Towards Paradigm Peace
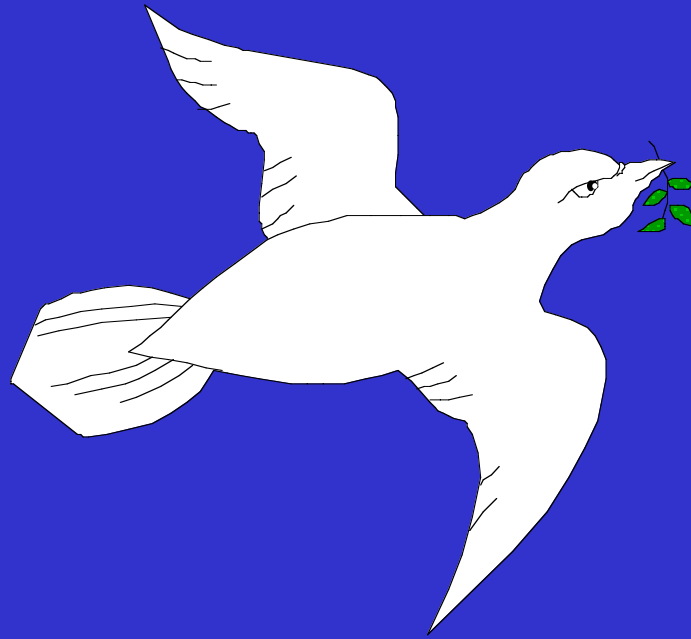# in Physics Education Research‡*

Richard R. Hake, Physics Department, Indiana University.
Both the paper and these slides are on the web at
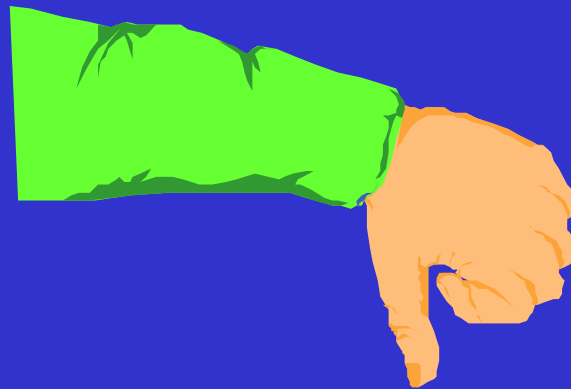<http://www.physics.indiana.edu/~hake>

In his address
"The Paradigm Wars and Their Aftermath,"
delivered over a decade ago at the annual AERA
meeting in San Francisco, Gage (1989) foresaw
three possible histories of education research _**as
written in 2009**_:

(1) "Raging during the 1980's, the **Paradigm Wars** resulted in the *demise of objectivity-seeking quantitative research* on teaching - a victim of putatively devastating attacks from **antinaturalists**, **interpretivists**, and **critical theorists**."
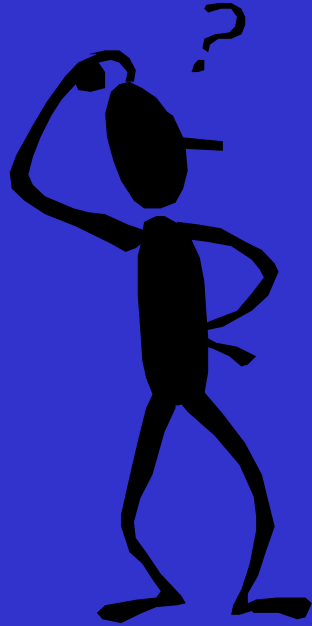

"Positivists", Meta-analysts, Achievement and Attitude Testers, Psychometricians, Correlational and Process-Product Researchers.

(2) "….from the jungle wars of the 1980's, educational researchers, including those concerned with teaching, *emerged into a <u>sunlit plain</u>* - a happy and productive arena in which the strengths of all three paradigms (a) objective-quantitative, (b) interpretive-qualitative, and (c) critical-theoretical) were abundantly realized, with a corresponding decrease in the harmful effects of their respective inadequacies."

(3) "What happened after 1989 in research in teaching was pretty much the same as what happened before 1989. The invective and vituperation continued."

Do harbingers of 2009 exist in current
   Physics Education Research (PER)?

