L.E.A.P.

Literature Review of Best Practices in College Physics and

Best Practices for Women in College Physics

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Background

Dr. Margaret Eisenhart from the School of Education began a review of research as part of the outreach component of the LEAP project in October, 2002. At that time, Dr. Eisenhart enlisted the assistance of P.h.D. student Kristy Martinez. Our review focused on two components of college women s experience within the sciences, primarily physics. We searched for *evidence-based* studies of (1) best practices in college teaching of science, and (2) best practices for teaching college women in science. For each study, we distinguished them by research question, treatment, outcome measures, research design, and actual outcomes. This report synthesizes our findings. Figure 2 includes the results of each review of each study.

We originally planned to extend the review to best practices in high school science and for high school girls. However, time did not permit us to complete this part.

Best Practices for Teaching College Physics

After searching the literature for best practices for teaching college physics since 1997 (the past 5 years) and reviewing the reference lists from this literature, we found twenty relevant articles. Figure 1 includes the full list of relevant articles. Of the 20 articles, only seven qualified as empirical studies of best teaching practices in college physics.° The evidence provided in these seven articles *suggests* that utilizing traditional teaching methods (teacher-directed lecture and problem-solving recitations) in introductory physics courses does not produce desired student outcomes, e.g., students conceptual understanding of physics concepts or positive attitudes toward physics and science. Put another way: Traditional teaching methods do not seem to be the best practice for consistently producing these desired outcomes. The studies describe alternative instructional practices and assess their results. The comparisons of traditional and alternative instructional methods suggest that the desired outcomes may be better achieved when students are active participants in class, when instructors have regular, quick ways of assess students understanding (flash cards, clickers) during class, and when instructors and students have in-class opportunities to discuss students understandings and difficulties. Note, however, that the positive results on desired outcomes come primarily from pre- and post-test comparisons of classes using traditional vs. alternative instructional methods. True control groups have usually not been established, thus the Hawthorne effect and other threats to validity remain unaccounted for. These methodological weaknesses limit the validity and generalizability of the results.

The first study, of a program called Peer Instruction (Crouch & Mazur, 2001), took place at Harvard University between 1990 and 2000. The study compared traditional physics courses with an average of 125 students per class with peer instruction courses with an average of 172 students. The Peer Instruction approach replaces the usual lecture component of instruction with mini lectures followed by intervals of student interaction. In Peer Instruction, introductory physics content was divided into a series of short presentations, each focusing on a central point and followed by a related conceptual question. Students were given time to formulate their individual answers and report their answer to their instructor. Students then discussed their answers with others sitting around them. The instructor then called an end to the discussion and polled the students for their individual answers. The researchers found that students who participated in peer instruction made greater gains on tests measuring conceptual understanding and problem solving than students who participated in traditional courses (Crouch and Mazur, 2001).

The second study, of a program called Fully Interactive Physics Lecture (Meltzer & Manivannan, 2001) and described as a variant of Peer Instruction, was conducted in 997-2002 at 3 universities. The study consisted of 331 students from Southeastern Louisiana University, the University of Virginia, and Southwest Missouri State University. Students participated in class using flash cards to indicate understanding during the lecture. Surveys showed that participating students react favorably to the peer instruction methods. In addition, pre-test to post-test gains were high, tripling those found in national samples using the same tests.

The third study, of a program called Traditional Problem Solving (Kim & Pak, 2001), questioned whether a traditional problem solving approach improves conceptual understanding. Twenty-seven students, nine females and eighteen males, who were first-year students in the Physics Education Department at Seoul National University participated in the study in 1994. The study compared students who solved (on the average) 1500 physics problems with those who solved only half as many. The study found that the students who solved the increased number of physics problems continued to demonstrate well known difficulties in basic understanding, although their scores on tests were high. Apparently, simply increasing the number of problems solved does not improve conceptual understanding.

