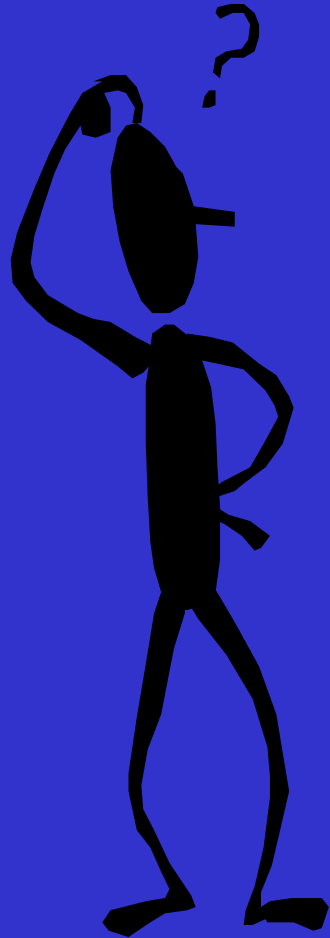


What Can We Learn From the Physics Education Reform Effort?†*



Richard R. Hake, Physics Department,
Indiana University, <rrhake@earthlink.net>,
<<http://www.physics.indiana.edu/~hake>>

† ASME Mechanical Engineering
Education Conference:

Drivers and Strategies of Major Program Change
Fort Lauderdale, Florida, March 26 - 29, 2000

* Partially supported by NSF Grant DUE/MD 9253965

†R.R. Hake, 27 March 2000. You may change, modify, copy, and distribute at will for use in your own institution, but please contact R.R. Hake before distributing your version beyond your own institution.

OUTLINE

- I. Failure of Traditional Introductory Physics Courses -
Anecdotal Evidence
 - II. Failure of Traditional Courses and *Relative Success* of
Active-Engagement Courses -
Research Evidence
 - III. Some Interactive-Engagement Classrooms
 - IV. Ten *Hard* Lessons from the Physics Education Reform Effort
- References and Footnotes*

I. FAILURE OF TRADITIONAL INTRODUCTORY PHYSICS COURSES - ANECDOTAL EVIDENCE

A. JOHN RIGDEN, excerpts, editorial, *Am. J. Phys.* 52, 304 (1984):

"THE INTRODUCTORY COURSE CONFUSION !!.....

THE STUDENTS: Most of them come because they *MUST* - they are premeds, *aspiring engineers*, budding chemists. For them physics is *required*.

THE FACULTY: They realize that the introductory course is a formidable challenge: the density of concepts is high, it quickly builds upon itself adding a logical layer upon another logical layer. Most of all the pace is *relentless*. There are no pauses for reflection; tomorrow another chapter will be started!



John Rigden

THE STUDENTS: Free-body diagrams are a bane to their sanity and the normal force is orthogonal to their sense of rationality. Newton's second law is an algebraic relation to solve for one quantity when good fortune provides the other two. Action-reaction pairs get confused: they act in the same direction, on the same body, but they show why a horse can pull a cart.

THE FACULTY: The objective of this course is to uproot the common-sense ideas based on everyday experience and to sow the seeds that will flower into the Newtonian view - airless, frictionless, idealized, abstract. Moreover the faculty have the somber realization that this conceptual transformation must be consummated in a few class periods. Quite a challenge: after all, it required the physicists of earlier eras years and years to assimilate the same ideas.

THE STUDENTS: They do not regard the introductory course as an opportunity to understand a few general principles that can be applied across a range of natural phenomena; they do not see that the course bears any significance to their day-to-day activities or to their future.



THE STUDENTS: They leave the introductory course with a disjointed, collage-like idea as to the content of physics and they leave with no idea whatsoever how it is that we know what we know.



THE FACULTY: They leave with a rekindled and deepened awareness of the conceptual richness of the introductory course. They are happy with the way they have brought the ideas together.

THE INTRODUCTORY COURSE **ILLUSION** !!!!"

B. ERIC SCHOCKET (as quoted by Sheila Tobias in *They're Not Dumb, They're Different: Stalking the Second Tier*. At that time Schocket was a graduate student - BA summa cum laude, literature, UC Berkeley; he's now an associate professor of literature at Hampshire College.):

"The lack of community, together with the lack of interchange between the professor and the students combines to produce a totally passive classroom experience.....The best classes I had were classes in which I was constantly engaged, constantly questioning and pushing the limits of the subject and myself. The way this course is organized accounts for the lack of student involvement The students are given pre-masticated information simply to mimic and apply to problems. Let them rather, be exposed to conceptual problems, try to find solutions to them on their own, and then help them to understand the mistakes they make along the way." (My italics.)

C. **SILVIA PLATH** in *The Bell Jar* (Harper & Row, 1971), p. 28-29



Sylvia Plath

"The day I went into physics class was deathA short dark man ...(held) ...a little wooden ball. He put the ball on a steep grooved slide and let it run down to the bottom. Then he started talking about let a equal acceleration and let t equal time. And suddenly he was scribbling letters and numbers and equals signs all over the blackboard and my mind went dead.Well, I studied those formulas, I went to class and watched balls roll down slides and listened to bells ring and by the end of the semester most of the other girls had failed and I had a straight A....but I was panic-struck. Physics made me sick the whole time I learned it. What I couldn't stand was this shrinking everything into letters and numbers. "
(My *italics*.)

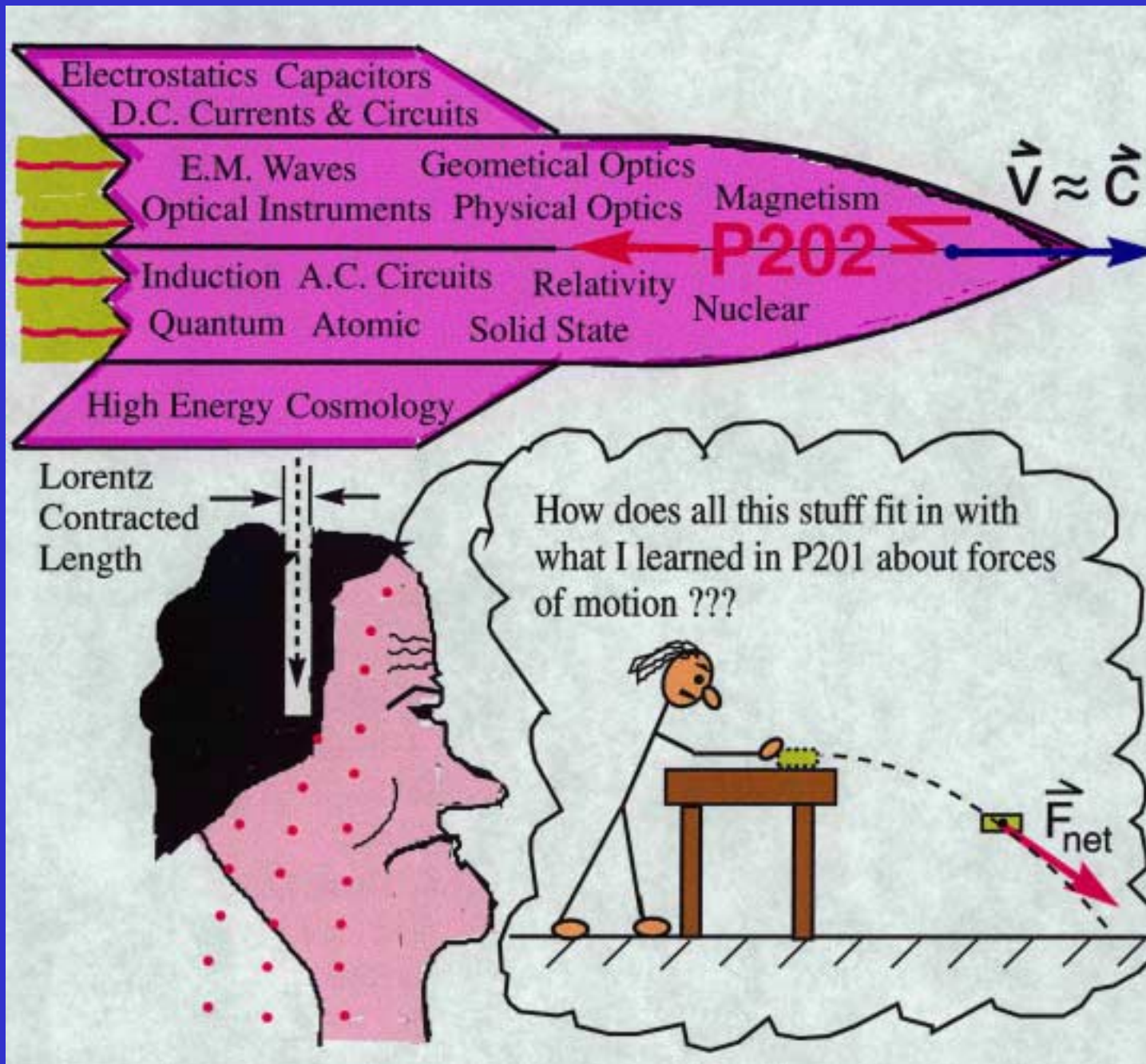
D. ARNOLD ARONS



Arnold Arons

THE STANDARD *RELATIVISTIC MODEL OF INSTRUCTION*

"The relativistic model is based on the premise that, if one starts with an **E- N- O- R- M- O- U- S** breadth of subject matter but passes it by the student at sufficiently high velocity, the Lorentz contraction will shorten it to the point at which it drops into the *hole* which is the student mind."



II. FAILURE OF TRADITIONAL COURSES & RELATIVE SUCCESS OF ACTIVE ENGAGEMENT COURSES - RESEARCH EVIDENCE

A. L.C. McDermott and E.F. (Joe) Redish, "Resource Letter on Physics Education Research" *Am. J. Phys.*, **67**(9), 755-767 (1999); <<http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>>.

Reviews over four decades of primarily qualitative and some quantitative research (largely ignored by the physics community) on both cognitive and affective aspects of physics instruction.



Lillian McDermott



Joe Redish

B. META-ANALYSIS: R.R. Hake, "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**(1), 64 - 74 (1998).

1. METHODOLOGY

- a. Used standard multiple-choice tests of conceptual understanding and problem-solving ability, recognized for high reliability and validity:

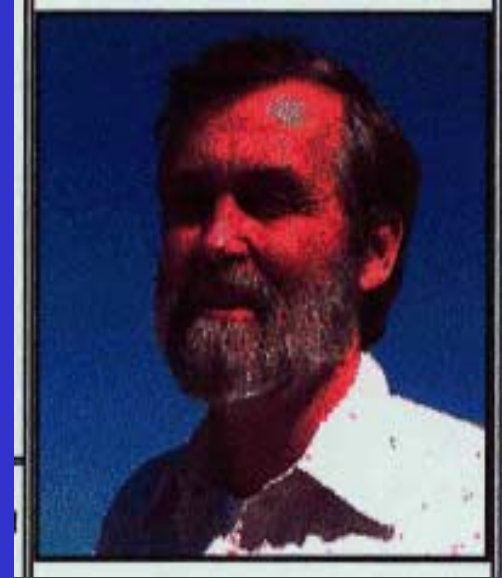
(1) Halloun/Hestenes, *Mechanics Diagnostic (MD)* test

(2) Hestenes, Wells, Swackhamer, *Force Concept Inventory (FCI)*

(3) Hestenes/Wells, *Mechanics Baseline (MB)* test



Ibrahim Halloun

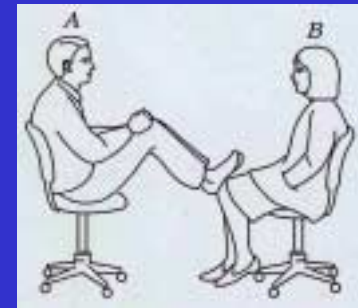


David Hestenes

b. Typical FCI question (#28 of 30)

In the following figure, student A has a mass of 75 kg and student B has a mass of 57 kg. They sit in identical office chairs facing each other. Student A places his bare feet on the knees of student B, as shown. Student A then suddenly pushes outward with his feet, causing both chairs to move.

