R. LeMaster, S. Reid, and C.E. Wieman, "PhET: Interactive Simulations for Teaching and Learning Physics" *Physics Teacher* **44**(1), 18-23, (2006)
27. N.D. Finkelstein, "Learning physics in context: a study of student learning about electricity and magnetism," *International Journal of Science Education*, **27**, 1187-1210, (2005).

28. P. Kohl* and N.D. Finkelstein, "Student representational competence, self-assessment, and problem solving in physics" *Physical Review, Special Topics: Physics Education Research*, **1**, 010104, 11pgs, (2005).
29. N.D. Finkelstein, K. Perkins, W. Adams,* K. Keller,* P. Kohl,* N. Podolefsky,* S. Reid, and R. LeMaster, "When learning about the real world is better done virtually: a study of substituting computer simulations for laboratory equipment," *Physical Review, Special Topics: Physics Education Research*, **1**, 010103, 8 pgs, (2005).
30. N.D. Finkelstein and S.J. Pollock, "Replicating and Understanding Successful Innovations: Implementing Tutorials in Introductory Physics" *Physical Review, Spec Topics: Physics Education Rsrch*, **1**, 010101, (2005).
31. Henderson, Beach and Finkelstein, "Promoting High Quality Teaching Practices in Higher Education: Lessons Learned from the United States," Warsaw Conference Volume on STEM Education (to appear).
32. C. Henderson, A. Beach, and N. Finkelstein, "Four Categories of Change Strategies for Transforming Undergraduate Instruction," in "Transitions and Transformations in Learning and Education." (Ed by P. Tynjälä, M-L. Stenström & M. Saarvivaara). (*anticipated 2011*).
33. J. Froyd, A. Beach, C. Henderson, and N. Finkelstein, "Improving Educational Change Agents' Efficacy in Science, Engineering, and Mathematics Education." In H. Hartman (ed.), *Integrating the Sciences and Society: Challenges, Practices, and Potentials*, Bingley, UK: JAI Press, pp. 227-256. (2008).

Reviewed Conference Proceedings:

1. C. Baily and N.D. Finkelstein, "Interpretation in Quantum Physics as Hidden Curriculum," *Proceedings of Physics Education Research Conference*, AIP Conf. Proc. 1289, 69 (2010).
2. R. Wulf, L. Mayhew and N.D. Finkelstein, "Impact of Informal Science Education on Children's Attitudes About Science," *Proceedings of Physics Education Research Conference*, AIP Conf. Proc. 1289, 337 (2010).
3. B. Spike, and N.D. Finkelstein, "Examining the Beliefs and Practice of Teaching Assistants" *Proceedings of Physics Education Research Conference*, AIP Conf. Proc. 1289, 309 (2010).
4. L. Kost-Smith, S.J. Pollock and N.D. Finkelstein, A. Miyake, G. Cohen, and T. Ito, "Gender Differences in Physics 1: The Impact of a Self-Affirmation Intervention," *Proceedings of Physics Education Research Conference*, AIP Conf. Proc. 1289, 197 (2010).
5. L. Kost, S. Pollock, and N. Finkelstein, "Unpacking Gender Differences in Students' Perceived Experiences in Introductory Physics" *Proceedings of the 2009 Phys Edu. Research Conf.*, AIP Press, **1179**, 177-180, (2009).
6. C. Baily* and N. Finkelstein, "Understanding and Teaching Quantum Interpretations in Modern Physics Courses" *Proceedings of the 2009 Physics Education Research Conf.*, AIP Press, **1179**, 81-84 (2009).
7. C. Turpen*, N. Finkelstein, and S. Pollock, "Towards Understanding Classroom Culture: Students' Perceptions of Tutorials" *Proceedings of the 2009 Physics Education Research Conf.*, AIP Press, **1179**, 285-288, (2009).
8. J. Bartley*, M. Mayhew*, N. Finkelstein, "Reaching Students through Informal Science Education" *Proceedings of the 2009 Physics Education Research Conf.*, AIP Press, **1179**, 93-96, (2009).
9. L. Mayhew* and N. Finkelstein, "Learning to Teach Science through Informal Science Education Experiences" *Proceeding of the 2009 Physics Education Research Conf.*, AIP Press, **1179**, 205-208, (2009).
10. B. Spike* & N. Finkelstein, "A Study of Undergraduate and Graduate Student Conceptions of Teaching" *Proceedings of the 2009 Physics Education Research Conf.*, AIP Press, **1179**, 281-284, (2009).
11. N.D. Finkelstein and L. Mayhew*, "Acting in Our Own Self-Interest: Blending University and Community" *Proceedings of the 2008 Physics Education Research Conf*, AIP Press. Melville NY, **1064**, (2008).
12. C. Turpen* and N.D. Finkelstein, "Institutionalizing Change: Case Studies & Institutional Analysis of Pedagogical Reform in Intro Phys" *Proc 2008 Phys Educ Rsrch Conf*, AIP Press. Melville NY, **1064**, (2008).
13. N. Podolefsky* and N.D. Finkelstein, "How Abstract is Abstract? Signs, Salience, and Meaning in Physics" *Proceedings of the 2008 Physics Education Research Conf*, AIP Press. Melville NY, **1064**, (2008).
14. C. Henderson, A. Beach & N. Finkelstein, "Facilitating Change in Undergraduate STEM: Preliminary Results from an Interdisciplinary Literature Review," *Proc. 2008 Phys Ed Rsrc Conf*, AIP. Melville NY, **1064**, (2008).
15. C. Baily* and N.D. Finkelstein, "Student Understanding of Quantum Measurement and Uncertainty" *Proceedings of the 2008 Physics Education Research Conf*, AIP Press. Melville NY, **1064**, (2008).
16. L. Mayhew* and N.D. Finkelstein, "New Media and Models for Engaging Under-Represented Students in Science" *Proceedings of the 2008 Physics Education Research Conf*, AIP Press. Melville NY, **1064**, (2008).
17. L. Kost,* S. Pollock and N.D. Finkelstein, "The Persistence of the Gender Gap in Introductory Physics" *Proceedings of the 2008 Physics Education Research Conf*, AIP Press. Melville NY, **1064**, (2008).
18. A Beach, C. Henderson, N.D Finkelstein, "Facilitating Change in Undergraduate Science Instruction: Synthesis of Change Strategies across Disciplines,," *Association for the Study of Higher Education*, 2008 **1064**, (2008).
19. P. Kohl* and N.D. Finkelstein, "Expert and Novice Use of Multiple Representations During Physics Problem Solving," *Proceedings of the 2007 Physics Education Research Conf*, AIP Press. Melville NY, **951** (2007).