The fourth study, of a program called Interactive Engagement Methods (Hake, 1998), took place during 1992 at the University of Indiana. The study involved various methods of making the physics environment more interactive. Interactive engagement activities included hands-on activities that brought immediate feedback followed by discussion with peers and instructors. Test score results demonstrated only low to medium gains as a result of interactive teaching methods, but conceptual understanding scores showed promising improvements. Teacher effects, e.g., familiarity with physics education research, are suggested as an important factor in these outcomes, although they were not measured in this study.

The fifth study, of a program called the Maryland Physics Expectation Survey (Redish et al., 1997), examined students attitudes, beliefs, and assumptions towards physics before and after taking an introductory calculus-based physics course. The survey group consisted of 1500 students from various colleges. The study was conducted in 1997 at the University of Maryland, University of Minnesota, Ohio State University, and Dickenson College and found that taking this particular introductory physics course lowered rather than raised students expectations of science.

The sixth study, of a program called Audience Based Feedback (Poulis et al., 1996), examined the effects of regular audience (student) feedback (20 minutes per class) on end-of-course pass rate, achievement, and attitudes. The study conducted between 1979 and 1992, at Eidhoven University of Technology, surveyed 5391 students. Feedback focused on students comprehension, ability to apply principles, and pace of instruction. The results were that students in the audience based feedback courses had a significantly higher pass rate, demonstrated less variability in achievement, and had more positive attitudes than students in traditional lecture classes.

The final study examining best teaching practices in physics, done between 1993 and 1995, explored the use of active-engagement, microcomputer-based labs as a substitute for traditional problem-solving recitation sessions in introductory calculus-based mechanics classes (Redish et al., 1996). The survey group consisted of 553 students at the University of Maryland. Students were given one-hour active-engagement tutorials using microcomputer-based laboratory equipment. Tutorials included concepts such as instantaneous velocity and Newton s third law. Students responded to the tutorials by answering multiple choice as well as free-response questions. Students in the microcomputer based labs produced better overall test gains than those in regular recitations.

Best Teaching Practices for College Women in Physics

We then turned to best practices for teaching women in college physics courses. Although the number of studies in this category is very small, similar patterns emerge in their results.

We found only two evidence-based studies of best practices for women in physics. The first study, of a program called Workshop Physics (Laws et al., 1999), consisted of questionnaires and interviews of 46 students in Introductory Physics courses between 1989 and 1990 at Dickinson College. Attitude surveys also were given to approximately 2800 students at 14 other U.S. colleges or universities in 1990. The study compared women s and men s attitudes and achievement after participating in workshop physics. Students were taught in a four-part sequence utilizing microcomputers and various scientific apparatuses. Students began a topic with an examination of their own preconceptions followed by qualitative observations. Students were given time for discussion, followed by the instructor s assistance with definitions and mathematical theories. Discussion ended with qualitative experimentation to verify mathematical theories (Laws et al., 1999). Women were more positive about some aspects of Workshop Physics than men (e.g., the learning lab), while average grades and the proportion of students likely to major in physics after taking Workshop Physics were roughly the same for women and men.

The final study examined best practices for teaching women and at-risk students in physics. The study compared two non-equivalent groups one group of at-risk students, mainly women (n=300), taking the alternative Extended General Physics, and one group of regular students taking traditional General Physics (n=5000) (Etkina et al., 1999). The study was conducted at Rutgers University between 1992 and 1997. Extended General Physics included active participation, cooperation among students, and activities designed to be fun as well as relevant. These features were not present in the traditional General Physics classes. The results were that the at-risk students in Extended Physics had higher course retention rates, rated their instruction more highly, and scored higher on common instruments than the students in General Physics. Another result was that the cost per *successful* student was roughly the same, despite the fact that Extended Physics is much more labor-intensive for colleges and universities.

Conclusion

In summary, our review suggests that when desired outcomes for college students (including women) are conceptual understanding in physics and positive attitudes toward physics and science, these outcomes are better achieved using alternative instructional methods than with traditional instructional methods. The alternative instructional methods that show promise are various activities that allow students to be active class participants, procedures or devices that give instructors quick ways to assess their students understanding during class, in-class opportunities to discuss students understandings and difficulties, and activities specially designed to be fun, challenging, and relevant. However, the small number of studies and their methodological weaknesses limit the validity and generalizability of the results and point to the need for more controlled studies of effective college physics instruction.