I shall give :

   I. An Example of *Quantitative* PER

   II. An Example of *Qualitative* PER

   **III. Arguments for the *Complimentarity*
       of the Above**

   IV. A *Prediction* for 2009.

I. AN EXAMPLE OF *QUANTITATIVE* PER
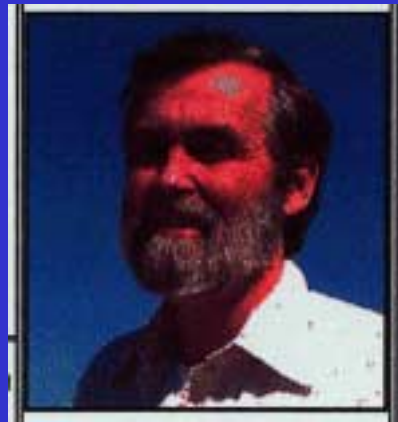
A meta-analysis: R.R. Hake (1998)

A. METHODOLOGY

1. Standard multiple-choice tests of conceptual understanding and problem-solving ability (high reliability and validity):

Mechanics Diagnostic (Halloun & Hestenes, 1985)
Force Concept Inventory (Hestenes, Wells, Swackhamer, 1992)
Mechanics Baseline (Hestenes & Wells, 1992)

.

David Hestenes

B. DEFINITIONS

1. Average *normalized* gain <g>:

$$\langle g \rangle = \%\langle G \rangle \quad / \quad \%\langle G \rangle_{max}$$