During the push and while the students are still touching one another,



- A. neither student exerts a force on the other.
- B. student A exerts a force on student B, but B does not exert any force on A.
- C. each student exerts a force on the other, but B exerts the larger force.
- D. each student exerts a force on the other, but A exerts the larger force.
- E. each student exerts the same amount of force on the other.

c. Starting in 1992, I requested that pre-/post-FCI test data and post-test MB data be sent to me. Thus the detector is *biased* in favor of relatively high-gain courses, but can still answer a crucial research question:

"*Can* the use of Interactive Engagement (IE) methods increase the effectiveness of introductory mechanics courses well beyond that obtained by traditional methods?"

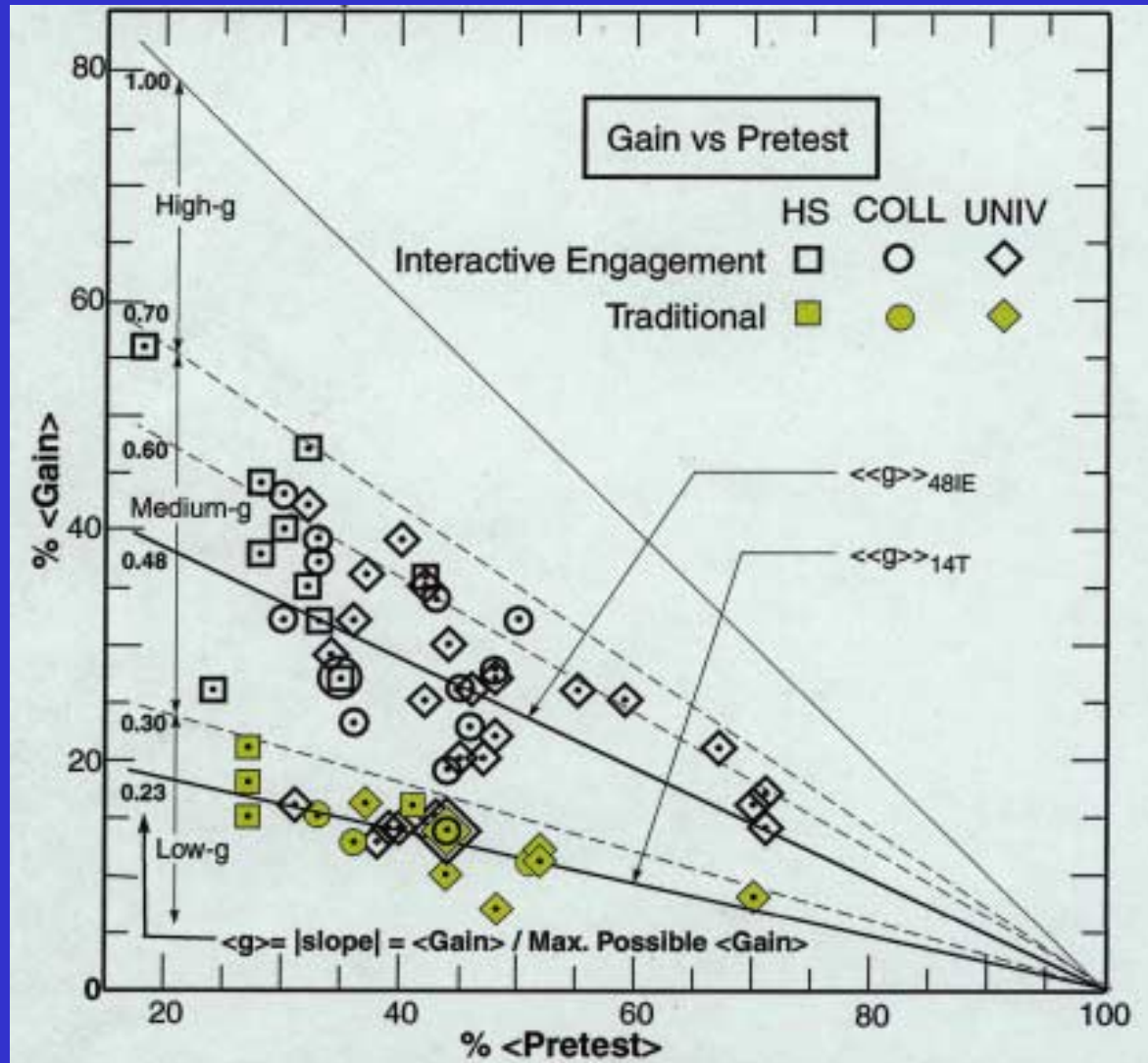
d. For survey classification and analysis purposes I defined:

(1) "Interactive Engagement (IE) methods" as those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities that yield immediate feedback through discussion with peers and/or instructors, all as judged by their literature descriptions.

- (2) "Traditional (T) courses" as those reported by instructors to make little or no use of IE methods, relying primarily on passive-student lectures, recipe labs, and algorithmic-problem exams.
- (3) "IE courses" as those reported by instructors to make substantial use of IE methods.
- (4) Average *normalized* gain $\langle g \rangle$ for a course as the ratio of the *actual* average gain $\langle G \rangle$ to the *maximum* possible average gain, i.e.,

$$\begin{aligned}\langle g \rangle &= \frac{\% \langle G \rangle}{\% \langle G \rangle_{\max}} \\ &= (\% \langle \text{post} \rangle - \% \langle \text{pre} \rangle) / (100 - \% \langle \text{pre} \rangle).\end{aligned}$$

2. GAIN vs PRE-TEST - ALL DATA (FCI or MD Tests)

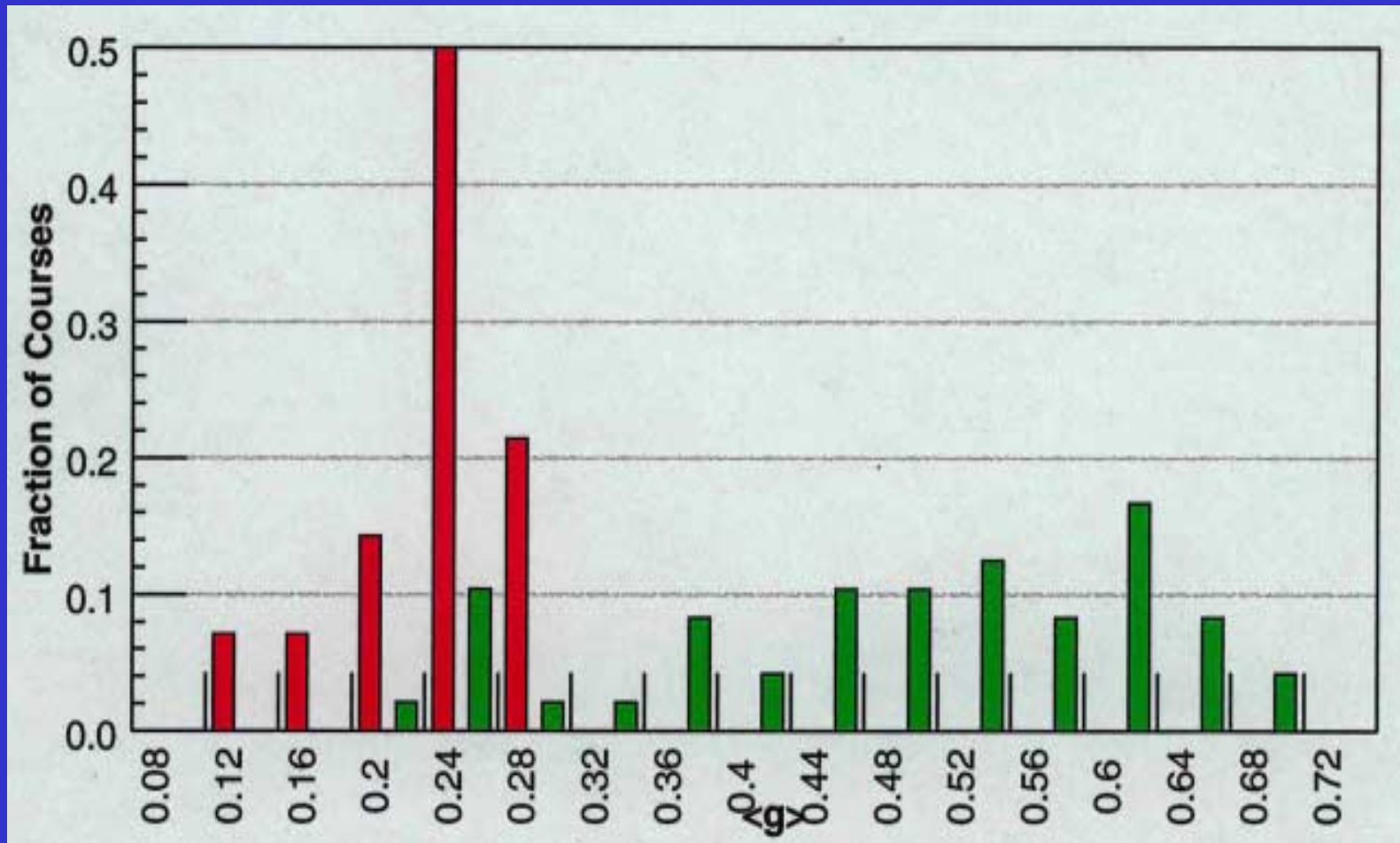


62 courses (N = 6542)

48 IE (N = 4458): $\langle\langle g \rangle\rangle$ (48 IE) = $0.48 \pm 0.14sd$

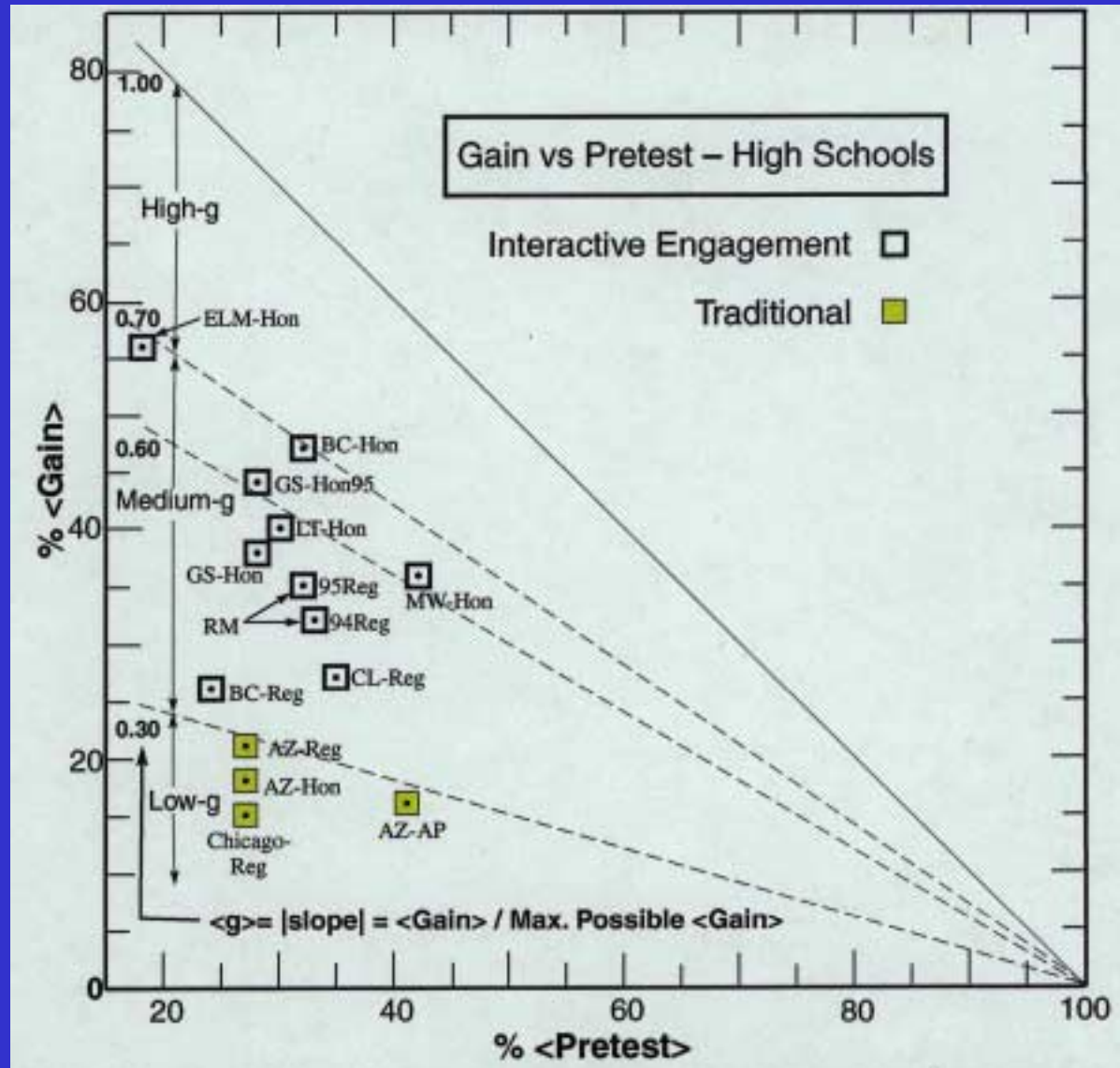
14 T (N = 2084): $\langle\langle g \rangle\rangle$ (14 T) = $0.23 \pm 0.04sd$