FIGURE 1: List of Articles Read (in chronological order, from most recent to earliest):

October 2002, American Journal of Physics 70 (10), Comment of How Do We Know If We Are Doing A Good Job In Physics Teaching? By Richard Hake

*June 2002, American Journal of Physics 70 (6), Students Do Not Overcome Conceptual Difficulties After Solving 1000 Traditional Problems, By Eunsook Kim and Sung-Jae Pak.

*June 2002, American Journal of Physics 70 (6), Transforming the Lecture-Hall Environment: The Fully Interactive Physics Lecture, By David Meltzer and Kandiah Manivannan.

May 2002, American Journal of Physics 70 (5), Comment of How Do We Know If We Are Doing A Good Job In Physics Teaching? By Bernard J. Feldman

January 2002, American Journal of Physics 70 (1), How Do We Know If We Are Doing A Good Job In Physics Teaching? By Robert Ehrlich.

November 2001, American Journal of Physics 69 (11), Milikan Lecture 1999: The Workplace, Student Minds, and Physics Learning Systems, By Alan Van Heuvelen.

November 2001, American Journal of Physics 69 (11), Oersted Medal Lecture 2001: Physics Education Research — The Key to Student Learning by Lillian Christie McDermott.

*September 2001, American Journal of Physics 69 (9), Peer Instruction: Ten Years of Experience and Results by Catherine H. Crouch and Eric Mazur.

July 2001, American Journal of Physics 69 Suppl. S1, Helping Physics Students Learn How to Learn by Andrew Elby.

*September 1999, American Journal of Physics 67 (9), Lessons Learned: A Case Study of an Integrated Way of Teaching Introductory Physics to At-Risk Students at Rutgers University, By E. Etkina, K. Gibbons, B.L. Holton, and G.K. Horton.

July 1999, American Journal of Physics 67 (7), Milikan Lecture 1998: Building a Science of Teaching Physics, By Edward Redish.

*July 1999, American Journal of Physics Suppl. 67 (7), Women s Responses to an Activity-Based Introductory Physics Program by Priscilla Laws, Pamela Rosborough, and Frances Poodry.

April 1999, American Journal of Physics 67 (4), Peer Instruction: A User s Manual by Eric Mazur and Mark D. Somers.

January 1999, Physics Today, Teaching Physics: Figuring Out What Works by Edward F. Redish and Richard N. Steinberg.

July 15th, 1998, Physics Education Research Group at the University of Maryland, Resource Letter on Physics Education Research by Lillian McDermott and Edward F. Redish.

*May 1998, American Journal of Physics 66 (5), Interactive engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses by Richard R. Hake.

*May 1998, American Journal of Physics 66 (5), Physics Lecturing with Audience Paced Feedback by J. Poulis and C. Massen, E. Robens, and M. Gilbert.

*March 1998, American Journal of Physics 66 (3), Student Expectations in Introductory Physics by Edward F. Redish, Jeffery M. Saul, and Richard N. Steinberg.

January 1998, American Journal of Physics 66 (1), Where Are All The Physics Majors? By Robert Ehrlich.

*January 1997, American Journal of Physics 65 (1), On the Effectiveness of Active-Engagement Microcomputer-Based Laboratories by Edward F. Redish, Jeffery M. Saul, and Richard N. Steinberg.

January 1997, American Journal of Physics 65 (1), Millikan Lecture 1996: Promoting Active Learning Based on Physics Education Research in Introductory Physics Courses by P.W. Laws.

December 1991, Physics Today, Calculus-Based Physics Without Lectures by Priscilla Laws.