20. C. Turpen* and N. Finkelstein, "Understanding Physics Faculty's Use of Peer Instruction," *Proceedings of the 2007 Physics Education Research Conference*, AIP Press. Melville NY, **951** (2007).
21. L. Kost,* S. Pollock, and N. Finkelstein, "Investigating the Source of the Gender Gap in Introductory Physics," *Proceedings of the 2007 Physics Education Research Conference*, AIP Press. Melville NY, **951** (2007).
22. N. Podolefsky* and N. Finkelstein, "Salience of Representations and Analogies in Physics," *Proceedings of the 2007 Physics Education Research Conference*, AIP Press. Melville NY, **951** (2007).
23. C. Keller,* N. Finkelstein, S. Pollock, C. Turpen,* "Research-based Practices For Effective Clicker Use," *Proceedings of the 2007 Physics Education Research Conference*, AIP Press. Melville NY, **951** (2007).
24. C. Keller,* N. Finkelstein, K. Perkins, and S. Pollock, "Studying the Use of Computer Simulations in Undergraduate Laboratory Environments" *Proceedings of the 2006 Physics Education Research Conference*, AIP Press. Melville NY, **883**, 121-124, (2007).
25. P. Kohl,* D. Rosengrant and N.D. Finkelstein, "Comparing Explicit and Implicit Teaching of Multiple Representation Use in Physics Problem Solving," *Proceedings of the 2006 Physics Education Research Conference*, AIP Press. Melville NY, **883**, 145-148, (2007).
26. S. J. Pollock and N.D. Finkelstein, "Sustaining Change: Instructor Effects in Transformed Large Lecture Courses," *Proc of the 2006 Physics Education Research Conf*, AIP Press. Melville NY, **883**, 109-112, (2007).
27. N.S. Podolefsky* and N.D. Finkelstein, "Reframing Analogy: framing, blending, and representations as mechanisms of learning by analogy," *Proceedings of the 2006 Physics Education Research Conference*, AIP Press. Melville NY, **883**, 97-100, (2007).
28. N. D. Finkelstein, C. Turpen,* S. Pollock, M. Dubson, S. Iona, C. Keller,* and V. Otero, "Evaluating a model of research-based practices for teacher preparation in a physics department: Colorado PhysTEC" *Proceedings of the 2005 Physics Education Research Conference*, AIP Press. Melville NY, **818**, 3-6, (2006).
29. C. Keller,* N. D. Finkelstein, K.K. Perkins, and S.J. Pollock, "Assessing The Effectiveness of A Computer Simulation In Conjunction with Tutorials In Introductory Physics," *Proceedings of the 2005 Physics Education Research Conference*, AIP Press. Melville NY, **818**, 109-112 (2006).
30. P.B. Kohl* and N.D. Finkelstein, "Representational Competence and Introductory Physics" *Proceedings of the 2005 Physics Education Research Conference*, AIP Press. Melville NY, **818**, 93-97, (2006).
31. K.K. Perkins, M.M. Gratny,* W.K. Adams,* N.D. Finkelstein and C.E. Wieman, "Towards characterizing the relationship between students' self-reported interest in and their surveyed beliefs about physics" *Proceedings of the 2005 Physics Education Research Conference*, AIP Press. Melville NY, **818**, 137-141, (2006).
32. N.D. Finkelstein, K. K. Perkins, W. Adams,* P. Kohl,* and N. Podolefsky,* "Can Computer Simulations Replace Real Equipment in Undergraduate Laboratories?" *Proceedings of the 2004 Physics Education Research Conference*, AIP Publishing: Melville, NY, **790**. 101-104, (2005).
33. P. Kohl* and N.D. Finkelstein, "Representational Format, Student Choice, and Problem Solving in Physics," *Proceedings of the 2004 Physics Education Rsrch Conf*, AIP Publishing: Melville, NY, **790**. 121-124, (2005).
34. W. K. Adams,* K. K. Perkins, M. Dubson, N.D. Finkelstein, and C. E. Wieman "The Design and Validation of the Colorado Learning Attitudes about Science Survey," *Proceedings of the 2004 Physics Education Research Conference*, AIP Publishing: Melville, NY, **790**, 45-48, (2005).
35. K. K. Perkins, W. K. Adams,* S. J. Pollock, N.D. Finkelstein and C. E. Wieman "Correlating Student Attitudes With Student Learning Using The Colorado Learning Attitudes about Science Survey" *Proceedings of the 2004 Physics Education Research Conference*, AIP Publishing: Melville, NY, **790**. 61-64, (2005).
36. N.D. Finkelstein and E. Price "Seeding Change: The Challenges of Transfer and Transformation of Educational Practice & Research in Physics (Part I)" *Proc 2004 PER Conf*, AIP Pub: Melville, NY, **790**. 15-18, (2005).
37. E. Price and N.D. Finkelstein "Seeding Change: The Challenges of Transfer and Transformation of Educational Practice and Research in Physics (Part II)" *Proceedings of the 2004 Physics Education Research Conference*, AIP Publishing: Melville, NY, **790**, 19-22, (2005).