$\langle\langle g \rangle\rangle$ (IE) is over twice that of $\langle\langle g \rangle\rangle$ (T) and differs by almost 2 sd's of sd(IE)



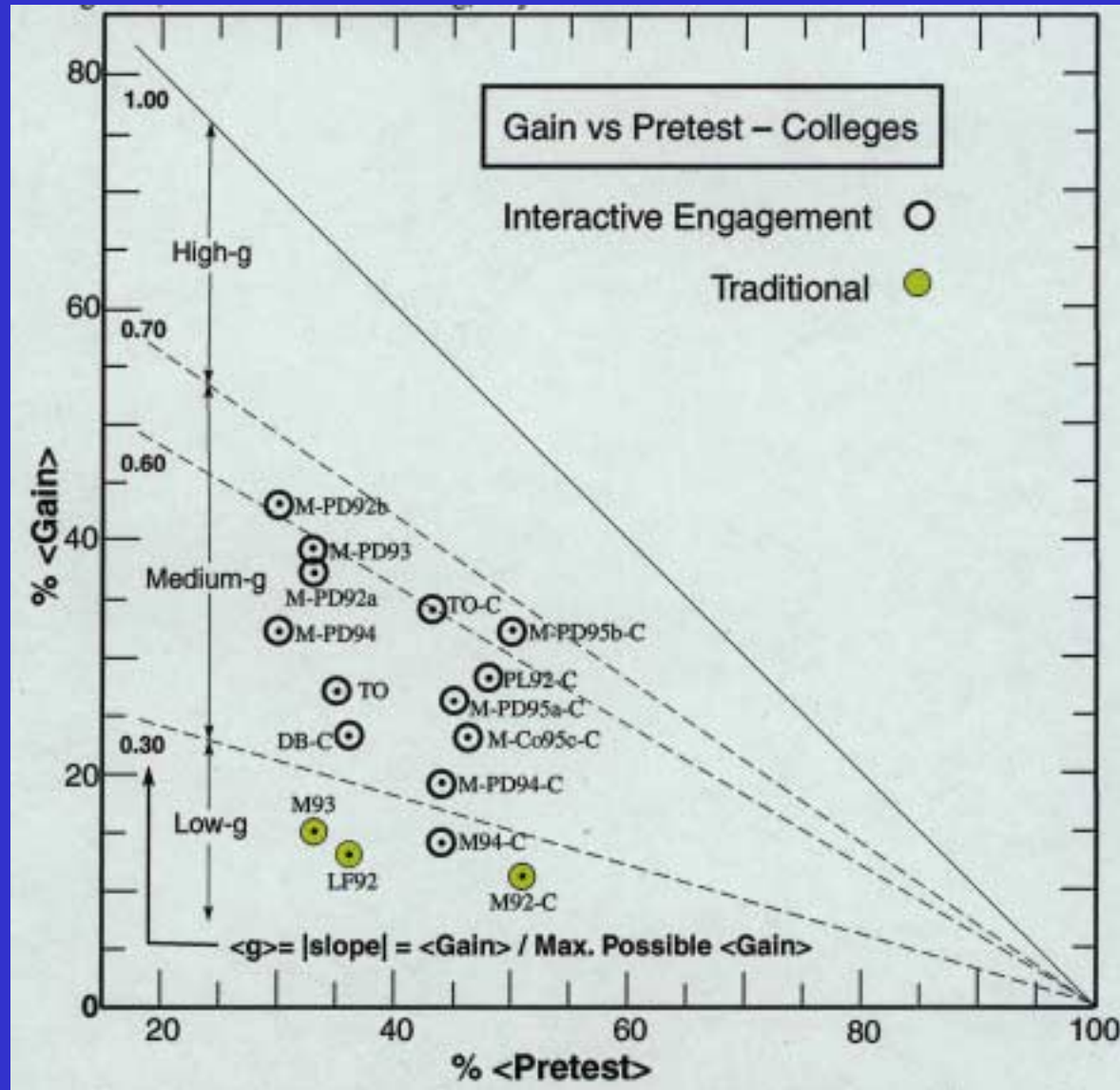
Histogram of the normalized gain $\langle g \rangle$: **red** bars show the *fraction* of 14 traditional courses ($N = 2084$), and **green** bars show the *fraction* of 48 interactive engagement courses ($N = 4458$), both within bins of width $\delta\langle g \rangle = 0.04$ centered on the $\langle g \rangle$ values shown.

3. GAIN vs PRE-TEST - HIGH SCHOOLS



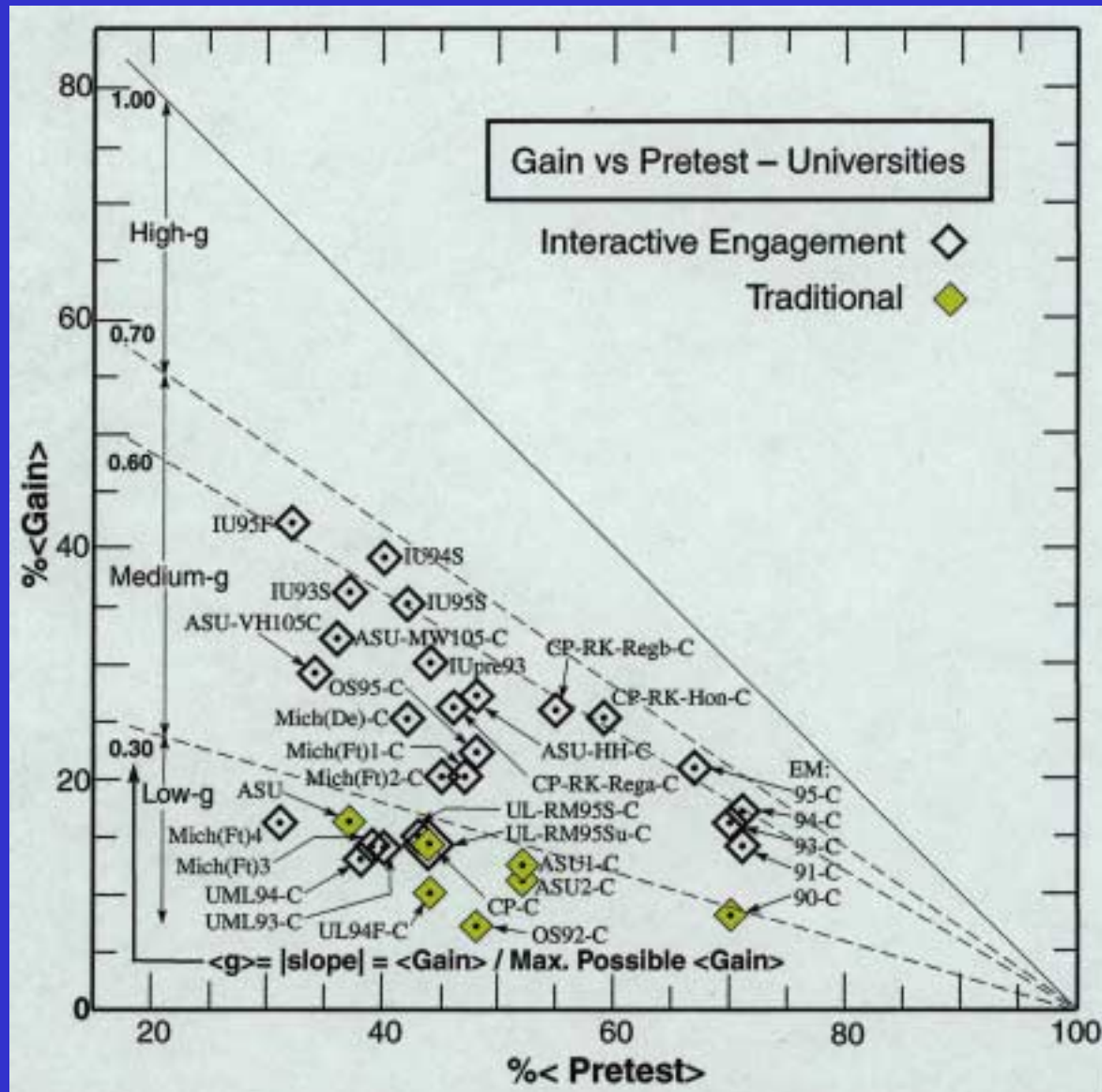
14 HS courses (N = 1113), $\langle \langle g \rangle \rangle$ (10 IE) = $0.55 \pm 0.11\text{sd.}$

4. GAIN vs PRE-TEST - COLLEGES



16 College courses (N = 597): $\langle\langle g \rangle\rangle$ (13 IE) = $0.48 \pm 0.12\text{sd}$.

5. GAIN vs PRE-TEST - UNIVERSITIES



32 Univ. courses (N = 4832): $\langle\langle g \rangle\rangle$ (25 IE) = $0.45 \pm 0.15\text{sd}$.

6. EXPERIMENTAL JUSTIFICATION OF $\langle g \rangle$ AS A COMPARATIVE MEASURE OF COURSE EFFECTIVENESS

- a. The correlation of the average normalized $\langle g \rangle$ with $\% \langle \text{pre} \rangle$ for the 62 survey courses is a very low $+ 0.02$.
- b. In contrast, the average *posttest* score $\% \langle \text{post} \rangle$ and the average *actual gain* $\% \langle G \rangle$ are less suitable for comparing course effectiveness over diverse groups since the correlation of:

$\% \langle \text{post} \rangle$ with $\% \langle \text{pre} \rangle$ is $+ 0.55$, and
 $\% \langle G \rangle$ with $\% \langle \text{pre} \rangle$ is $- 0.49$,

as is reasonable. Note that in the *absence* of instruction, a high positive correlation of $\% \langle \text{post} \rangle$ with $\% \langle \text{pre} \rangle$ would be expected.

7. SYSTEMATIC ERRORS ARE PROBABLY INSIGNIFICANT

(For a detailed treatment of systematic and random errors see my survey paper "Interactive-engagement vs traditional methods.....")

a. Question Ambiguities and Isolated False Positives.

Very few due to careful work of the ASU group.

b. Teaching to the Test and Test-question Leakage.