See Also: physicsweb.com

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* Indicates empirical studies used

FIGURE 2: REVIEW OF EVIDENCE-BASED STUDIES

Reference and Date	Program Name	Research Question	Treatment	Outcome Measures/Dimensions of Contrast	Samples and Methods of Data Collection	Outcomes
Laws et al. 1999	Workshop Physics W.P.	Do Women Like Workshop Physics Better than Men?	Workshop Physics- At least 1 semester Constructivist, activity- based course involving collaborative work	Women s Attitudes toward and Achievement in physics	1. Exams, course evals, course taking and performance. Questionnaires and interviews of Dickinson Intro Physics Students 1989 and 1990 (approx 46 students) 2. Attitude survey given to approximately 2800 students at 14 U.S. institutions in 1990 3. Focus group interviews with 15 women still in college that disliked taking workshop physics	1. Proportion of Men and Women choosing to major in physics is roughly the same after taking workshop physics. 2. Women more likely than men to view successful learning in physics as straight forward fact gathering Freshman and sophomore women more positive about computer use after W.P. than men or upper division women Average grades for men and women roughly the same in W.P. Women value W.P. lab learning experience more than men Women less confident about lab skills than men after W.P. Jr. & Sr. women more neg. (fewer learning gains) about lab work after workshop physics * All (2) outcomes are from Dickinson samples (24 men and 22 women) only & based on recall of before attitudes in comparison to current (post W.P.) attitudes 3. Stressful collaborations contribute to neg. attitudes towards labs Excessive or unclear time demands contribute to neg. attitudes towards labs

Comments:

- Within campus comparison of attitude survey (from 1 college) results shows students in W.P. more positive about learning experiences and mastered more concepts than students in traditional courses.
- Relevant findings based upon small numbers (24 men and 22 women).
- Lab Work seems to constitute the bulk of what Workshop Physics stresses; therefore, findings about it are particularly salient.
- Speculation about difference between fresh-soph & jr.-sr. women is that the later group are closer to the need to prepare for medical school or grad. school acceptance.
- Conclusion: Any attempt to change the rules for succeeding in physics courses is very stressful to students who are not confident intellectually. (p. 536)

Reference and Date	Program Name	Research Question	Treatment	Outcome Measure/ Dimension of Contrast	Samples and Methods of Data Collection	Outcomes
Crouch & Mazur 2001	Peer Instructi on (P.I.)	What is P.I.? What are the Advantages of P.I.?	2 intro. Physics courses for non-majors at Harvard designed and refined to follow tenets of P.I. (increased teacher questioning of students and student — student instruction to uncover students conceptual (mis) understandings, strengthen understanding, present arguments for an answer, pre-reading of class material.	1. Reading Incentives 2. Cooperative activities 3. Quant. Problem solving 4. Student Motivation 5. Use of Concept tests 6. Time management 7. Teaching Assistant training 8. Resource use	1. Case study of 10 years pf development, implementation, and refinement at Harvard 2. Quantitative Comparisons (1990 — 2000) a. Force Concept Inventory b. Mechanics Baseline Test c. Exam questions d. Concept test performance N s= Traditional Ave. 125 in 2 diff. years P.I. Ave. 172 across 8 diff years	1. See Article for Description of Results a. Higher normalized gain scores for P.I. than traditional courses b. Some improvement with Intro of P.I. but no X-Course comparisons c. Quant. Problem solving skills in P.I. comparable or better than traditional instruction d. Improved performance pre & post P.I., but no X-course comparisons

Comments:

- Pre-Post Improvements with introduction of P.I. hold up over time (1990 — 2000), across 2 different types of courses (calculus-based and algebra-based), and across 5 different instructors.
- Significant effort must be put into student motivation to achieve high scores of student s reactions to P.I.

