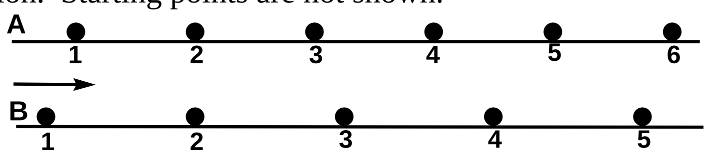
# Interactive-engagement vs Traditional Methods in Mechanics Instruction*

*Richard R. Hake*

Physics-education research of the past two decades strongly suggests that (a) traditional methods of introductory physics instruction (i.e., passive-student lectures, recipe labs, and algorithmic-problem exams) fail to convey much conceptual understanding of physics to the average student, and (b) non-traditional methods are often more effective.[1]

One of the more dramatic demonstrations of the failure of introductory mechanics courses occurred in 1985 when Halloun and Hestenes[2] (HH) published a careful study of pre/post testing of 560 Arizona State University students enrolled in both calculus and non-calculus-based courses. HH used their Mechanics Diagnostic[2a] (MD) test, 36 multiple-choice questions assessing students' ability to discriminate between the applicability of scientific concepts and naive alternatives in common physical situations. A typical MD test question is shown below:

1. Two balls A and B move at *constant* speeds on separate tracks. Positions occupied by the two balls at *the same time* are indicated in the figure below by *identical numbers*. The arrow indicates the direction of motion. Starting points are not shown.




Do the two balls ever have the same speed? A. Yes, at instant "2." B. Yes, at instant "5."
C. Yes, at instant "6." D. Yes, at instants "2" and "6." E. No. (Alternative "A" represents a common preconception, stemming from a confusion between position and speed.[2b,3])

HH concluded: (a) "....the student's initial qualitative, common-sense beliefs about motion and....(its).... causes have a large effect on performance in physics, but conventional instruction induces only a small change in those beliefs." (b) "Considering the wide differences in the teaching styles of the four professors....(involved in the study)....the basic knowledge gain under conventional instruction is essentially independent of the professor."

Although the work of HH[2] and others[1] has stimulated considerable effort to improve introductory physics courses, it has had little impact on the teaching practices of the average physicist. Seeking more definitive information on the relative effectiveness of alternate vs traditional teaching strategies, I undertook a large-scale survey over the years 1992 - 96, and recently reported[4] the results, which consisted, in part, of pre/post test data using the MD test[2a] or more recent Force Concept Inventory[5] (FCI) for 62 introductory physics courses enrolling a total number of students N = 6542. A consistent analysis over diverse student populations in high schools, colleges, and universities was obtained by

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taking the average normalized gain <g> as a rough measure of the average effectiveness of a course in promoting conceptual understanding. Here <g> was defined as the ratio of the actual average gain (%<post> – %<pre>) to the maximum possible average gain (100 – %<pre>). Fourteen "traditional" (T) courses (N = 2084) which made little or no use of interactive-engagement (IE) methods achieved an average gain $\langle g \rangle_{\text{T-ave}} = 0.23 \pm 0.04$ (std dev). In sharp contrast, forty-eight courses (N = 4458) which made substantial use of IE methods achieved an average gain $\langle g \rangle_{\text{IE-ave}} = 0.48 \pm 0.14$ (std dev), *almost two standard deviations of* $\langle g \rangle_{\text{IE-ave}}$ *above that of the traditional courses.*

Results on the problem-solving Mechanics Baseline[6] (MB) test were available for 30 (N = 3259) of the above 62 courses. The MB results implied that IE strategies *enhanced* problem-solving ability. The conceptual and problem-solving test results strongly suggested ***that the classroom use of IE methods can increase mechanics-course effectiveness well beyond that obtained in traditional practice.***

I defined "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 which yield immediate feedback through discussion with peers and/or instructors, all as judged by their literature descriptions. A detailed breakdown of the instructional strategies as well as materials and their sources for each of the 48 IE courses of the survey was presented.[4b] Among the more popular IE methods were Collaborative Peer Instruction,[7] Microcomputer-Based Labs,[8] Concept Tests,[9] Modeling,[10] Active Learning Problem Sets or Overview Case Studies,[11] Socratic Dialogue Inducing Labs,[12] and use of a physics-education-research based text[13] or no text.