No evidence of this.

c. Fraction "f" of Course Time Spent on Mechanics

No apparent correlation of $\langle g \rangle$ with "f".

d. Post and Pretest Motivation of Students

No apparent correlation of $\langle g \rangle$ with amount of grade credit for post-test FCI score.

e. Hawthorne/John Henry Effects

Relatively high $\langle g \rangle$'s for IE courses given for many years to hundreds of students at Harvard and Indiana University.

8. IMPLEMENTATION PROBLEMS

Seven IE courses (N = 717) achieved $\langle g \rangle$'s ranging from 0.21 to 0.26, characteristic of T courses. Case histories of those seven suggest that implementation failures occurred that might be mitigated by:

- a. *apprenticeship* education of instructors new to IE methods,
- b. emphasis on the nature of science and learning throughout the course,
- c. careful attention to motivational factors and the provision of grade incentives for taking IE activities seriously,
- d. recognition of and positive intervention for potential low-gain students ,
- e. administration of exams in which a substantial number of the questions probe the degree of conceptual understanding induced by the IE methods ,
- f. use of IE methods in *all* components of a course and *tight integration* of those components.

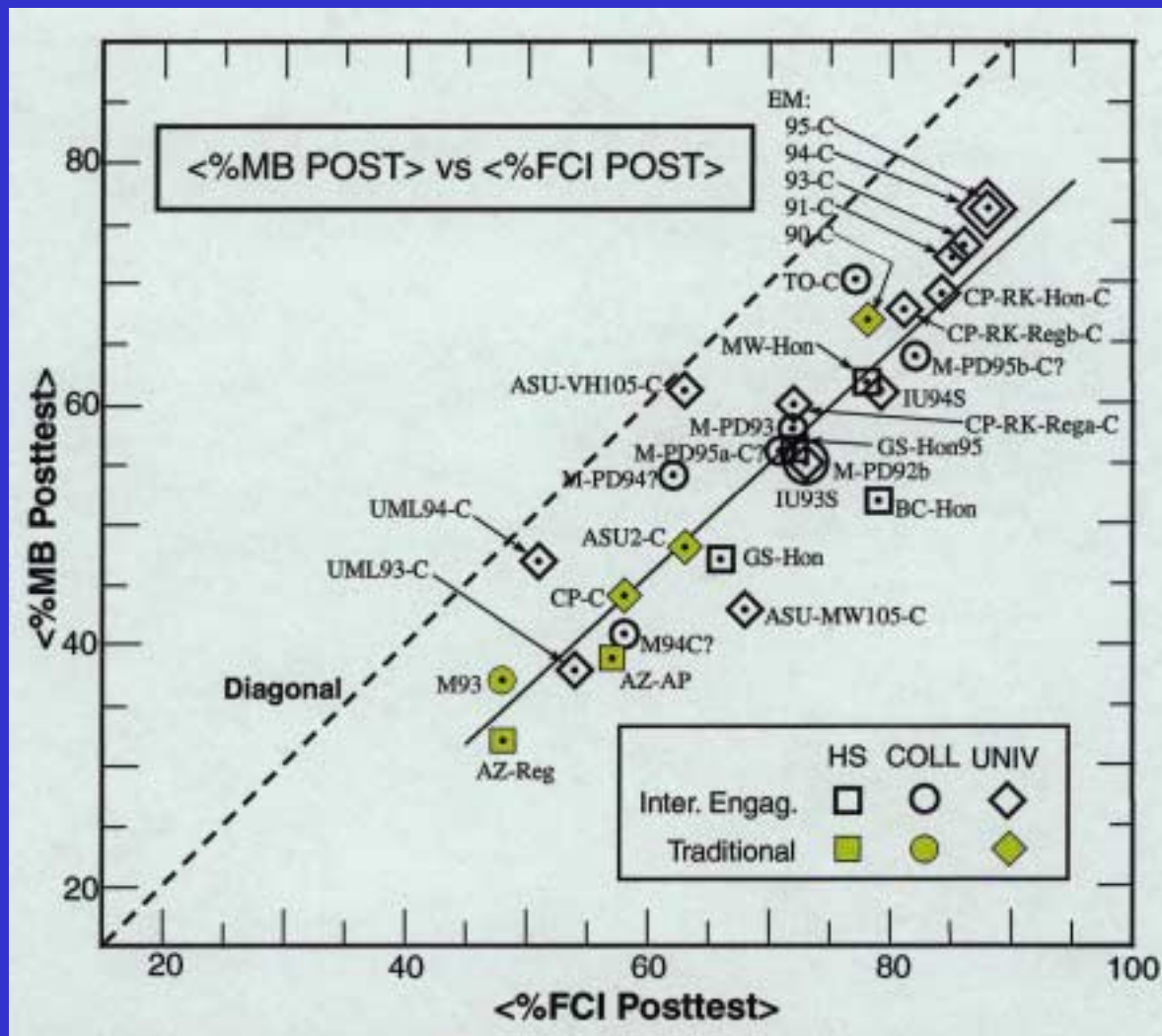
"One does not get anywhere simply by going over the successes again and again, whereas by talking over the difficulties people can hope to make some progress."

P.A.M. Dirac in "The Evolution of the Physicist's Picture of Nature," *Scientific American* **208**(5), 45-53 (1963).



Paul Dirac

9. POST-TEST SCORES: MB vs FCI



Post-course MB (problem-solving) vs FCI (conceptual understanding) test scores for the 30 high school, college, and university courses ($N = 3259$) for which both sets of data were available. The solid line is a least squares fit. The correlation coefficient is $r = +0.91$.

10. NUMBER OF SURVEY COURSES USING SPECIFIC IE METHODS DUE TO SPECIFIC INVESTIGATORS

(Of course, relative popularity has no necessary connection with relative merit!)

- a. Collaborative Peer Instruction: 48 - all IE courses
(Johnson, Johnson, and Smith; Heller & Heller)
- b. Microcomputer-based labs: 35 (Tinker, Thornton & Sokoloff)
- c. Concept Tests: 20 (Mazur)
- d. Modeling: 19 (Hestenes)
- e. Active Learning Problem Sets (ALPS) or Overview Case Studies: 17
(Van Heuvelen)
- f. Physics education research based text or no text: 13
- g. Socratic Dialogue Inducing (SDI) Labs (Hake): 9

11. SUMMARY AND CONCLUSIONS

- a. Fourteen T courses ($N = 2084$) which made little or no use of IE methods achieved an average normalized gain $\langle\langle g \rangle\rangle = 0.23 \pm 0.04\text{sd}$. In sharp contrast, 48 IE courses ($N = 4458$) that made substantial use of IE methods achieved an average gain $\langle\langle g \rangle\rangle = 0.48 \pm 0.14\text{sd}$. It is extremely unlikely that systematic errors play a significant role in the *nearly two-standard deviation difference* of the T and IE courses.
- b. A plot of average course scores on the problem-solving MB test vs those on the conceptual FCI show a strong positive correlation $r = +0.91$. Comparison of IE and traditional courses implies that *IE methods enhance problem-solving ability*.
- c. The above conceptual and problem solving test results strongly suggest that *the use of IE strategies can increase mechanics-course effectiveness well beyond that obtained with traditional methods.*

10. RECENT RESEARCH CONSISTENT WITH THE ABOVE META-ANALYSIS

- a. University of Maryland (Redish, Saul, Steinberg -1997; Saul - 1998; Redish & Steinberg - 1999; Redish - 1999).
- b. University of Montana (Francis, Adams, and Noonan - 1998).
- c. Rensselaer and Tufts (Cummings, Marx, Thornton, Kuhl - 1999).
- d. North Carolina State University (Beichner, Bernold, Burniston, Dail, Felder, Gastineau, Gjertsen, Riskey - 1999).
- e. Hogskolan Dalarna - Sweden (Bernard - 1999).

III. SOME IE CLASSROOMS (little if any lecturing)

A. SOCRATIC DIALOGUE INDUCING (SDI) LAB



GROUND RULES FOR SDI LABS:

1. Write down *operational* definitions of terms, e.g., position (x,y,z) , displacement \mathbf{s} , force \mathbf{F} , velocity \mathbf{v} , acceleration \mathbf{a} .
2. Perform (often *predict* and then perform) simple mechanics experiments (above picture shows gyroscope experiments).
3. Draw "snap-shot sketches" showing color-coded vectors \mathbf{s} , \mathbf{F} , \mathbf{v} , \mathbf{a} .
4. Cooperate in groups of four to discuss and answer lab-manual questions that probe for conceptual understanding.
5. If confused, call in a Socratic dialogist (bearded expert to right) .
6. Lab manual only annotated, grade determined by written lab exam.

B. A PEER INSTRUCTION CLASSROOM



1. Large enrollment (100 - 200 students) held in "lecture" hall equipped with a "classroom communication system" such as "Classtalk."
2. Students are encouraged to study the text assignment by required *web submission* of answers to three questions by 9 pm the night before the "lecture," as in IUPUI's "Just In Time Teaching." Third question is "What did you find confusing?"
3. Answers graded rapidly *on effort rather than validity* before lecture. Often bounce back points of confusion in the form of ConcepTest questions placed on the overhead 3 or 4 times during "lecture."
4. Each student considers the question and answers by means of her/his hand-held computer networked to instructor's computer.
5. Then students discuss the question in groups of 3 or 4 and answer again. Second average response score is usually much higher than initial because the students learn from one another.

C. NORTH CAROLINA STATE UNIVERSITY STUDIO



1. Students sit in 3 groups of 3 students at 6-ft diameter round tables with 3 networked laptops.
2. Instructors circulate and work with teams and individuals.
3. Instruction is developed around hands-on activities, simulations, or interesting questions and problems.
4. NCSU "designs new materials and also borrows liberally from research-based curricula, including Hake's Socratic Dialogs, Workshop & RealTime Physics, Univ. of Washington Tutorials, Mazur's ConcepTests, Chabay & Sherwood's E & M activities, and Overview: Case Study Physics."

IV. TEN *HARD* LESSONS FROM THE PHYSICS EDUCATION REFORM EFFORT

(1) Faculty tend to overestimate the effectiveness of their own instructional efforts and thus tend to see little need for reform.

(2) Teachers must (a) possess both content knowledge and “pedagogical content knowledge,” and (b) properly implement IE methods in order to deliver effective instruction as measured by comparing initial and final knowledge states of the students.

(3) The development of valid and reliable measures of *knowledge gain* and *affective impact* is crucial for (a) testing the efficacy of traditional and non-traditional modes of instruction, (b) convincing faculty members of the need to *CHANGE* the way they’re teaching and buy into reform efforts.

(4) A major problem in undergraduate SMET (Science, Math, Engineering, and Technology) educational reform is the inadequate SMET preparation of incoming students. This is due in no small measure to the abysmal failure of most universities (*NOT just education schools!*) to adequately prepare prospective K-12 teachers - they come to the SMET departments to learn SMET and then teach the way they were taught.

(5) Education R&D by *disciplinary experts*, and of the same quality and nature as traditional hard-core science/engineering R&D, is needed to improve educational methods within each discipline. But the experts should take advantage of the insights of (a) disciplinary experts doing education R&D in *other* disciplines, (b) cognitive scientists, (c) faculty and graduates of education schools, and (d) classroom teachers.

(6) The use of high-tech methods, *by itself*, does *NOT* insure superior student learning. However, high technology *can be* very advantageous when it promotes *interactive engagement* (as in computerized classroom communication systems, microcomputer-based labs, and the web-based “Just-In-Time Teaching”).

(7) “*Education is not rocket science, it’s much harder.*”

(George Nelson, astronaut and astrophysicist, quoted by Joe Redish)

(8) Development of effective instructional methods requires: long-term classroom *field testing, feedback, assessment*, research *analysis*, and *redesign* of non-traditional educational methods and curricula.

(9) *Interdisciplinary* cooperation of instructors, departments, institutions, and professional organizations is required for *synthesis*, *integration*, and *change* of the *entire* chaotic educational *system*.