Reference and Date	Program Name	Research Question	Treatment	Outcome Measure/ Dimension of Contrast	Samples and Methods of Data Collection	Outcomes
Meltzer and Manivannan 2001	Fully Interacti ve Physics Lecture	Can the interactive-lecture method be applied to physics lectures in a way that is practical, effective, and amenable to widespread implementatio n?	Student s response system implemented using flash cards to respond to multiple choice questions presented throughout the lecture. Students given Workbook for Introductory Physics vs. Traditional Textbook.	1. Students given a brief introduction lecture lasting 3-7 min. Students are then given a sequence of multiple choice questions and an opportunity to respond with flashcards. The class concludes with follow-up activities. 2. Students given a workbook which included many multiple choice questions (to be used during lecture). Workbook also included a set of lecture notes, free response worksheets, and a large collection of quizzes and exams.	1. End of class survey 2. Quantitative Comparisons: a. Conceptual Survey in Electricity (CSE) given on the first and last day of class between 1997-2000 (approx 331 students). b. Conceptual Survey in Electricity Magnetism (CSEM) given between 199-2000 (approx 223 students. Program administered at Southeastern Louisiana University, The University of Virginia, and Southwest Missouri State University. (CSE) N s= 331 students. (CSEM) N s = 223 students. National Sample N s = 1898	1. End of class survey shows that most students react favorably to the instructional methods, with approximately 30%-40% giving maximum ratings on evaluations. Less than 10% despise the methods. a. Pre-test to post-test gains are quite high showing a normalized gain <0.46>-<0.69> and effect size. b. Pre-test to post-test gains <0.68>-<0.71> triple those found in national samples of the same test administered.

Comments:

- This study involved seven years of development and testing on a variant of the Peer Instruction pioneered by Mazur.
- Author claims that this method would apply well to large lecture hall style physics courses, although they did not test their methods on classes larger than 100 students.
- On the CSE pre-test students were given the full-item multiple choice test usually given, but on the post-test students were given 23 item subset of the CSE. Because of this the authors did not compare their gains to that of a national survey.

Reference and Date	Program Name	Research Question	Treatment	Outcome Measures/Dimensions of Contrast	Samples and Methods of Data Collection	Outcomes
Eunsook Kim and Sung-Jae Pak 2001	Traditional Problem Solving	Does an increase in traditional question/problem solving improve conceptual understanding in physics?	Students in traditional physics courses given a textbook with 1400 qualitative questions and 3400 quantitative problems. Note: Students actually answered between 300 — 2900 problems with an average of 1500. Note: Traditional physics text typically have approximately 700 qualitative questions and 1600 quantitative problems.	1. Use of text Fundamentals of Physics. By Halliday, Resnick and Walker 2. Use of a set of conceptual understanding tutorials developed at the University of Washington 3. Problem solving ability	1. Conceptual Understanding Questionnaire/tutorials used during 1994 at Seoul National University. 2. Quantitative Comparisons a. Halloun-Hestenes Mathematics test used during 1994 at Seoul National Universit. b. Hestenes-Wells Mechanics Baseline Test (MBT) Ns: 27 students 9 females 18 males	1. Students demonstrated well known difficulties in basic concepts of understanding, despite the increased question/problem solving. 2. Students scored high on the Mathematics Test. See Table I. 3. Students scored high on the Mechanics Baseline Test. See Table I.

Comments:

- Conceptual understanding tutorials were analyzed by one of the authors of this study and a Ph.D./Teaching assistant. The two graders disagreed less than 10% of the time and resolved differences through discussion.
- Common conceptual difficulties were categorized into 3 areas: (a) Lack of Differentiation among force, acceleration, and velocity, (b) Misunderstanding Newton s Law, and (c) a gap between the use of algebra expressions and the associated physics concepts.
- Although the title of the study indicates that the student solved 1000 physics textbook problems, on the average, students performed 1500 problems with many solving over 1000 problems. The title is likely based upon 1000 problems because a typical workbook used by students at Seoul University contains 1000 problems.
- Tests and tutorials used in this study were translated into Korean by the researchers.
- Traditional problem solving increases understanding of physics concepts, however, conceptual understanding requires other approaches.