* indicates Graduate Student, undergrad or postdoc supported by CAREER project

Invited and Contributed Talks

200+ (85 invited) related presentations/papers available at:

<http://spot.colorado.edu/~finkelsn>

Partnerships/Outreach:

Coupled to this CAREER project we have developed the PISEC: Partnerships in Informal Science Education in the Community, a community partnership program with support from both from this CAREER program and from complementary projects (the NSF Physics Frontier Center at JILA, and the Colorado PhysTEC program supported by the APS, AIP and AAPT).

See: <http://spot.colorado.edu/~mayhew/PISEC>

Our efforts have stabilized at running four local afterschool programs (each semester impacting ~100 low income middle school students; 90% second language learners) in weekly 2-hour meetings that couple university students with children in informal science programs over an 8-10 week period.

These programs directly couple with the CAREER research as they serve as opportunities for undergraduates in the Colorado Learning Assistant Program to learn physics by teaching. These projects have expanded in partnership with the NSF Physics Frontier Center at JILA and an NSF supported project at the Center for Engineering Education and Outreach at Tufts University. We are seeking ways of institutionalizing this opportunity for teaching and research on informal science education as part of our new teacher certification program, CU Teach.

Current efforts are also underway to build on these community partnership programs to conduct research on: (i) the impact of these informal science program on children's understanding, interest and identity in science; (ii) the influence of these partnerships on university educators' (undergraduate and graduate students') understanding of education, community organizations such as these (low-income), and the abilities of these educators to communicate science in everyday language; (iii) the institutional structures that allow long-term, sustained partnerships.

As noted above, this CAREER award has supported the development of the PER group and subsequently fostered the development of a broader discipline-based education research (DBER) community. The PER and DBER programs, along with the Colorado Learning Assistant program have been instrumental components in building a campus-wide Center for STEM Education, currently dubbed Integrating STEM Education (though the Center will be for Discipline-based Education Research in STEM). See <http://www.colorado.edu/istem>

Meanwhile, the iSTEM efforts on campus along with PISEC have underscored the need to establish a regional center/network for STEM Education programs. As such we are developing the Boulder Area STEM Education Coalition (BASEC). BASEC has been underway for almost one year and represents a coalition among university, industry, national labs, community, schools and local government. More information is available at:

<http://www.boulderareastem.org>

This project has supported academic partnerships with several other institutions. In one line of work partnering with researchers at Western Michigan University, we continued our investigation of models of change in undergraduate STEM education. This continues to be a rich vein of work, and has resulted in preliminary models of institutional change.

<http://www.stemreform.org>

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

This project has made significant contributions to theoretical and experimental research base of the field of PER. The project has emphasized the role of theory in PER as well as to introduce a contextual lens with which we might engage in research in the field.

Contributions to other disciplines of science or engineering

These efforts improve the education of students more broadly and contribute to the long-term improvement of science and engineering. These efforts in PER are serving as a model and spreading to other science disciplines. As noted, University of Colorado efforts are underway to establish at Center for STEM education research supporting programs in biology, astronomy, geoscience and chemistry. As noted above, I am a co-PI on a funded project (led by the University Chancellor) NSF-I3, "Towards a Center for Science Technology Engineering and Math Education." We are well on our way to establishing this Center.

In February 2010 I testified before Congress on the reauthorization of the America COMPETES Act (for the House Science and Technology Committee). Subsequently with House Staff, I provided input on the current framing of the Act. This framing emphasizes the role of scholarship in STEM Education, and programmatic funding for studying scalable and sustainable change, and identifying Grand Challenges in STEM Education Research.