(10) Judging from the only modest success of *scientists* in promoting large-scale SMET education reform, and the promising work of the *Engineering Coalitions* and *ABET* in such endeavor, **ENGINEERS** may be the ones who will lead the way in “*correlating scientific exactitude with chaos*” to bring education-reform “*visions into focus*,” and “*get things done*.”

"The essence of engineering is *integrating* all knowledge for some purpose. As society's 'master integrators,' engineers must provide leadership in the concurrent and interactive processes of innovation and wealth creation. The engineer must be able to work across many different disciplines and fields - and make the connections that will lead to deeper insights, more creative solutions, and *getting things done*. In a poetic sense, paraphrasing the words of Italo Calvino (1988), *the engineer must be adept at correlating exactitude with chaos to bring visions into focus.*" (My italics.)



Joseph Bordogna

References and Footnotes

Slide #6 - Eric Schocket

1. S. Tobias, *They're Not Dumb, They're Different: Stalking the Second Tier* (Research Corporation, Tucson, AZ, 1990), esp. pp. 19 - 32, "Introductory Physics: The 'Eric Experiment'."
2. R.M. Felder, "Reaching the Second Tier: Learning and Teaching Styles in College Science Education," *J. College Science Teaching* **23**(5), 286-290 (1993): "All the points raised by Tobias about the poor quality of introductory college science instruction can be expressed directly as failures to address certain common learning styles."

Slide #8 - Arnold Arons's Relativistic Model of Instruction

1. The quote is from A.B. Arons, "Conceptual Difficulties in Science," *Proceedings of the Chicago Conferences on Liberal Education, No. 1*, " edited by M.R. Rice (Univ. of Chicago, 1986), p. 23-32; see also ref. 2.
2. A.B. Arons, *A Guide To Introductory Physics Teaching* (Wiley, 1990); reprinted with minor updates in *Teaching Introductory Physics* (Wiley, 1997). The latter book also contains "Homework and Test Questions for Introductory Physics Teaching" (Wiley, 1994) along with a new monograph "Introduction to Classical Conservation Laws."

Slide #9 - Cartoon - The Relativistic Model of Instruction

1. R.R. Hake, "My Conversion To The Arons-Advocated Method Of Science Education," *Teaching Education* **3**(2), 109-111 (1991); to be placed on the web at <<http://physics.indiana.edu/~hake/>>.

Slide #12 - The ASU Tests

1. (a) I. Halloun and D. Hestenes, "The initial knowledge state of college physics students," *Am. J. Phys.* **53**, 1043-1055 (1985); corrections to the *Mechanics Diagnostic* test are given in ref. 2; (b) "Common sense concepts about motion," *ibid.* **53**, 1056-1065 (1985).
2. I. Halloun and D. Hestenes, "Modeling instruction in mechanics," *Am. J. Phys.* **55**, 455-462 (1987).
3. (a) D. Hestenes, M. Wells, and G. Swackhamer, "Force Concept Inventory," *Phys. Teach.* **30**, 141-158 (1992). (b) I. Halloun, R.R. Hake, E.P. Mosca, and D. Hestenes, "Force Concept Inventory (Revised, 1995)" in ref. 4 and password protected at <http://modeling.la.asu.edu/modeling.html>. The use of the 1995 revised FCI, with fewer ambiguities and a smaller likelihood of false positives, has had little impact on $\langle g \rangle$ (IE) as measured at Indiana and Harvard Universities.
4. E. Mazur, *Peer Instruction: A User's Manual* (Prentice Hall, 1997); on the web at <http://galileo.harvard.edu/>.
5. D. Hestenes and M. Wells, "A Mechanics Baseline Test," *Phys. Teach.* **30**, 159-166 (1992). The test is also in ref. 4 and password protected at <http://modeling.la.asu.edu/modeling.html>.
6. D. Hestenes, "Guest Comment: Who needs physics education research!?" *Am. J. Phys.* **66**, 465-467 (1998).

Slides #14 - # 27 - Hake's Meta-Analysis

1. R.R. Hake, "Interactive-engagement vs traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," *Am. J. Phys.* **66**, 64-74 (1998); on the Web at <http://physics.indiana.edu/~sdi/>; see also refs. 2 - 5
2. R.R. Hake, "Interactive-engagement methods in introductory mechanics courses," on the web at <http://physics.indiana.edu/~sdi/>, and submitted on 6/19/98 to the *Physics Education Research Supplement to AJP* (PERS).
3. R.R. Hake, "Interactive-engagement vs Traditional Methods in Mechanics Instruction," *APS Forum on Education Newsletter*, Summer 1998, p. 5-7, also at <http://physics.indiana.edu/~sdi/>. Some criticisms of ref. 1 and of physics-education reform generally are countered.
4. R.R. Hake, "Analyzing change/gain scores" (an analysis of the data of refs. 1-2 in terms of "effect size," so commonly considered in the educational literature); on the web at <http://physics.indiana.edu/~sdi/>.
5. R.R. Hake, "Towards Paradigm Peace in Physics Education Research," accepted for presentation at the annual meeting of the American Educational Research Association, New Orleans, 24-28 April 2000. Lists recent research which is consistent with ref. 1, and discusses the complementarity of *quantitative* and *qualitative* research in physics education; on the web at <http://physics.indiana.edu/~sdi/>.
6. M. Hunt, *How Science Takes Stock: The Story of Meta-Analysis* (Russel Sage Foundation, 1997).

Slide #28 - Recent Research Consistent with Hake's Meta-Analysis

1. E.F. Redish, J.M., Saul, R.N. Steinberg, "On the effectiveness of active-engagement microcomputer-based laboratories," *Am. J. Phys.* **65**, 45-54 (1997); on the web at <<http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>>.
2. J.M. Saul, "Beyond Problem Solving: Evaluating Introductory Physics Courses Through the Hidden Curriculum," Ph.D. thesis, Univ. of Maryland, 1998.
3. E.F. Redish, "Millikan Lecture 1998: Building a Science of Teaching Physics," *Am. J. Phys.* **67**(7), 562-573 (1999); on the web at <<http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>>.
4. E.F. Redish and R.N. Steinberg, "Teaching Physics: Figuring Out What Works," *Phys. Today* **52**(1), 24-30 (1999); on the web at <<http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>>.
5. G.E. Francis, J.P. Adams, E.J. Noonan, "Do They Stay Fixed?" *Phys. Teach.* **36**(8), 488-491 (1998).
6. K. Cummings, J. Marx, R. Thornton, and D. Kuhl, "Evaluating innovations in studio physics," *Physics Ed. Res., Supplement 1 to the Am. J. Phys.* **67**(7), S38-S44 (1999).
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8. J. Bernhard, "How Long-lived is Post-Course Understanding of Mechanics Concepts?" submitted to *Phys. Teach.* (1999); on the web at <<http://www.du.se/~jbe/fou/didaktik/papers/fixed.html>>.

Slide #29 - SDI Lab Classroom

1. R.R. Hake, "Promoting student crossover to the Newtonian world," *Am. J. Phys.* **55**, 878-884(1987).
2. R.R. Hake, "Socratic Pedagogy in the Introductory Physics Lab," *Phys. Teach.* **30**, 546-552(1992); an updated (4/27/98) version is on the web at <<http://www.physics.indiana.edu/~sdi>>.
3. S. Tobias and R.R. Hake, "Professors as physics students: What can they teach us?" *Am. J. Phys.* **56**, 786-794 (1988).
4. SDI labs and ancillary materials are on the web at <<http://www.physics.indiana.edu/~sdi>> and also at <<http://galileo.harvard.edu/>> under "Hands-on Methods."
5. J.L. Uretsky, "Using 'Dialogue' Labs in a Community-College Physics Course," *Phys. Teach.* **31**(8), 478-481 (1993). Uretsky has developed dialogue labs for E & M.

Slide #30 - Peer Instruction Classroom

1. E. Mazur, *Peer Instruction: A User's Manual* (Prentice Hall, 1997); on the web at <<http://galileo.harvard.edu/>>.
2. C. H. Crouch and E. Mazur, "How to Get To Know 200 Students (Almost) Overnight," *AAPT Announcer* **29**(4), 74(1999); an abstract is on the web at <http://mazor-www.harvard.edu/mazor-www/talks/talks.taf?_function=detail&id=318> the talk itself can be downloaded as a 2MB pdf file at <http://mazor-www.harvard.edu/Talks/pdf_files/Talk_318.pdf>.

3. Electronic Classroom Communication Systems:

a. Classtalk (Better Education of Yorktown, VA)

<<http://www.pcs.cnu.edu/~fhartlin/graphics/ClasstalkProj.html#anchor419081>>

<<http://www.bedu.com>>

b. Personal Response System (EduCue of Hong Kong)

<<http://www.educue.com/>>

4. G. Novak and E. Patterson, "Just-In-Time Teaching: Active Learner Pedagogy with the WWW," paper presented at the IASTED International Conference on Computers and Advanced Technology in Education, May 27 -30, 1998 in Cancun, Mexico; on the web at

<<http://webphysics.iupui.edu/JITT/ccjitt.html>>. See also G. M. Novak, E. T. Patterson, A.D. Gavrin, and W. Christian, *Just in Time Teaching* (Prentice Hall, 1999); a description of the book is on the web at <<http://webphysics.iupui.edu/jitt/jitt.html>>.

Slide #31 - North Carolina State University Studio Classroom

1. R. Beichner, L. Bernold, E. Burniston, P. Dail, R. Felder, J. Gastineau, M. Gjertsen, J. Risley, "Case study of the physics component of an integrated curriculum," *Physics Ed. Res.*, supplement 1 to the *Am. J. Phys.* **67**(7), S16-S24 (1999).

2. NCSU Physics Education R&D at <<http://www.ncsu.edu/PER/>>, see, esp, (a) the "SCALE UP" Project at <<http://www.ncsu.edu/PER/SCALE-UP%20Description.html>> ; and (b) the "Integrated Math, Physics, Engineering, and Chemistry, IMPEC" project under the SUCCEED Engineering Coalition umbrella grant at <<http://www2.ncsu.edu/ncsu/pams/physics/PCEP/impec/impechome.html>>.

Slides #32 - #36 - Ten Hard Lessons from the Physics Education Reform Effort

(1) Faculty members overestimate the effectiveness of their teaching.

1. E. Mazur, *Peer Instruction: A User's Manual* (Prentice Hall, 1997); on the web at <http://galileo.harvard.edu/>. As indicated on page 4, Mazur was very satisfied with his introductory-course teaching - he received very positive student evaluations and his students did reasonably well on "difficult" exam problems. Thus it came as a shock when his students fared hardly better on the "simple" FCI than on their "difficult" midterm exam. As a result, Mazur developed and implemented his interactive-engagement "Peer Instruction" method as a replacement for his previous traditional passive-student lectures. This change resulted in much higher $\langle g \rangle$'s on the FCI.
2. Like Mazur, most Harvard faculty members are proud of their undergraduate science courses. However, the videotape *Private Universe* shows Harvard graduating seniors being asked "What causes the seasons?" Most of them confidently explain that the seasons are caused by yearly changes in the distance between the Sun and the Earth! See <http://cfa-www.harvard.edu/cfa/sed/privateuniv.html>.
3. Physicist Robert Ehrlich thought that "... the size of the sample Hake used for the traditional courses was fairly small, so a statistical fluctuation was always a possibility" (private communication). Testing his conjecture, Ehrlich elicited pre/post FCI testing in 12 more-or-less traditional courses taught by instructors with whom he was acquainted. These yielded an average normalized gain $\langle g \rangle = 0.20 \pm 0.06sd$, consistent with my results for 14 T courses. See R.R. Hake, "Interactive-engagement vs Traditional Methods in Mechanics Instruction," *APS Forum on Education Newsletter*, Summer 1998, p. 5-7, also at <http://physics.indiana.edu/~sdi/>.
4. R.R. Hake, "My Conversion To The Arons-Advocated Method Of Science Education," *Teaching Education* **3**(2), 109-111 (1991); to be placed on the web at <http://physics.indiana.edu/~hake/>.