$$= (\%\langle post \rangle - \%\langle pre \rangle) \ / \ (100 - \%\langle pre \rangle).$$

Useful because the correlation of -

$$\langle g \rangle \ \text{with} \ \%\langle pre \rangle = +0.02$$
$$\%\langle post \rangle \ \text{with} \ \%\langle pre \rangle = +0.55$$
$$\%\langle G \rangle \ \text{with} \ \%\langle pre \rangle = -0.49$$

2. *IE Courses* (IE = Interactive Engagement): those reported by instructors to make substantial use of *IE methods*.
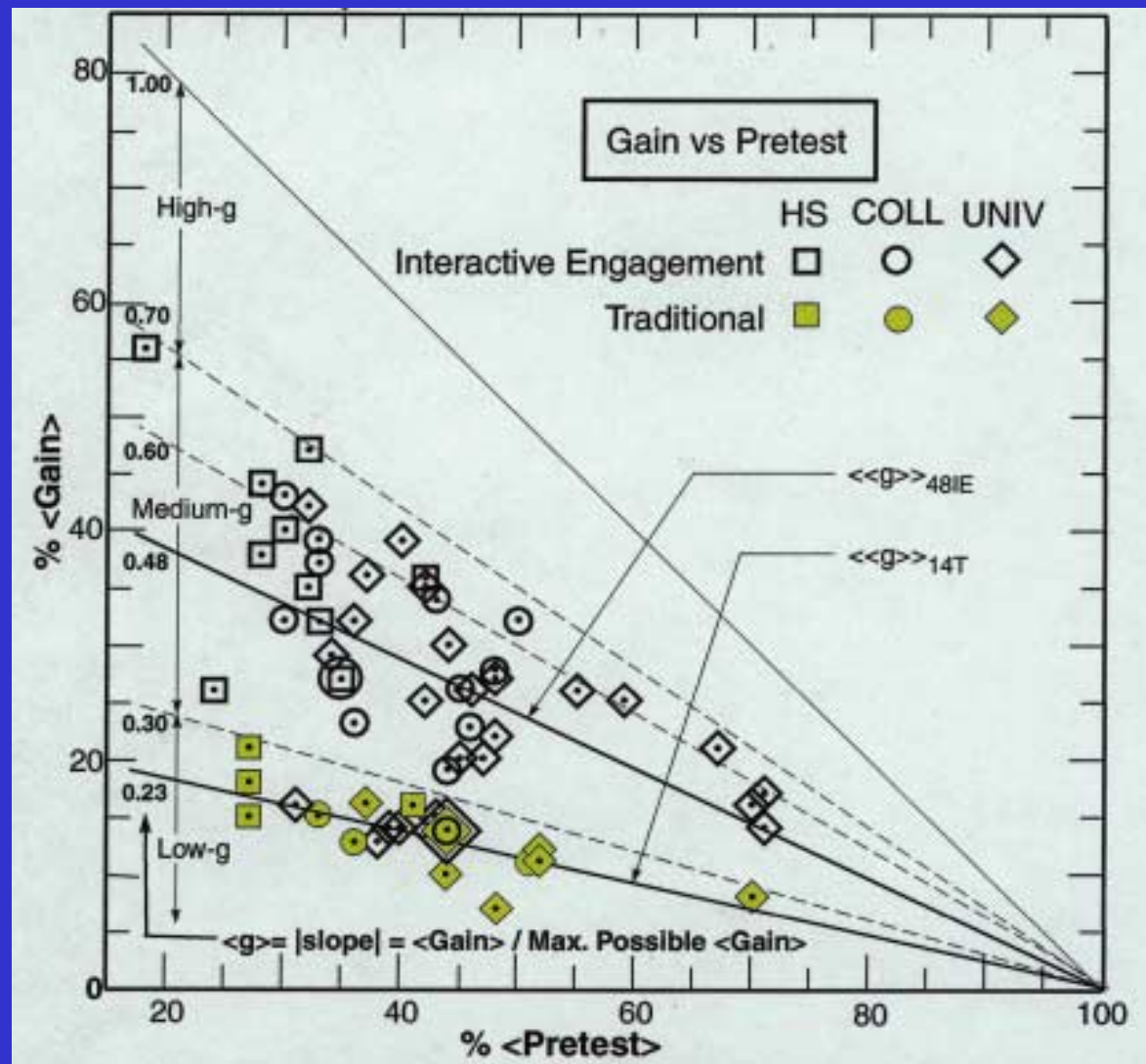
3. *IE methods*: those *designed by physics education researchers* to promote conceptual understanding through interactive engagement of students in *heads-on* (always) and *hands-on* (usually) activities that yield *immediate feedback* through discussion with peers and/or instructors, all as judged by their literature descriptions.