Contributions to the development of human resources

These efforts have contributed to the development of a nationally recognized research group in physics education. The research program has contributed directly and indirectly to the support and development of eight graduate researchers, three postdocs in PER, and many faculty in PER as well as traditional faculty who now engage in scholarly approaches to physics education. More broadly, this effort contributes to the discipline-based education research (DBER) community at Boulder, which includes a weekly average 25+ people (12-15 faculty from 9 disciplines, 8 postdocs, and 10+ graduate researchers)

The outcomes of the research are improved education with an improved undergraduate and graduate curriculum at the University of Colorado physics. K12 teachers are being recruited and prepared in larger numbers than have ever been seen in the University of Colorado physics department history.

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

The establishment of a viable and significant research group in PER has provided critical infrastructure. This infrastructure has, in significant fraction, been provided by the CAREER grant. Beyond the research group, our efforts are expanding to examine institutional change and sustainable models of educational transformation. Findings from this CAREER research grant have been cited by members of the National Academies as well as members of the U.S. Congress in arguing for increased support of science education in the United States. For example, See http://science.house.gov/Publications/hearings_markups_details.aspx?NewsID=2723

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

In particular we investigate how we might encourage undergraduate physics majors to become precollege teachers (the LA program, <http://laprogram.colorado.edu/>) and how, more broadly, education can be infused the culture of physics through our community partnerships programs. These programs are becoming national models, as cited by the American Physical Society and the Association of Public and Landgrant Universities, for transforming undergraduate physics and the recruitment and preparation of future physics teachers.

APPENDIX:

**SUPPLEMENTAL MATERIALS ON RESEARCH FINDINGS
1-PAGE SUMMARIES OF:**

Representational Competence and Learning Physics

with Pat Kohl (Ph.D., Physics, 2007)

Analogy and Representation Use in Instruction and Learning Physics

with Noah Podolefsky (Ph.D., Physics, 2008)

Characterizing and Improving Students Interpretations of Quantum Physics

with Charles Bialy (Ph.D., Physics, 2011).

Documenting and Addressing the Gender Gap in Introductory Physics

with Lauren Kost (Ph.D., Physics, 2011).

Instructional Choices & Student Perceptions of Educational Reforms in College Physics

with Chandra Turpen (Ph.D., Physics, 2010)

Physics Graduate Teaching Assistants in Transformed Environments: Developing Teaching Knowledge.

with Benjamin Spike (Ph.D., Physics, anticipated 2012).

Understanding How Students Use Representations in Physics Problem Solving

Patrick Kohl* & °Noah Finkelstein

Depts. of Physics, *Colorado School of Mines & °CU - Boulder

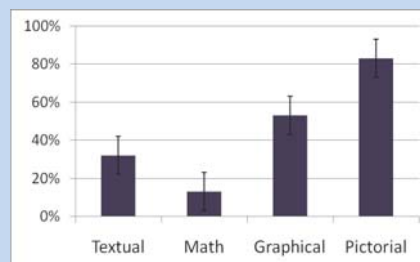
Research Goals

Prior work indicates that novice and expert physics problem solvers differ significantly in their ability to coordinate multiple representations of a problem (pictures and equations, for example). In this research program we:

- Document that different representations affect performance, and identify mechanisms
- Evaluate the effect of different approaches to teaching representation use
- Begin to characterize the expert and novice representation use when solving physics problems

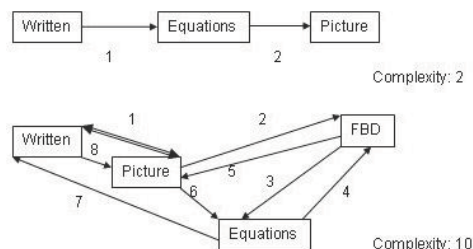
Students' abilities to solve isomorphic physics problems are impacted by representational format:

In a large-scale (N=600) study of introductory college students' use of representations [1] we find that given the same problem (wording, concept, multiple choice answer selection), students' ability to correctly answer varied dramatically depending on question format



Experts and novices vary in representation use

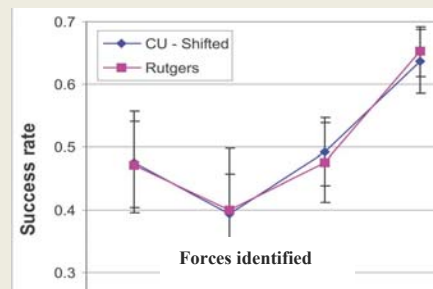
- In detailed analyses of undergraduate (novice) and graduate (experts) problem solving in think-aloud interviews
- Charted significant variations in how students use representations (see figure, right)
- Novice use is more linear; expert use is more iterative and reflective and complex[2]



Different methods of modeling representation use can be successful

- Compared a Rutgers course with explicit descriptions of multiple representation strategies to a CU course where m.rep. use is modeled implicitly; we found [3] that:

Both courses showed significant gains in student problem solving. Better coordination of representations led to better success.