(2a) Teachers must (a) possess both content knowledge and “pedagogical content knowledge,” in order to deliver effective instruction.

1. E.F. Redish, (Millikan Lecture 1998: Building a Science of Teaching Physics, *Am. J. Phys.* **67**(7), 562-573 (1999); on the web at <<http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>>.
2. L. Shulman, "Those who understand: Knowledge growth in teaching," *Educational Researcher* **15**(2), 4-14 (1986).
3. L. Shulman, "Knowledge and teaching: Foundations of the new reform" *Harvard Educational Review* **57**, 1-22 (1987).
4. J.D. Bransford, A.L. Brown, R.R. Cocking, eds. *How People Learn: Brain, Mind, Experience, and School* (Nat. Acad. Press, 1999); on the web at <<http://books.nap.edu/html/howpeople1/>>; see esp. Chapter 7, "Effective Teaching: Examples in History, Mathematics, and Science."

(2b) Teachers must (b) properly implement IE methods in order to deliver effective instruction.

1. See references for slides #14 - #27 on Hake's meta-analysis.
2. L.C. McDermott and E.F. Redish, "Resource Letter on Physics Education Research" *Am. J. Phys.*, **67**(9), 755-767 (1999).
3. L. Springer, M.E. Stanne, and S. Donovan, "Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis," *Review of Educational Research* (University of Wisconsin - Madison, National Institute for Science Education, 1998), in press; on the web at <<http://www.wcer.wisc.edu/nise/CL1/CL/resource/R2.htm>>.

(3) The development of valid and reliable measures of *knowledge gain* and *affective impact* is crucial.

1. For measures of *knowledge gain* see references for Slide #12 (ASU Tests) and also refs. 2 - 7 below. For measures of *affective impact* see refs. 8 - 14.
2. Physics concept tests at the AAPT "Physical Science Resource Center"; <http://www.psrc-online.org/> under "Evaluation Instruments"/ "Conceptual Learning Assessments."
3. Univ. of Wisconsin's *Field-tested Learning Assessment Guide for Science, Math, Engineering, and Technology Instructors*, on the web at <http://www.wcer.wisc.edu/nise/cl1/flag/flaghome.asp>.
4. T.R. Rhoads and R.J. Roedel, "The Wave Concept Inventory - A Cognitive Instrument Based on Bloom's Taxonomy," ASEE/IEEE Frontiers in Education Conference, San Juan, Puerto Rico, November 10-13, 1999; on the web at <http://fairway.ecn.purdue.edu/~fie/fie99/authors/R.htm>.
5. B. Bloom et al. "Bloom's Taxonomy: A Forty-Year Retrospective," in *Ninety Third Yearbook of The National Society for the Study of Education*, L.W. Anderson and L.A. Sosnick, eds., (Univ. of Chicago Press, 1994).
6. V. I. Willson, "Calculus Concept Test," Texas A & M University. Used by the Texas A & M contingent of the Foundation Coalition, according to ref. 7.
7. C.M. Ackerman and V.L. Willson, "Learning Styles and Student Achievement in the Texas A & M Freshman Coalition Program," paper presented at the 1997 Southwest Educational Research Association Meeting, Austin, Texas; on the web at <http://coalition.tamu.edu/papers/sera97.html>.

8. I. Halloun, "Views About Science and Physics Achievement: The VASS Story," in *The Changing Role of Physics Departments in Modern Universities: Proceedings of the ICUPE*, ed. by E.F. Redish and J.S. Rigden, (AIP, Woodbury, NY, 1997). p. 605 - 613.
9. I. Halloun and D. Hestenes, "Interpreting VASS Dimensions and Profiles," *Science & Education*, 7(6), 553-577 (1998). (VASS - Views About Sciences Survey) Biology, physics, chemistry, and math versions are available at <<http://modeling.la.asu.edu/modeling/R&E/Research.html>>. E-mail a request to Larry Dukerich <Dukerich@asu.edu> to obtain a password. A description of VASS is available at <<http://modeling.la.asu.edu/halloun/hallounDP.html>>.
10. E.F. Redish, R.N. Steinberg, and J.M. Saul, "The Distribution and Change of Student Expectations in Introductory Physics," in *The Changing Role of Physics Departments in Modern Universities: Proceedings of the ICUPE*, ed. by E.F. Redish and J.S. Rigden, (AIP, Woodbury, NY, 1997). p. 689-697.
11. E.F. Redish, J.M. Saul, and R.N. Steinberg, "Student expectations in introductory physics," *Am. J. Phys.* **66**, 212-224 (1998).
12. I. Novodvorsky and C. Johnson, "Computer Delivery of an Instrument to Assess Students' Attitudes Towards Science," *AAPT Announcer* **24**(4), 77 (1994).
13. R.R. Hake and J. C. Swihart, "DIagnostic Student COmputerized Evaluation of Multicomponent Courses (DISCOE)" *Teaching and Learning* (Indiana University), January 1979, available on the web at <<http://www.physics.indiana.edu/~sdi/>>.
14. D.R. Woods, A.N Hrymak, and H.M. Wright "Approaches to Learning and Learning Environments in PBL versus Lecture-based Learning," ASEE Conference Proceedings, June 2000, forthcoming. D.R. Woods, *Motivating University Teachers to Improve Student Learning*, forthcoming book.

(4) Inadequate preparation of incoming students - the failure of the universities

1. S. Bowen, "TIMSS - An Analysis of the International High School Physics Test," *APS Forum on Education Newsletter*, Summer 1998, pp. 7-10, on the web at <http://www.research.att.com/~kbl/APS/aug98/TIMSS2.htm>.
2. M. Neuschatz, "What can the TIMSS teach us?" *The Science Teacher* **66**(1), 23-26 (1999).
3. NRC Committee for Science, Mathematics, and Engineering Education, *Global Perspectives For Local Action: Using TIMSS to Improve U.S. Mathematics and Engineering Education* (National Academy Press, 1999). A description of the book is on the web at <http://www.nap.edu/catalog/9605.html>.
4. *The Nation's Report Card*, National Assessment of Educational Progress (NAEP); on the web at <http://nces.ed.gov/nationsreportcard/site/home.asp>. C. Y. O'Sullivan, C. M. Reese, and J. Mazzeo *NAEP 1996 Science: Report Card for the Nation and the States*, on the web at <http://nces.ed.gov/nationsreportcard/96report/97497.shtml>: "Three percent of the nation's students reached the Advanced level at all three grade levels. Twenty-six percent of fourth- and eighth-grade students and 18 percent of the twelfth-grade students performed within the Proficient level, while 38 percent, 32 percent, and 36 percent performed within the Basic level for grades 4, 8, and 12, respectively."
5. *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Advisory Committee to the NSF Directorate for Education and Human Services chaired by Melvin George, 1996), on the web at <http://www.nsf.gov/cgi-bin/getpub?nsf96139>: "Many faculty in SME&T at the post-secondary level continue to blame the schools for sending underprepared students to them. But, increasingly, the higher education community has come to recognize the fact that teachers and principals in the K-12 system are all people who have been educated at the undergraduate level, mostly in situations in which SME&T programs have not taken seriously enough their vital part of the responsibility for the quality of America's teachers."

6. J.I. Goodlad, *Teachers For Our Nation's Schools* (Jossey-Bass, 1990) : "Few matters are more important than the quality of the teachers in our nation's schools. Few matters are as neglected.... A central thesis of this book is that there is a natural connection between good teachers and good schools and that this connection has been largely ignored It is folly to assume that schools can be exemplary when their stewards are ill-prepared." (My *italics*.)

7. K. Haycock, "The Role of Higher Education in the Standards Movement" in *1999 National Education Summit Briefing Book* at <<http://www.summit99.org/briefing/briefing.html>>: "Higher education.... (unlike Governors and CEO's) has been left out of the loop and off the hook...(in the effort to improve America's public schools since release of *A Nation at Risk* in 1983).... Present neither at the policy tables where improvement strategies are formulated nor on the ground where they are being put into place, most college and university leaders remain blithely ignorant of the roles their institutions play in helping K-12 schools get better - and the roles they currently play in maintaining the status quo.... How are we going to get our *students* to meet high standards if higher education continues to produce *teachers* who don't even meet those same standards? How are we going to get our high school students to work hard to meet new, higher standards if most colleges and universities will continue to admit them regardless of whether or not they even crack a book in high school?"

8. *Shaping the Future, Volume II: Perspectives on Undergraduate Education in Science, Mathematics, Engineering, and Technology* at <<http://www.nsf.gov/cgi-bin/getpub?nsf98128>> (contains an extensive bibliography on SMET undergraduate education which, unfortunately, omits most of the relevant physics literature).

(5a) High quality education R&D by disciplinary experts is needed to improve educational methods within each discipline.

1. E.F. Redish, "Millikan Lecture 1998: Building a Science of Teaching Physics," *Am. J. Phys.* **67**(7), 562-573 (1999); on the web at <http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>.
2. F. Reif, (a) "Educational Challenges for the University," *Science* **184**, 537-542 (1974); (b) "Scientific approaches to science education," *Phys. Today* **39**(11), 48-54 (1986); (c) "Millikan Lecture 1994: Understanding and teaching important scientific thought processes," *Am. J. Phys.* **63**, 17-32 (1995).
3. D. Hestenes, "Guest Comment: Who needs physics education research!?" *Am. J. Phys.* **66**(6), 465-467 (1998): "Most of our colleagues have been oblivious to(physics education research)..... if not contemptuous of it. Some are beginning to realize that it is more than another 'educational fad.' It is a serious program to apply to our teaching the same scientific standards that we apply to physics research."
4. For overviews of physics-education research see, e.g., (a) *Toward a scientific practice of science education*, ed. by M. Gardner, J.G. Greeno, F. Reif, A.H. Schoenfeld, A. diSessa, and E. Stage (Erlbaum, 1990); (b) *Research in Physics Learning: Theoretical Issues and Empirical Studies*, R. Duit, F. Goldberg, and H. Niedderer, eds. (Institute for Science Ed., Kiel, 1992); (c) A. Van Heuvelen "Learning to think like a physicist: A review of research-based instructional strategies," *Am. J. Phys.* **59**, 891-897 (1991); (d) A. B. Arons, "Generalizations to be drawn from results of research on teaching and learning" in *Thinking Physics for Teaching*, ed. by C. Bernardini, C. Tarsitani, and M. Vicintini (Plenum, 1995); (e) D. Hammer, "More than misconceptions: Multiple perspectives on student knowledge and reasoning, and an appropriate role for education research," *Am. J. Phys.* **64**, 1316-1325 (1996); (f) L.C. McDermott, "Students' conceptions and problem solving in mechanics" in *Connecting Research in Physics Education with Teacher Education*, A. Tiberghien, E.L. Jossem, and J. Barojas, eds. (I.C.P.E., 1998) also at <http://aapt.org/> under "Physical Science Resource Center" /"Physics Education Research."

5. Physics Education Research programs are listed at the AAPT's *Physical Science Resource Center* <<http://www.psrc-online.org/>> under "Resource Center"/ "Physics Education Research".

6. J.R. Anderson, L.M. Reder, and H. A. Simon, "Radical Constructivism and Cognitive Psychology" in *Brookings Papers on Education Policy - 1998*, Diane Ravitch, ed. (Brookings Institution Press, 1998), p. 227-278. (Includes supporting comments by K. Andres Ericsson and Robert Glaser.) Anderson et al. write: "The time has come to abandon philosophies of education and turn to a *science of education* If progress is to be made to a more scientific approach, traditional philosophies will be found to be like the doctrines of folk medicine. They contain some elements of truth and some elements of misinformation. This is true of the radical constructivist approach. Only when a *science of education* develops that sorts truth from fancy - as it is beginning to develop now will dramatic improvements in educational practice be seen." (My *italics*.)