C. MAJOR IE METHODS USED BY SURVEY COURSES

IE Methods by PER's used in N courses

a. Collaborative Peer Instruction (Heller & Heller): 48 - ***all*** courses

b. Microcomputer-based labs (Tinker, Thornton & Sokoloff): 35

c. Concept Tests (Mazur): 20

d. Modeling (Hestenes & Wells): 19

e. Active Learning Problem Sets (ALPS) or Overview Case Studies (Van Heuvelen): 17

f. Physics education research based text or no text: 13

g. Socratic Dialogue Inducing (SDI) Labs (Hake): 9

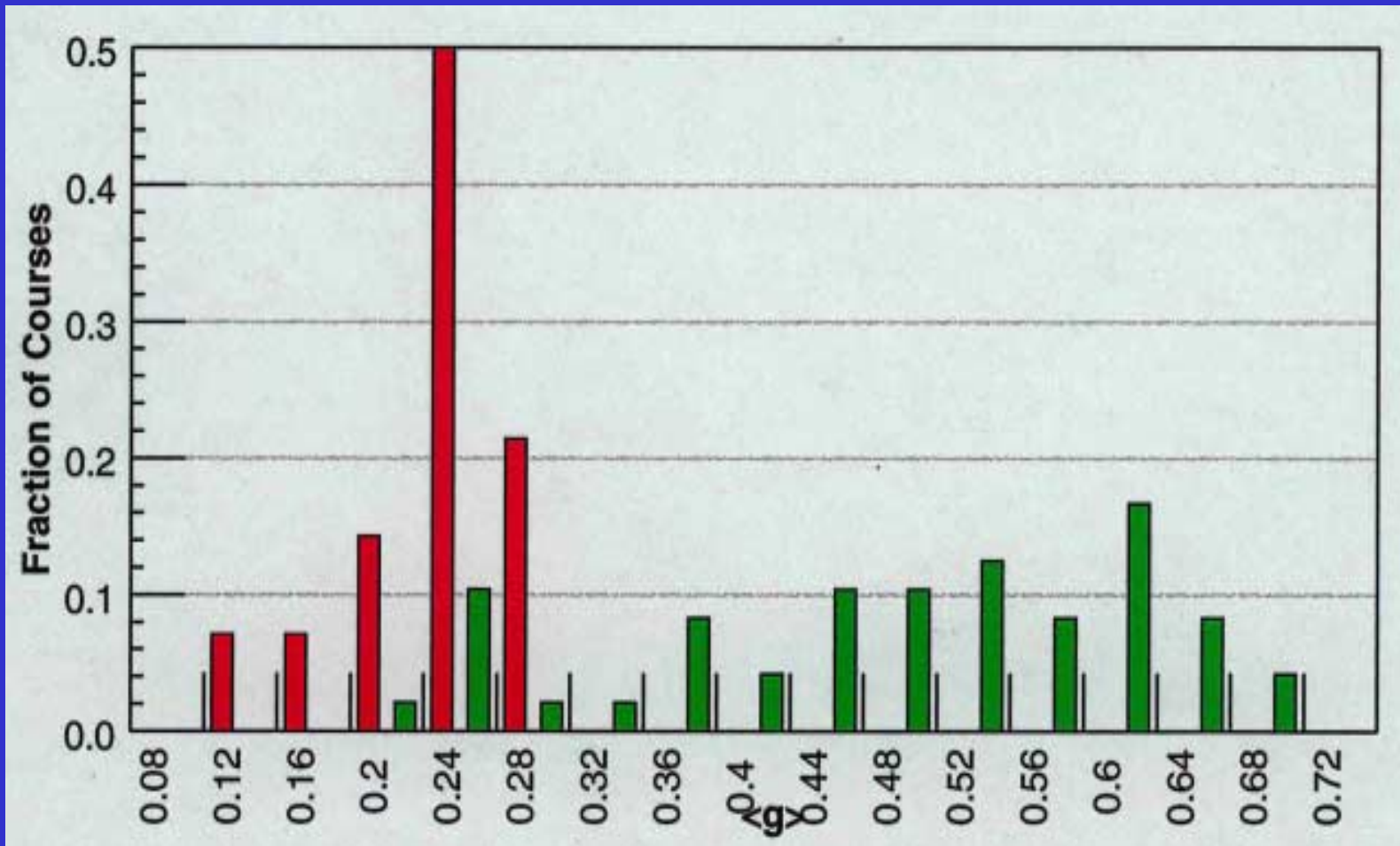# D. GAIN vs PRE-TEST - *ALL* DATA (FCI or MD Tests)

62 courses (N = 6542)
48 IE (N = 4458): <<g>> (48 IE) = 0.48 ± 0.14sd
14 T (N = 2084):   <<g>> (14 T) = 0.23 ± 0.04sd
<<g>> (IE) is over twice that of <<g>> (T) and differs by almost 2 sd's of sd(I E)

Histogram of the normalized gain <g>: 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 δ<g> = 0.04 centered on the <g> values shown.

E. 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. This and direct comparison of IE and T courses at the same institution imply that IE courses *enhance problem solving ability.*

F. SUMMARY AND CONCLUSIONS

1. 62 courses (N = 6542)

   48 IE (N = 4458): $<<g>>_{48\ IE} = 0.48 \pm 0.14$sd

   14 T (N = 2084): $<<g>>_{14\ T} = 0.23 \pm 0.04$sd

   $<<g>>_{IE}$ is over twice that of $<<g>>_T$ and differs by almost 2 sd's of sd(I E)

   It is extremely unlikely that random or systematic errors play a significant role [see Hake (1998) for detailed error analysis].

2. IE methods appear to enhance problem-solving ability.

3. "1" and "2" strongly suggest that *the use of IE strategies <u>can</u> increase mechanics-course effectiveness well beyond that obtained with traditional methods*. However, IE strategies and their implementation need to be improved.