Reference and Date	Program Name	Research Question	Treatment	Outcome Measures/Dimensions of Contrast	Samples and Methods of Data Collection	Outcomes
Etkina et al. 1999	Extended General Physics (E.G.P.)	What are the Structures and comparative results of G.P. and E.G.P.?	2- Semester Intro. Physics Courses in traditional general physics (G.P.) for traditional vs. Extended General Physics (E.G.P.) for at-risk students (including active participation, cooperation, fun, excitement and relevance at Rutgers, 1992-1995	1. Student Selection 2. Section Size 3. Course Pace 4. Student Support 5. Instruction Assignments 6. Textbooks, etc. 7. Mini-labs of Qualitative Experiments 8. Real-world Problem Solving 9. Labs Requiring Student Initiative 10. Notebook Write-ups of Activities 11. Interactive Lectures for Communication Building and Socialization 12. Exams and Grading (many common ? s for E.G.P. and G.P. on final exams	1. Case-study of G.P. and E.G.P. for 5 years at Rutgers 2. Quantit. Comparisons a. Course retention rates 1992-1995 b. Student instructional rating 1992-1995 c. Final scores on common questions over 5 years d. Program costs Ns: G.P. = 5000 E.G.P. == 300	1. See article a. Higher in E.G.P. than G.P. especially women and African-Americans b. Higher in E.G.P. than G.P. c. Higher average scores for E.G.P. than G.P. d. Costs per successful student are roughly equal (as opposed to the more common measure of cost per enrolled ss)

Comments:

- Extraordinarily positive results, especially considering that E.G.P. students are at-risk, predominately women, some had dropped out of G.P. etc..
- Authors stress importance of combining the dimensions of contrast (all of which have been individually proposed and studied by others) listed above for a successful curriculum.
- Authors thank Sheila Tobias for her assistance and inspiration.

Reference and Date	Program Name	Research Question	Treatment	Outcome Measure/ Dimension of Contrast	Samples and Methods of Data Collection	Outcomes
Hake 1998	Interactive Engagement Methods (IE)	Does the use of I.E. improve the effectiveness of mechanics course well beyond that of traditional methods?	Use of I.E. methods v. no or little use of I.E. methods (traditional).	1. Conceptual understanding (MD,FCI) 2. Problem solving ability 3. Normalized gain score (Hi, M, Low)	1. Halloun-Hestenes Mechanics Diagnostic Test (MD) 2. Forced Concept Inventory Test (FCI) 3. Hestenes-Wells Mechanics Baseline Test (MB) Survey of Pre/Post test comparisons where above instruments used All then published reports and known unpublished reports of the uses of these tests in intro. Physics in classes using I.E. and traditional methods (collected by author) N= 62 Courses. Enrolling 6542 students: 14 high school (1113 students) 16 college (597 students) 32 University (4832 students)	1. 14 traditional courses had gain of .23 +/- .04. 2. 48 courses using I.E. had gain of .48 +/- .14, but all gains characterized as med or low (none as high). 3. I.E. particularly effective at raising conceptual understanding scores.

Comments:

- Footnote 17(a) cites another Hake article (companion article) with detail about the particular characteristics of how the 62 courses were taught and the outcomes of each. This article can be found at http://carini.physics.indiana.edu/SDI/.
- 12 I.E. courses with high normalized gains tend to be taught by instructors who have demonstrated considerable familiarity with physics education.
- Implementation problems with I.E. may limit its success (see bottom, p. 70-Comparisons p. 71) lack of standards for measuring physics outcomes may limit X class.

Reference and Date	Program Name	Research Question	Treatment	Outcome Measure/ Dimension of Contrast	Samples and Methods of Data Collection	Outcomes
Redish et al. 1997	Maryland Physics Expectation Survey (M.P.E.X.)	Does the student s expectation of what science is about, how it is done, and what goes on in a science course play a role in what they get out of intro college physics?	M.P.E.X. survey (Likert scale) given to students at the beginning and end of the first semester of calculus-based physics. M.P.E.X. survey also given to a group of experts (comprised of experienced physics instructors) to test whether the survey correctly represents elements of the hidden curriculum.	1. Student s attitudes, beliefs, and assumptions towards physics pre and post introductory calculus-based physics.	1. M.P.E.X. survey given to 1500 students at University of Maryland, University of Minnesota, Ohio State University, Dickinson College, a small liberal arts university and a medium sized public two-year college 2. 100 hours of videotaped student interviews to validate interpretation of results 3. M.P.E.X. survey given to high school teachers, university and college teachers, and members of the U.S. International Physics Olympics Team N s= 1500 students at over 6 colleges 602 experts	1. In all cases, the result of instruction on the overall survey was an increase in unfavorable responses and a decrease in favorable responses. Instruction produced deterioration rather than improvement in student expectations. A significant part of the deterioration was effort cluster, cognitive and independent dimensions deteriorated as well, two-thirds on the coherence dimension, half on the math link, and all on the reality link. 2. Students not always consistent with their responses when provided with similar questions and situations in an interview format. 3. The expert group was consistent , agreeing on the desirable student outcome 87% of the time.