(5b) Disciplinary experts should take advantage of the insights of disciplinary experts doing education R&D in *other* disciplines.

1. R.R. Hake, "REsearch, Development, and Change in Undergraduate Biology Education: A Web Guide for Non-Biologists (REDCUBE.pdf)" at <<http://www.physics.indiana.edu/~redcube>>. This Adobe Acrobat portable document file (pdf) gives non-biologists a point of entry into the vast literature and web resources relevant to research, development, and change in undergraduate biology education. The 9/8/99 version contains 47 biology-educator profiles; 446 references (including 124 relevant to general science-education reform); and 490 hot-linked URL's on:

- (a) Biology Associations,
- (b) Biology Teacher's Web Sites,
- (c) Scientific Societies and Projects (not confined to Biology),
- (d) Higher Education,
- (e) Cognitive Science and Psychology,
- (f) U.S. Government, and
- (g) Searches and Directories.

The references and URL's may be generally useful to teachers and education researchers, and may provide some ideas for hastening education reform.

2. R.R. Hake, "What Can We Learn from the Biologists About Research, Development, and Change in Undergraduate Education?" *AAPT Announcer* **29**(4), 99 (1999); available on the web as (a) a 1.1MB PowerPoint document (for anyone with a standard browser), or (b) as a 0.204MB pdf file at ref. 7 on the web page <<http://physics.indiana.edu/~hake>>. I discuss (a) the potential of the WWW as a mechanism for promoting interdisciplinary synergy in education reform; (b) the benefit of constructing web guides REDCUXE (X = Engineering, Chemistry, Mathematics, etc.); (c) the possible impact of ABET on Physics Departments with courses catering to captive engineers.

(5c) Disciplinary experts should take advantage of the insights of cognitive scientists.

1. H. Gardner, *The Mind's New Science: A History of the Cognitive Revolution* (Basic Books, 1985).
2. D. Druckman and R.A. Bjork, eds., *Learning, Remembering, Believing: Enhancing Human Performance* (Nat. Acad. Press, 1994); on the web at <http://www.nap.edu/readingroom/enter2.cgi?ED.html>
3. J.D. Bransford, A.L. Brown, R.R. Cocking, eds. *How People Learn: Brain, Mind, Experience, and School* (Nat. Acad. Press, 1999); on the web at <http://books.nap.edu/html/howpeople1/>, esp. index entries on "Problem-based Learning," "Case-based Learning," "Apprenticeship Learning," "Situated Learning," "Constructivism."
4. E.F. Redish, "Implications of cognitive studies for teaching physics," *Am. J. Phys.* **62**, 796-803 (1994).
5. J. Mestre and J. Touger, "Cognitive Research--What's in It for Physics Teachers?" *Phys. Teach.* **27**, 447-456 (1989).
6. H.A. Simon, "What We Know About Learning," *J. Eng. Education*; October, 1998; pp. 343-348.
7. J.T. Bruer, *Schools for Thought: A Science of Learning in the Classroom* (MIT Press, 1994); *The Myth of the First Three Years* (Free Press, 1999); "Education and the Brain: A Bridge Too Far," *Educational Researcher* **26**(8), 4-16 (1997) [The *Educational Researcher* is now online at <http://www.aera.net/pubs/er/>.]
8. T. Marchese, "The New Conversations About Learning: Insights from Neuroscience and Anthropology, Cognitive Science and Work-Place Studies" in *Assessing Impact: Evidence and Action*, (AAHE, 1997), p. 79-95, also at http://www.newhorizons.org/lrnbus_marchese.html.

9. For some cognitive-science articles relevant to "Problem-Based Learning" (an IE method popular in engineering and medical schools) see, J.S. Brown, A. Collins, and P. Duguid, "Situated Cognition and the Culture of Learning" *Educational Researcher* **18**(1), 34-41 (1989) on the web at <<http://www.ilt.columbia.edu/ilt/papers/JohnBrown.html>>; A. Collins, J.S. Brown, and S. Newman, "Cognitive apprenticeship: Teaching students the craft of reading, writing, and mathematics," in *Knowing, learning, and instruction: Essays in honor of Robert Glaser*, L.B. Resnick, ed., (Erlbaum, 1989), p. 453-494. For a critique of these papers from the standpoint of "information-processing psychology" see J.R. Anderson, L.M. Reder, and H.A. Simon, "Situated Learning and Cognition," *Educational Researcher* **25**(4), 5-11 (1996), with a counter by J.G. Greeno, "On Claims That Answer the Wrong Question," *ibid.* **26**(1), 5-17 (1997); then a counter-counter by J.R. Anderson, L.M. Reder, and H.A. Simon, "Situative Versus Cognitive Perspectives: Form versus Substance," *ibid.* **26**(1), 18-21 (1997). Extensive references to the literature of Problem-Based Learning are at the PhysLrnR discussion group archives at <<http://listserv.boisestate.edu/archives/physlrnr.html>> - click on "Search the archives," and enter "PBL" in the subject slot to obtain 6 hits and "problem-based" to obtain 4 hits.

10. Greg Kearsley, "Explorations in Learning & Instruction: The Theory Into Practice Database at <<http://www.gwu.edu/~tip/>>. "The theories" section is a good source of references to learning theories relevant to Problem Based Learning; see esp., "Situated Learning (J. Lave)," "Genetic Epistemology" (Piaget), "Adult Learning" (P.Cross), "Androgogy" (M. Knowles), "Anchored Instruction" (J. Bransford and the Cognition & Technology Group at Vanderbilt (CTGV), "Cognitive Dissonance" (L. Festinger), "Constructivist Theory" (J. Bruner), "Cognitive Flexibility Theory" (R. Spiro, P. Feltovitch & R. Coulson), "Experiential Learning" (C. Rogers), "Elaboration Theory" (C. Reigeluth), "Mathematical Problem Solving" (A. Schoenfeld), "Modes of Learning" (D. Rumelhart and D. Norman), "Multiple Intelligences" (H. Gardner), "Social Development Theory" (L. Vygotsky), "Triarchic Theory" (R. Sternberg). Kearsley's sections on "Learning Domains" and "Learning Concepts" are also useful.

(6) The use of high-tech methods, *by itself*, does *NOT* insure superior student learning.

1. K. Cummings, J Marx, R. Thornton, D. Kuhl, "Evaluating innovations in studio physics, *Physics Ed. Res.*, supplement 1 to the *Am. J. Phys.* **67**(7), S38-S44 (1999): "To measure gains, we utilized the *Force Concept Inventory* and the *Force Motion Concept Evaluation (FMCE)* we verified the effectiveness of *Interactive Lecture Demonstrations* [$\langle g \rangle \text{FCI} = 0.35 \pm 0.06(\text{sd})$ and $\langle g \rangle \text{FMCE} = 0.45 \pm 0.03(\text{sd})$], and *Cooperative Group Problem Solving* [$\langle g \rangle \text{FCI} = 0.36$ and $\langle g \rangle \text{FMCE} = 0.36$] Further, we have assessed conceptual learning in the standard Studio Physics course [$\langle g \rangle \text{FCI}, 1998 = 0.18 \pm 0.12(\text{sd})$ and $\langle g \rangle \text{FMCE}, 1998 = 0.21 \pm 0.05(\text{sd})$]. Overall this study.... [in accord with the early thorough work of M.A. Cooper, *An Evaluation of the Implementation of an Integrated Learning System for Introductory College Physics*, Ph.D. thesis, Rutgers, 1993]. implies that the standard(high tech)....studio format used in introductory physics instruction at Rensselaer is *no more successful at teaching fundamental concepts of Newtonian physics than traditional instruction.* (My italics.)

2. R.R. Hake, "Interactive-engagement methods in introductory mechanics courses," on the Web at <http://physics.indiana.edu/~sdi/> and submitted on 6/19/98 to the *Physics Education Research Supplement to AJP (PERS)*. Sec. III, "Implementation Problems" discusses several high-tech courses that achieved $\langle g \rangle$'s ranging from 0.21 to 0.26, characteristic of traditional courses.

(7) "Education is not rocket science, it's much harder."

1. George Nelson, astronaut and astrophysicist, quoted in ref. 22 of E.F. Redish, "Millikan Lecture 1998: Building a Science of Teaching Physics," *Am. J. Phys.* **67**(7), 562-573 (1999); on the web at <http://www.physics.umd.edu/rgroups/ripe/perg/cpt.html>.

(8) Development of effective instructional methods requires long-term classroom field testing, feedback, assessment, research analysis, and redesign of non-traditional educational methods and curricula.

1. K.G. Wilson and B. Daviss, *Redesigning Education* (Henry Holt, 1994); see also at <http://www-physics.mps.ohio-state.edu/~kgw/RE.html>.
2. (a) L. C. McDermott, "Millikan Lecture 1990: What we teach and what is learned: Closing the gap," *Am. J. Phys.* **59**, 301-315 (1991); (b) L.C. McDermott, P.S. Shaffer, and M.D. Somers, "Research as a guide for teaching introductory mechanics: An illustration in the context of the Atwood's machine," *ibid.*, **62**, 46-55 (1994).
3. S.B. Sarason, *The Predictable Failure of Educational Reform* (Jossey-Bass, 1990); *Revisiting "The Culture of The School and The Problem of Change"* (Teachers College Press, 1996).
4. *Preparing for the 21st Century: The Education Imperative* (National Research Council, 1997), also available at <http://www2.nas.edu/21st> >. Also in this series at <http://www2.nas.edu/21st> > in HTML and PDF formats are: (a) *Science and Engineering Research in a Changing World*, (b) *Technology and the Nation's Future*, (c) *Challenges Facing a Changing Society*, (d) *The Environment and the Human Future*, (e) *Focussing on Quality in a Changing Health Care System*.
5. NISE - National Institute for Science Education <http://www.wcer.wisc.edu/nise> >:
 - a. College Level One <http://www.wcer.wisc.edu/nise/CL1/> >
 - b. Project FLAG (Field-Tested Learning Assessment Guide for SMET) <http://newtraditions.chem.wisc.edu/FLAG/nt-flag.htm> >
 - c. NISE - Collaborative Learning (CL) & Small Group Learning [under "Resources" is an annotated bibliography of CL articles which may be searched by discipline (including engineering)] <http://www.wcer.wisc.edu/nise/CL1/CL/clhome.asp> >

6. *Unlocking Our Future: Toward a New National Science Policy*, A Report to Congress by The House committee on Science chaired by Vernon Ehlers, 9/24/98 at http://www.house.gov/science/science_policy_study.htm: "Currently, the U.S. spends approximately \$300 billion a year on education and less than 30 million, 0.01% of the overall education budget, on education research. At a time when technology promises to revolutionize both teaching and learning, this miniscule investment suggests a feeble long-term commitment to improving our educational system."

7. *Reinventing undergraduate education: A blueprint for America's Research Universities. The Boyer Commission on Educating Undergraduates in the Research University* (Carnegie Foundation for the Advancement of Teaching, 1998), also at <http://notes.cc.sunysb.edu/Pres/boyer.nsf> >: "The university's essential and irreplaceable function has always been the exploration of knowledge. This report insists that the exploration must go on through what has been considered the 'teaching' function as well as the traditional 'research' function. The reward structures in the modern research university need to reflect the synergy of teaching and research - and the essential reality of university life: that baccalaureate students are the university's economic life blood and are increasingly self-aware."

8. *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (National Academy Press, 1999); on the web at <http://www.nap.edu/readingroom/enter2.cgi?ED.html>: "Institutions of higher education should provide diverse opportunities for *all* undergraduates to study science, mathematics, engineering, and technology as practiced by scientist and engineers, and as early in their academic careers as possible."

(9) Interdisciplinary cooperation of instructors, departments, institutions, and professional organizations is required for synthesis, integration, and change of the entire chaotic educational system.