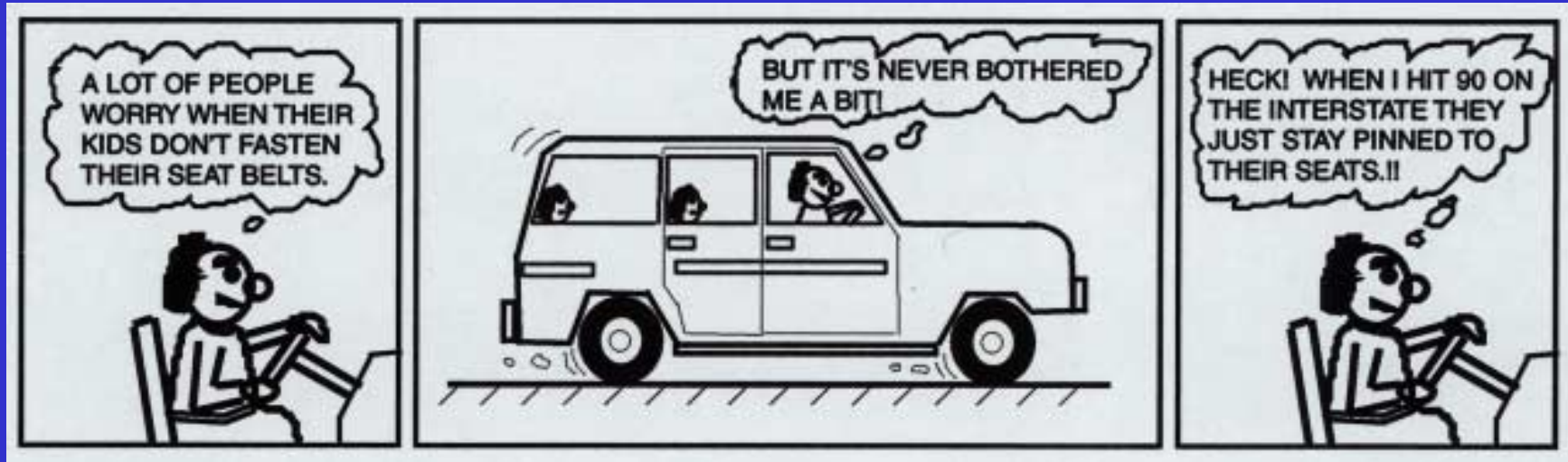## F. RECENT RESEARCH CONSISTENT WITH THE ABOVE META-ANALYSIS

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, Risley - 1999).

e. Hogskolan Dalarna - Sweden (Bernard - 1999).

Thus in PER, just as in hard-core traditional physics research, it is possible to perform *quantitative* experiments which can be reproduced (or refuted) by other investigators and thus contribute to the construction of a *community map*. (Redish, 1999).

I. AN EXAMPLE OF *QUALITATIVE* PER

Pinning a Kid To Her Seat (from Socratic Dialogue Inducing (SDI)
Lab #2, *Newton's Second Law* <http:www.indiana.physics.edu/~sdi>
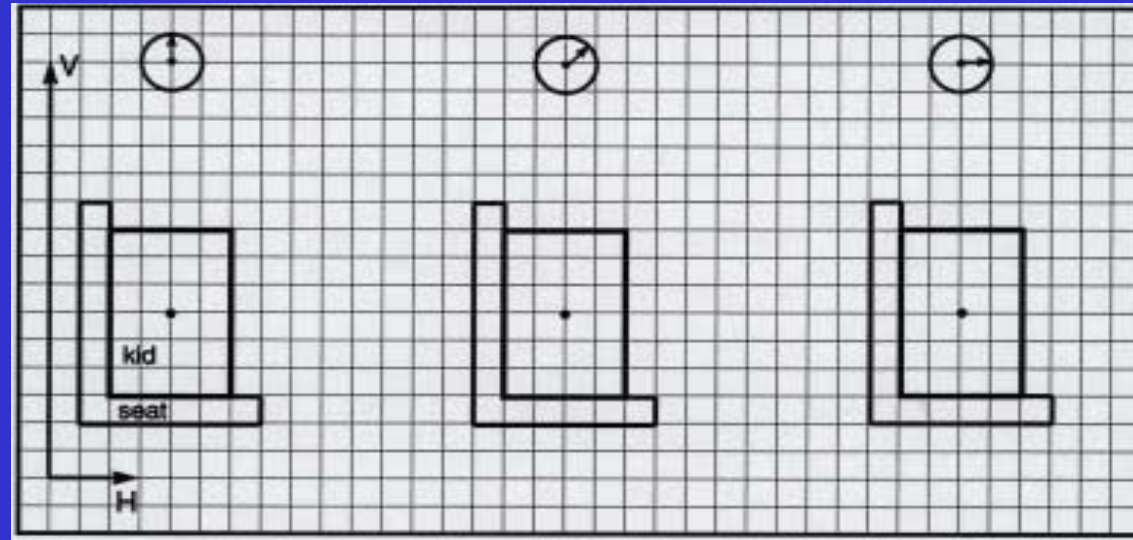

Videotape PST1 - 4a shows Pat, Mary, June, and Doug tackling the question:

A. Can a truck driver pin a kid to her seat by driving his truck at a very high constant velocity **v** as suggested in the cartoon above? {Y, N, U, NOT}

After discussion, the students decide in the *negative*. They encircle "N" and justify their choices in writing in their lab manuals.