Meta-representational competence is difficult to develop

- Students have strong opinions regarding which representations they handle best
- These opinions have little correlation with performance

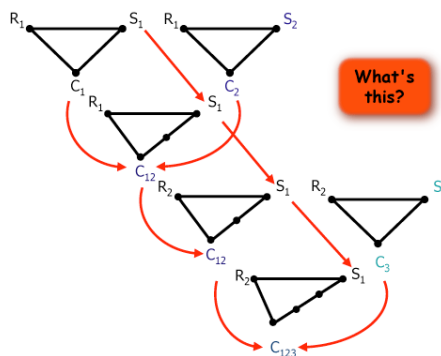
References

1. P. B. Kohl and N. D. Finkelstein. "Student representational competence and self-assessment when solving physics problems." Phys. Rev. ST Phys. Educ. Res. **1**, 010104 (2005).
2. P. B. Kohl and N. D. Finkelstein. "The effect of instructional environment on physics students' representational skills." Phys. Rev. ST Phys. Educ. Res. **2**, 010102 (2006).
3. P. B. Kohl, D. Rosengrant, and N. D. Finkelstein. "Strongly and weakly-directed approaches to teaching multiple representation use in physics." Phys. Rev. ST Phys. Educ. Res. **3**, 010108 (2007)

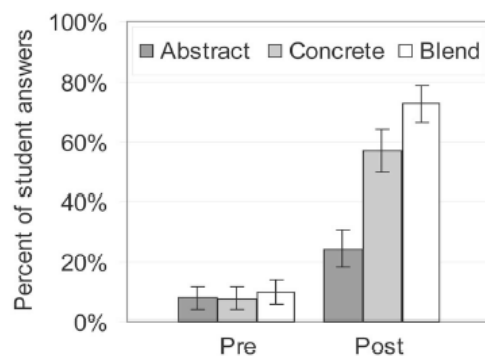
Analogy and Representation Use in Instruction and Learning Physics

Noah Podolefsky and Noah Finkelstein

This work focuses on student use of analogy for learning physics. We introduce a new model of analogy, and present a series of experiments that test and confirm the utility of this model to describe and predict student learning in physics with analogy. Pilot studies demonstrate that representations (e.g., diagrams) can play a key role in students' use of analogy.¹ A new model of analogy, Analogical Scaffolding, is developed to explain these initial empirical results.² This model draws on cognitive science research on analogy, metaphor, and conceptual blending. It also borrows from semiotics, specifically Pierce's theory of sign systems.



This model is applied to describe and predict the outcomes of further experiments.³ Two large-scale ($N > 100$) studies will demonstrate that: **(1) students taught with analogies, according to the Analogical Scaffolding model, significantly outperform students taught without analogies** on pre-post assessments focused on electromagnetic waves; **(2) the representational forms used to teach with analogy can play a significant role in student learning**, with students in one treatment group outperforming students in other treatment groups by factors of two or three. In data at the right (from reference (3)), 'blended' representations use both concrete and abstracted representations to teach about E/M wave propagation via analogy (to air and a rope).



We have demonstrated that Analogical Scaffolding can be used to predict these results, as well as finer-grained results such as the types of distracters students choose in different treatment groups, and to describe and analyze student reasoning in interviews. Abstraction in physics is reconsidered using Analogical Scaffolding. In a series of papers,^{4,5,6} an operational definition of abstraction is developed within the Analogical Scaffolding framework and employed to explain (a) why physicists consider some ideas more abstract than others in physics, and (b) how students' conceptions of these ideas can be modeled. This new approach to abstraction suggests novel approaches to curriculum design in physics using Analogical Scaffolding.

More information is at:

<http://www.colorado.edu/physics/EducationIssues/analogy/>

¹ N.S. Podolefsky, N.D. Finkelstein "The Use of Analogy in Learning Physics: The Role of Representations." Phys. Rev. ST - Phys. Educ. Res. 2, 020101 (2006)

² N.S. Podolefsky, N.D. Finkelstein "Analogical scaffolding and the learning of abstract ideas in physics: An example from electromagnetic waves." Phys. Rev. ST - Phys. Educ. Res. 3, 010109 (2007)

³ N.S. Podolefsky, N.D. Finkelstein "Analogical scaffolding and the learning of abstract ideas in physics: Empirical studies." Phys. Rev. ST - Phys. Educ. Res. 3, 020104 (2007)

⁴ N.S. Podolefsky, N.D. Finkelstein "How Abstract is Abstract? Layering Meaning in Physics." PERC Proceedings 2008. AIP

⁵ N.S. Podolefsky, N.D. Finkelstein "Reframing analogy: framing as a mechanism of analogy use." PERC Proceedings 2006. AIP

⁶ N.S. Podolefsky, N.D. Finkelstein "Salience of Representations and Analogies in Physics." PERC Proceedings 2007. AIP