1. J.J. Duderstadt (president emeritus and Professor of Science and Engineering, Univ. of Michigan - Ann Arbor), "New Roles for the 21st-Century University: Changing times demand a new social contract between society and the institutions of higher education," *Issues* **16**(2), 37-51 (1999-2000); on the web at <<http://www.nap.edu/issues/16.2/duderstadt.htm>>: "...a 21st-century analog to the land-grant university might be termed a 'learn-grant' university, designed to develop human resources as its top priority along with the infrastructure necessary to sustain a knowledge-driven society." J.J. Duderstadt, *A University for the 21st Century* (University of Michigan Press, 2000); for a synopsis see <<http://www.press.uchicago.edu/cgi-bin/hfs.cgi/500/11091.ctl>>.
2. R.C. Hilborn, "Physics at the Crossroads: Innovation and Revitalization in Undergraduate Physics – Plans for Action," report on a College Park AAPT conference of 9/96, <<http://www.aapt.org/events/events.html>>; "Guest Comment: Revitalizing undergraduate physics – Who needs it?" *Am. J. Phys.* **65**, 175-177 (1997): "All of us - students; physics faculty; the science, engineering, and technology communities; and indeed the general public - need the revitalization of undergraduate physics."
3. S. Tobias, (a) "Guest Comment: Science Education Reform: What's wrong with the process?" *Am. J. Phys.* **60**, 679-681 (1992); (b) *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't* (Research Corporation, 1992); (c) "Conceptualizing a New Degree," *APS News* **8**(11), 5 (1999); on the web at <<http://www.aps.org/apsnews/1299/129908.html>>; (d) "Guest Comment: From Innovation to Change: Forging A Physics Education Agenda for the 21st Century," *Am. J. Phys.* **68**(2), 103-104 (2000). See also <<http://www.Sheila.Tobias.net>>.

4. Karl Pister (former Chancellor of UC - Santa Cruz), "Renewing the Research University," *University of California at Santa Cruz Review* (Winter 1996): "Three cultural shifts must occur if.... (public universities).....are to succeed...(in meeting the needs of the country).... First, we need to encourage innovative ways of looking at problems, moving away from the increasing specialization of academia to develop *new interdisciplinary fields that can address complex real-world problems from new perspectives*. Second, the orientation of faculty effort and the faculty reward system in our universities must support the full range of institutional missions in a more balanced manner. Third, our society must be willing to make quality education, especially in science and technology, accessible at all levels for all students. Education must be seen more as an investment in society's well-being and less as a cost." (My italics.)

<http://www.ucsc.edu/news_events/review/text_only/Winter-96/Win_96-Pister-Renewing_.html>

5. *Daedalus* **127**(4), 1998 issue "Education yesterday, education tomorrow." For a description see <<http://daedalus.amacad.org/inprint.html>>. Contains essays by researchers in education and by historians of more rapidly developing institutions such as power systems, communications, health care, and agriculture. Sets out to answer a challenge posed by Kenneth Wilson: "If other major American 'systems' have so effectively demonstrated the ability to change, why has the education 'system' been so singularly resistant to change? What might the lessons learned from other systems' efforts to adapt and evolve have to teach us about bringing about change - successful change - in America's schools?" For a partial answer, see ref. 6.

See also <<http://www.physics.ohio-state.edu/~redesign/>>.

6. K.G. Wilson and C.K. Barsky, "Applied Research and Development: Support for Continuing Improvement in Education," *Daedalus* 127(4), 233- 258 (1998): "We see the need for a launch of a research and development initiative in education, paralleling existing national research initiatives related to AIDS or global climate change Today we have to think of education as demanding in multiple dimensions: as a science, as a design challenge, and as a performing art while still being an imperative for life in a democracy. Handed down traditions are no longer enough." See also <<http://www.physics.ohio-state.edu/~redesign/>>.

7. T. Marchese, "Not-So-Distant Competitors: How New Providers Are Remaking the Postsecondary Marketplace," *AAHE Bulletin*, May 1998, also at <http://www.aahe.org/bulletin/bull_1may98.htm>: "Quite suddenly, in just two or three years, American higher education has come face-to-face with an explosive array of new competitors What would the postsecondary marketplace look like if (say) Microsoft, Deutsche Telekom, International Thomson, and the University of California combined to offer UC courses and degrees worldwide? In time, its only competitor could be a combine of like standing and deep pockets: an IBM-Elsevier-NEC-Oxford combine, for example. We shall see."

8. G. Holton, "A Nation at Risk Revisited," in *The Advancement of Science and its Burdens* (Univ. of Cambridge Press, 1986): "If the Constitution and the Tenth Amendment are interpreted narrowly, as is now the fashion, one cannot be surprised by the movement to phase out most or all of the federal responsibility for education.....Thomas Jefferson, in asking Congress for a remedy, said 'An amendment of our Constitution must here come in aid of the public education. The influence on government must be shared by all the people.'.....Without a device that encourages cumulative improvement over the long haul, without a built-in mandate to identify and promote the national interest in education as well as to 'help fund and support efforts to protect and promote that interest'we shall go to sleep again between the challenges of a Sputnik and a Honda."

(10) Judging from the promising work of the *Engineering Coalitions* and *ABET, ENGINEERS* may be the ones who will lead the way in “*correlating scientific exactitude with chaos*” to bring education-reform “*visions into focus,*” and “*get things done.*”

1. The quote on Slide 36 is from J. Bordogna, "Making Connections: The Role of Engineers and Engineering Education," *The Bridge* **27**(1), Spring 1997; on the web at [http://www.nae.edu/nae/nae.nsf/NAE+Publications/The+Bridge+Archives,+1997+\(Volume+27\)?OpenDocument](http://www.nae.edu/nae/nae.nsf/NAE+Publications/The+Bridge+Archives,+1997+(Volume+27)?OpenDocument).
2. W.A. Wulf, "The Urgency of Engineering Education Reform," *The Bridge* **28**(1), Spring 1998; on the web at [http://www.nae.edu/nae/nae.nsf/NAE+Publications/The+Bridge+Archives,+1998+\(Volume+28\)?OpenDocument](http://www.nae.edu/nae/nae.nsf/NAE+Publications/The+Bridge+Archives,+1998+(Volume+28)?OpenDocument).
3. Richard Felder's *Resources in Engineering and Science Education* (North Carolina State University) <http://www2.ncsu.edu/unity/lockers/users/f/felder/public/RMF.html>.
4. R.M. Felder, "The Warm Winds of Change," *Chem. Engr. Education* **30**(1), 34-35 (1996); on the web at <http://www2.ncsu.edu/unity/lockers/users/f/felder/public/Columns/Windso.html>: "In short, the growing pressures on universities to pay more attention to the quality of their undergraduate education programs, the availability of external funding to support educational reform and innovation, the proliferation of programs to improve education on campuses around the country, the increasing amount of faculty involvement in these programs, and the increased willingness of professors to learn about and try better ways to teach, all suggest that engineering education is on the brink of a major renewal. Granted, the same thing might have been said in other periods - most recently in the early 1970's. Call me an incurable optimist if you will, but I'm convinced that this time it's for real."

5. "The Future of Engineering Education":

"I. A Vision for a New Century," A. Rugarcia, R. M. Felder, D. R. Woods, J. E. Stice, *Chem. Engr. Education* **34**(1), 16-25 (2000);

"II. Teaching Methods that Work," R. M. Felder, D. R. Woods, J. E. Stice, A. Rugarcia, *Chem. Engr. Education* **34**(1), 26-39 (2000);

"III. Developing Critical Skills," D. R. Woods, R. M. Felder, A. Rugarcia, J. E. Stice, *Chem. Engr. Education*, in press;

"IV. Learning How to Teach," J. E. Stice, R. M. Felder, D. R. Woods, A. Rugarcia, *Chem. Engr. Education*, in press.

"I" and "II" are on the web as pdf documents at

<http://www2.ncsu.edu/unity/lockers/users/f/felder/public/RMF.html>.

6. K.A. Smith and A.A. Waller, "New Paradigms for Engineering Education," on the web at <http://fairway.ecn.purdue.edu/~fie/fie97/papers/1007.pdf>; adapted from W.E. Campbell & K.A. Smith, eds., *New Paradigms for College Teaching* (Interaction Books, 1997). For other resources see Smith's homepage at <http://www.msu.edu/~smithk73/>.

7. R. Sack, R.L. Bass, D.E. Daniel, C. Hendrickson, K.A. Smith, "Reinventing Civil Engineering Education," ASEE/IEEE Frontiers in Education Conference, San Juan, Puerto Rico, November 10-13, 1999; on the web at <http://fairway.ecn.purdue.edu/~fie/fie99/authors/S.htm>.

8. D.W. Johnson, R.T. Johnson, and K.A. Smith, *Cooperative Learning: Increasing College Faculty Instructional Productivity* (George Washington University, 1991).

9. D.R. Woods, A.N Hrymak, and H.M. Wright, "Approaches to Learning and Learning Environments in PBL versus Lecture-based Learning," ASEE Conference Proceedings, June 2000, forthcoming. D.R. Woods, *Motivating University Teachers to Improve Student Learning*, forthcoming book.

10. *Restructuring Engineering Education: A focus on change* - Report of an NSF Workshop on Engineering Education - April 1995 (National Science Foundation, 1995, Report NSF 95-65 - new).

11. ASEE - American Society for Engineering Education, <<http://www.asee.org/>>; Prism magazine on-line <<http://www.asee.org/prism/>>.

12. NAE - National Academy of Engineering, <<http://www.nae.edu/nae/nae.nsf/Homepage/>>.

13. National Science Foundation Engineering Education Coalitions, on the web at <<http://needs.me.berkeley.edu/coalitions/index.html>>; see, esp., under "Cross-Coalition Information" at <<http://needs.me.berkeley.edu/coalitions/info/index.html>> and "Index of Projects" at <<http://needs.me.berkeley.edu/coalitions/info/projects/index.html>>.

14. Univ. of Alabama, "Foundation Coalition Success Stories," on the web at <<http://foundation.ua.edu/>>.

15. B. Muramatsu, F. McMartin, and A. Agogino, "Innovative Uses of Engineering Courseware Availability through NEEDS - The National Engineering Education Delivery System," ASEE/IEEE Frontiers in Education Conference, San Juan, Puerto Rico, November 10-13, 1999; on the web at <<http://fairway.ecn.purdue.edu/~fie/fie99/authors/M.htm>>. The NEEDS (a) data base is at <<http://www.needs.org/>>; (b) "review of courseware" is at <<http://needs.me.berkeley.edu/quality/index.html>>.

16. R.J. Coleman, "A Progress Report: The Engineering Education Coalitions - The promise, programs, accomplishments, and problems of a wide-scale effort to reform engineering education," ASEE, 1998, on the web at <<http://www.asee.org/pubs/html/coalitions.htm>>: "Today the EEC program holds an additional promise now that the Accreditation Board for Engineering and Technology is establishing new accreditation standards. Much of ABET's new criteria—teamwork skills, integration of materials, interdisciplinary education, and real-world design—parallel the program's aims. As engineering schools prepare to meet these new standards, the coalition schools can serve as important models."

17. D. Bigio and J. Schmidt, "A Workshop for Faculty Development on the Underlying Pedagogical Issues of ABET EC 2000," ASEE/IEEE Frontiers in Education Conference, San Juan, Puerto Rico, November 10-13, 1999; on the web at <<http://fairway.ecn.purdue.edu/~fie/fie99/authors/B.htm>>.

18. R. Jenison and A. Dieterich, "Faculty Involvement in ABET Criteria 2000," ASEE/IEEE Frontiers in Education Conference, San Juan, Puerto Rico, November 10-13, 1999; on the web at <<http://fairway.ecn.purdue.edu/~fie/fie99/authors/J.htm>>.

19. The ABET homepage is at <<http://www.abet.org/>>.