Comments:

- Survey focused on 6 different structures: independence, coherence, concepts, the link between physics and the real world, understanding of the role of math in physics, and the kind of effort they expect to make.
- Authors argue that some physics courses may actually reward students with inappropriate attitudes, such as those who prefer memorizing to understanding, while driving away students who might excel in science given a more supportive structure.

Reference and Date	Program Name	Research Question	Treatment	Outcome Measures/Dimensions of Contrast	Samples and Methods of Data Collection	Outcomes
Poulis and Massen et al. 1996	Audience Based Feedback (A.P.F.)	Does audience based feedback improve the student s learning process in physics courses?	Lectures given using audience based feedback (A.P.F.) substituted for traditional lectures in physics courses.	1. 45 min. lecture with 20 min. devoted to A.P.F. where handsets and reception with display used 2. Student provided with a handset to answer multiple choice questions from the instructor 3. Responses calibrated as percentages displayed to entire class 3. Full audience participation required from all students on every question 4. Student s replies are anonymous	1. End of Course examination given over four years at Eidhoven University of Technology. Sample taken between 1979-1992 (approx 5391 students). 2. Opinion survey given to 288 students at Eindhoven University of Technology who received A.P.F. Opinion Survey also given to traditional lecture style courses for comparison. Ns: 5391 A.B.F. = 2550 Traditional= 2841	1. The mean A.P.F. pass rate is significantly higher than that where instructors used conventional methods. A.P.F. additionally reduces the variability between the achievements of different students. 2. Students prefer lectures involving A.P..F. and react more positively than students in traditional lecture style courses.

Comments:

- Questions used during A.P.F. include questions designed to explore the students understanding, verify the student s comprehension, interrogate the student s ability to apply the work to a given situation, and further organize the lecture assessing the pace of the lecture.
- Authors acknowledge that study may likely contain a residual Hawthorne-like effect because the students were given handsets and responded to the lecturer s clear set of OHPs.

Reference and Date	Program Name	Research Question	Treatment	Outcome Measures/Dimensions of Contrast	Samples and Methods of Data Collection	Outcomes
Redish et al. 1996	Microcomputer-Based Lab (M.B.L.)	Can computer activities successfully teach basic physics concepts?	1-Hour active-engagement tutorials using microcomputer based laboratories (M.B.L.) substituted for traditional problem-solving recitations in introductory calculus-based mechanics classes. Vs. Traditional recitations.	1. Weekly Upgraded Pretests 2. Weekly training for Faculty and Teaching Assistants 3. 50-minuete Tutorial Sessions 4. Cooperative Activities w/Facilitators 5. Instruction Assignments 6. Examination based upon laboratory activities 7. Use of Concept Tests 8. Use of Multiple Choice Velocity Questions	1. Case-study of M.B.L. and Traditional Recitations for 2 years at University of Maryland 2. Quantit. Comparisons a. Concept Test Performance 1993-1995 b. Multiple Choice Velocity Questions 1993-1995 Ns: 553 M.B.L. = 312 Traditional= 241	1. See article a. M.B.L. produced better overall FCI gains than the non-tutorial classes b. Substantially higher in M.B.L. than G.P.

Comments:

- Study produced dramatic results, a large fraction of traditional students missed all but the simplest of the velocity graph questions, but the error rate dropped to below 10% on all of the questions for students in the computer-based labs.
- Authors stress importance of further study on whether students can apply the concepts learned outside of a multiple choice context. Students showed that they needed improvement when full responses required.
- Authors thank Richard Hake for discussions and comments on this paper.