Quantum Perspectives in Modern Physics Instruction

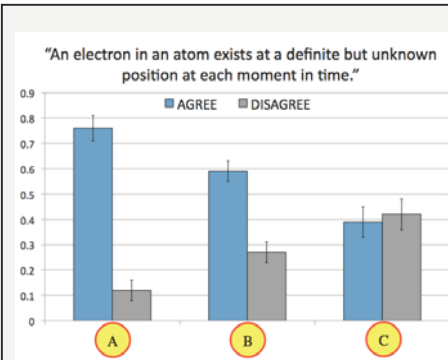
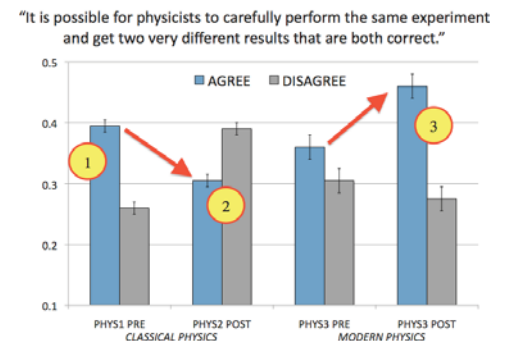
Charles Baily & Noah Finkelstein

Research Summary:

A common learning goal for modern physics instructors is for students to recognize a difference between the experimental uncertainty of classical physics and the fundamental uncertainty of quantum mechanics. We have developed a framework for understanding and characterizing student perspectives on the physical interpretation of quantum mechanics, and demonstrated the differential impact on student thinking of the myriad ways instructors approach interpretive themes in their introductory courses. Our transformed modern physics curriculum (implemented at the University of Colorado) can positively impact student perspectives on indeterminacy and wave-particle duality, by making questions of classical and quantum reality a central theme of our course, but also by making the beliefs of our students, and not just those of scientists, an explicit topic of discussion.

Student attitudes about measurement change over time⁷:

1. Before taking introductory physics, more students agree than disagree with the statement: *It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.*
2. Classical physics instruction results in a significant decrease in agreement and increase in disagreement, indicating a reinforcement of deterministic (classical) attitudes.
3. This trend reverses itself following a single semester of modern physics instruction, indicating a greater preference among students for probabilistic (quantum) attitudes.

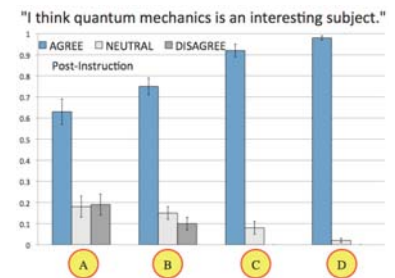


Instructor choices influence student thinking⁸:

1. Student interpretations of quantum phenomena are significantly influenced by their stances on fundamental questions⁹, such as: *Do atomic electrons exist as localized particles at all times?*
2. Agreement with this statement would be consistent with *realist* (deterministic/classical) expectations, which are favored by students from courses promoting *realist* interpretations (A).
3. Students from courses promoting alternative interpretations (B & C) are more likely to disagree, but a majority may still favor *realist* perspectives on quantum mechanics despite instruction to the contrary.

A transformed curriculum can positively impact student perspectives on quantum mechanics:

1. Make explicit the *realist* (classical) expectations of introductory students throughout the course, and offer *experimental evidence* against them. Students offer more consistent interpretations across contexts, and are less likely to favor *realist* expectations.
2. Introduce topics (such as *entanglement*) addressing the nature of quantum reality, and apply to quantum theories of computing, encryption, etc...
3. Post-instruction student interest in quantum mechanics (D) is higher than other engineering courses (A & B), and on par with a course for majors (C).



⁷ C. Baily and N. D. Finkelstein, *PhysRev: ST Phys Ed. Rsrch* **5**, 010106 (2009)

⁸ C. Baily and N. D. Finkelstein, *PhysRev: ST Phys Ed. Rsrch* **6**, 010101 (2010)

⁹ C. Baily and N. D. Finkelstein, *PhysRev: ST Phys Ed. Rsrch* **6**, 020113 (2010)

Characterizing, Modeling, and Addressing Gender Disparities in Introductory College Physics

Lauren Kost-Smith, Steven Pollock, and Noah Finkelstein
Department of Physics, University of Colorado at Boulder

Research Questions:

The underrepresentation and underperformance of females in physics is well documented and has long concerned policy-makers, educators, and the physics community. We seek to understand and address these issues by asking:

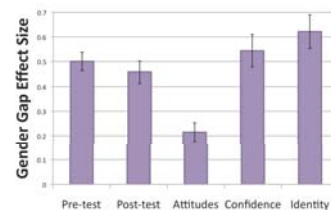
- On what measures do we observe gender differences in the introductory physics courses?
- Can gender differences in student performance be accounted for by student academic background factors?
- Can a self-affirmation intervention reduce, or even eliminate, gender differences in performance?

Population and Methodological Approach:

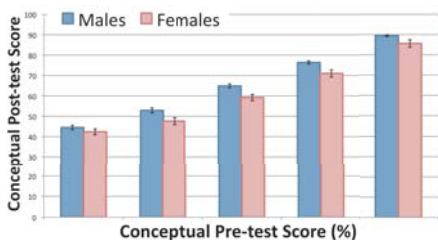
- We collect data from roughly 8,000 students who enrolled in Physics 1 over a seven-year time span at CU.
- Data were collected on a variety of student factors: demographics (gender, ethnicity), academic background (standardized test scores, high school performance), Physics 1 performance (course grades, conceptual surveys), attitudes and beliefs about physics, physics-related self-confidence, and identification with physics.
- Both epidemiological and experimental design approaches are used throughout our studies.