B. If you were a truck driver and wished to pin a kid to her seat what might you do? (Three time-sequential snapshot sketches with force **F**, velocity **v**, and acceleration **a** vectors and clocks are worth 10 terawords.)

After discussion, the students conclude that the driver *could* pin a kid to her seat by giving the bus a constant forward acceleration $\mathbf{a}_{bus}$. They draw correct snapshot sketches showing:

$\mathbf{v}_{kid}$ increasing with time;

$\mathbf{a}_{kid} = \mathbf{a}_{bus}$ = constant in time but not 0;

equal and opposite vertical forces $\mathbf{F}_{on\ kid\ by\ seat}$ and $\mathbf{F}_{on\ kid\ by\ Earth}$;

constant forward horizontal force $\mathbf{F}_{on\ kid\ by\ seat}$.

Mary also shows a backward horizontal "pinning force" $\mathbf{F}_{\text{on kid}}$, thinking it's the "force due to acceleration."

Truncated exchange:

Socrates: Now you have here $\mathbf{F}_{\text{on kid by seat}}$. That's great, but I'm really worried about that force...... (points to $\mathbf{F}_{\text{on kid}}$) .... is that really there?

Mary: Well, it's gotta be...that's what's pin'n it back.

Doug: Not in the first part where there's no.....

Mary: (excitedly) NO!! IT'S NOT!!! IT'S NOT THERE!!

Doug: IT'S THERE!!! ..... it's $\mathbf{F}_{\text{on seat by kid}}$.

June: It exists by Newton's third law, but we're not concerned with it because we're not dealing with that one.

Mary: Well, that was tricky! (laughs)

Socrates: Yeah, that is tricky!

As for all SDI lab experiments, the selection and phrasing of Socratic questions such as "A" and "B," and the activities surrounding them have been developed by *qualitative* research (e.g., videotape analysis, student interviews, instructor discussions) extending over many years.

III. COMPLIMENTARITY OF *QUANTITATIVE* AND *QUALITATIVE* RESEARCH

A. At Indiana University over a 10-year period, "pre-med" physics courses (N = 1263) achieved $<<g>> = 0.60$, considerably higher than the average $<<g>> = 0.47$ of the other IE courses considered in the survey. Thus the *qualitative* research which has improved SDI labs has contributed to their effectiveness as shown by the *quantitative* survey results.

B. The Halloun-Hestenes tests used in the *quantitative* survey were developed by painstaking *qualitative* research involving analysis of students' verbal responses to open-ended, conceptually-oriented questions.

C. A critical review and listing of physics-education research articles over the past four decades (McDermott & Redish, 1999) shows a mix of mutually supportive *quantitative* and *qualitative* work.

III. A *PREDICTION* FOR 2009: On the basis of:

A. The present evidence for the effectiveness and complementarity of *quantitative* and *qualitative* PER.

B. The present state of *quantitative/qualitative* PER (McDermott & Redish, 1999).

C. Increasing interdisciplinary synergy (fostered by the web and organizations such as AERA (witness this meeting), AAHE, and NARST.

I shall predict that for PER (and possibly even education research generally):

By the year 2009, educational researchers will have "*emerged into a sunlit plain* - a happy and productive arena in which the strengths of all three paradigms….(are)…. abundantly realized."

objective quantivist

critical theorist

interpretive qualitativist

"Paradigm differences do not require paradigm conflict."

Some will reach the "sunlit plain" over paths marked *PRAGMATISM* or *POPPER'S PIECEMEAL SOCIAL ENGINEERING*, as suggested by Gage. But most will follow the sign *SCIENTIFIC METHOD*:

(1) "EMPIRICAL: Systematic investigation .... (by quantitative, qualitative, or any other means) .... of nature to find reproducible patterns.

(2) THEORETICAL: Construction and analysis of models representing patterns of nature." (Hestenes, 1999).

(3) "Continual interaction, exchange, evaluation, and criticism so as to build a .... community map" (Redish, 1999).

Joe Redish