Gender differences exist across a variety of measures.^{1,2}

- Females are less prepared coming into Physics 1 than males: females have lower math and physics pre-test scores and less expert-like physics attitudes.
- In Physics 1, females have lower exam scores than males (though females have higher homework scores) and lower end-of-semester conceptual post-test scores.
- Students' survey responses indicate that females have lower self-confidence related to succeeding in Physics 1 and are less likely to report seeing themselves or being seen by others as a "physics person", or as someone that can do physics.



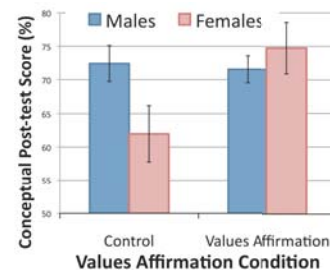
Gender differences in performance can largely be accounted for by student background.^{1,2}



- When students are grouped by their prior physics performance (effectively controlling for pre-test score), the resulting gender differences in each group are smaller than those for the entire sample.
- Using regression modeling we control for several background factors simultaneously, to compare similarly prepared males and females.
- When prior physics and mathematics understanding, prior attitudes and beliefs about physics, and prior physics self-confidence are taken into account, the modeled gender gap is reduced by up to 85%.

Self-affirmation may reduce gender differences in performance.³

- Students completed two 15-minute values affirmation writing exercises at the beginning of the semester. Students wrote either about values that are important to them (values affirmation condition) or to other people (control).
- Results from course exams and a conceptual survey show that there was a significant gender gap among students in the control condition, which was reduced or eliminated in the values affirmation condition.
- Further, values affirmation was most beneficial for female students who endorsed the stereotype that men are expected to do better in physics than women.



References:

(1) L.E. Kost, S.J. Pollock, & N.D. Finkelstein, "Characterizing the gender gap in introductory physics," *Phys. Rev. ST – Phys. Ed. Res.* **5**, 010101 (2009); (2) L.E. Kost-Smith, S.J. Pollock, & N.D. Finkelstein, "Gender disparities in second-semester college physics: The incremental effects of a 'smog of bias'," *Phys. Rev. ST – Phys. Ed. Res.* **6**, 020112 (2010); (3) A. Miyake, L.E. Kost-Smith, N.D. Finkelstein, S.J. Pollock, G.L. Cohen, & T.A. Ito, "Reducing the gender achievement gap in college science: A classroom study of values affirmation," *Science* **330**, 1234 (2010). This research has been supported by the National Science Foundation (#0448176 and #0910373), iSTEM at CU-Boulder (#0833364), and the Center for the Integration of Research, Teaching, and Learning (CIRTL) at CU-Boulder.

Instructional Choices and Student Perceptions of Educational Reforms in College Physics: A case study of Peer Instruction

Chandra Turpen & Noah Finkelstein

Research Questions:

Despite widespread use of Peer Instruction (PI) [Mazur, 1999], little work has been conducted on the choices faculty make in implementing PI and how students perceive the use of PI. We ask:

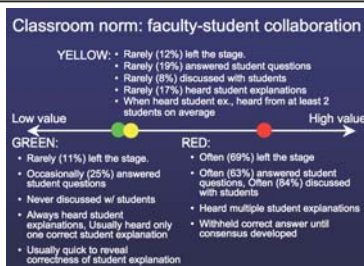
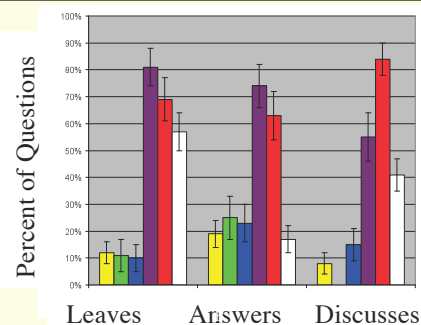
- What are the pedagogically relevant choices that faculty make when implementing PI?
- How do the results of these choices aggregate to establish classroom norms that signal to students what this activity is about?
- What are students' perceptions of PI and do they vary based on differences in classroom norms?

Population & Methodological Approach:

- We study six introductory physics courses at a large-scale research university encompassing six different instructors (Yellow, Green, Blue, Purple, Red and White) and approximately 2000 students.
- Data sources include: course observations, audiotape lectures, interviews, & student survey data.
- A rubric for categorizing instructional practices was developed from the analysis of narrative field notes. Associated student survey data were clustered along established categories.

Practices Vary by Instructor:

- 13 dimensions of practice were created to describe the choices that instructors make in using PI.
- An observation rubric was developed to quantify results of these choices.
- Variation in classroom practices is observed across instructors.
- The figure shows 3 different practices that instructors engage in during the student discussion phase of PI (whether the instructor leaves the stage, answers student questions, or discusses with the students, respectively). Notably, the degree of faculty-student collaboration varies.



Instructor Practices Over Time Establish Classroom Norms:

- The practices that result from repeated instructional choices aggregate over time to establish expected patterns of instructor and student behavior or norms.
- We identify several classroom norms established around PI.
- The figure shows the norm of valuing faculty-student collaboration. Yellow and Green are similarly categorized as relatively low value of collaboration while Red is categorized as relatively high value of collaboration.

Student Perceptions of Classroom Norms Vary by Instructor:

- From a survey of students' perceptions of PI, we observe that students perceive these classrooms differently (in correspondence with our characterization of instructor practices).
- On four questions about faculty-student collaboration, this figure shows the results of a statistical comparison between instructors' survey responses. We see that Red's students rate the course more highly than both Yellow and Green's. Yellow and Green however, are not different.

	Yellow-Red	Green-Red	Yellow-Green
Q3: Comfort discussing	↑ p=0.033	↑ p=0.001*	p=0.034
Q4: Awkward Questions	↑ p<0.001*	↑ p=0.002*	p=0.629
Q5: Speak to Professor	↑ p<0.001*	↑ p<0.001*	↑ p=0.024
Q6: Ask question	↑ p<0.001*	↑ p<0.001*	↑ p=0.032

* Significant

References & Resources

C. Turpen and N. Finkelstein, "Not all interactive engagement is the same: Variation in physics professors' implementation of Peer Instruction." *Physical Review Special Topics, Physics Education Research* 5, 020101 (2009). C. Turpen and N. Finkelstein, "The construction of different classroom norms during Peer Instruction: Students perceive differences." *Physical Review Special Topics, Physics Education Research* 6, 020123 (2010).

Physics Graduate Teaching Assistants in Transformed Environments: Characterizing Pedagogical Knowledge Across Contexts

Benjamin T. Spike & Noah D. Finkelstein
Dept. of Physics, University of Colorado – Boulder
benjamin.spike@colorado.edu

Research Questions:

As Research-based Instructional Strategies become more widespread, increasing attention is being paid to the role of graduate Teaching Assistants (TAs) in transformed environments, as well as the impact of the teaching experience on the instructors' own pedagogical development. Our primary research questions are:

- How can we characterize the specialized knowledge TAs draw upon when teaching?
- Is this knowledge stable across multiple contexts? Across semesters?

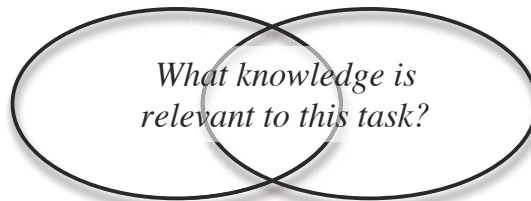
Methodology:

- Population: 8 Physics TAs, teaching 1-2 semesters using the UW *Tutorials in Introductory Physics*
- Data sources: classroom video recordings, interviews, surveys, field notes
- Rubric for coding is in development

Two different contexts for observing & characterizing teacher knowledge

Context 1: Interview

- Allows TAs to project into a particular space, describe what matters

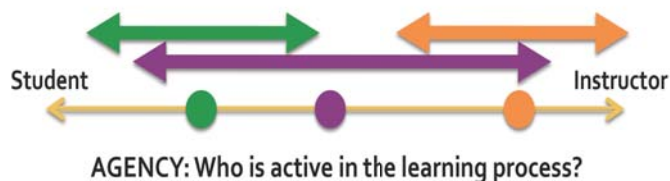


Context 2: Classroom

- Evidence of how TAs behave under real conditions, constraints

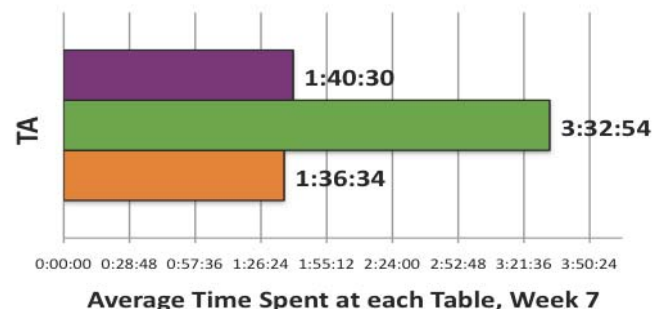
1: TAs exhibit differences in how they talk about their own teaching

- These differences may reflect variations in broader conceptions of teaching
- Can be coded along various dimensions: Agency (shown), Goal, Assessment, Motivation
 - TA Green: "Listening... lets them put out a bunch of ideas instead of supposing your way of thinking about it immediately."
 - TA Orange: "You have to tell them what the right answer is, and what the right way to do it is."



2: TAs exhibit differences in how they frame the tutorial activity

- A TA's framing shapes what they attend to when teaching, and how they respond
- Framing may provide different opportunities for students to engage in scientific discourse
 - How much time is spent with each group?
 - Verbal: Questioning/Directing/Telling
 - Nonverbal: posture, gestures



References:

B. T. Spike and N. D. Finkelstein, "Examining the Beliefs and Practice of Teaching Assistants: Two Case Studies", *Proceedings of the 2010 Physics Education Research Conference*, AIP Press (2010)