Various objections have been raised to calls for physics-education reform[14] and supporting evidence[1-6] for the need thereof. Some of these protests may be worth discussing because of their relevance to the puzzlement of Sam Bowen, editor of the present *Newsletter*: "I cannot understand why anyone who is thoughtful continues to teach in the traditional manner."

1. " ...we have been conscripted into this....(physics education )... revolution; and the first task of the leaders of a revolution is to convince everyone how bad the prevailing system is. Educators do this with tests: tests which demonstrate weak points that you can zero in on with special techniques which will then show amazing improvements, *many of which represent a generalized Hawthorne effect.*" (Our *italics.*)[15,16]

As discussed in ref. 4a, the Hawthorne effect can produce short-term benefits associated with the special attention (rather than the intrinsic worth of the treatment) given to a research test group. Such benefits would be expected to diminish when the treatment is applied as a regular long-term routine to large numbers of subjects, as was the case for 12 IE courses of my survey. The latter achieved normalized gains about the same as for IE courses in which Hawthorne effects were more likely to have occurred.

2. "...the size of the sample Hake used for the traditional courses was fairly small, so a statistical fluctuation was always a possibility.[17]

Testing his conjecture, Ehrlich[17] 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 <g> = 0.20 with a standard deviation of 0.06, consistent with my results[4] for 14 T courses.

3. " I do not believe that a bad score on the Force Concept Inventory proves that the student has not - at some level - learned the material."[18]

Griffiths seems to argue that such subliminal learning shows up in the final attainment of understanding after many spirals over the same material, as he himself experienced. Geilker[15] similarly discounts the apparent failure of introductory courses to correct misconceptions: "Physics is a spiral subject and student misconceptions tend to get corrected with further exposure and experience." But as Hilborn[16] points out: "The unfortunate fact is is that only 3% of the students taking introductory calculus-based physics in colleges and universities ever take another physics course. For more that 97% of our students, their spirals contain only one turn. Our introductory course is their terminal course."

4. "I have no doubt that that one can design a course that leads to much better results on such tests. But as my doctor once remarked, there is no such thing as intervention without side effects, and I would like to know what we are (perhaps inadvertently) sacrificing when we *teach to the Force Concept Inventory".*[18] (Our *italics.*)

If Griffiths means "teach to the FCI" in the sense of going over experiments, questions, or problems identical or nearly identical to the test items, then learning would doubtless have been sacrificed. But I have argued[4a] that it is unlikely that such practice had a significant impact on my survey:
(a) considering the elemental nature of the FCI questions, the maximum $\langle g \rangle = 0.69$ and average $\langle g \rangle_{48IE\text{-}ave} = 0.48$ are below those which might be expected if teaching to the test were an important influence; (b) the responses of IE instructors to a survey questionnaire indicated that they thought they had avoided "teaching to the test" in the restricted sense above.

If, on the other hand, Griffiths means "teach to the FCI" in the sense of emphasizing the basic concepts of Newtonian mechanics examined on the FCI/MD tests, then the IE courses of the survey are guilty. One of the sacrifices thereby entailed is breadth of coverage, but most of those[13,14,19] who seriously consider the current status of the introductory course agree that "less may be more."[20] Some may think that emphasis on concepts comes at the sacrifice of problem-solving skills, but as indicated above, the MB results of my survey imply that IE strategies *enhanced* problem-solving ability. Similar conclusions have been reached by Mazur[9] and Thacker *et al.*[21]

Returning to Sam Bowen's perplexity regarding those who continue to teach in the traditional manner, the reactions of Gielker, Ehrlich, and Griffiths are symptomatic of the skepticism of many thoughtful physicists regarding the need to reform traditional teaching practices. I hope this piece will prompt more physicists to suppress their natural skepticism long enough to consider the physics-education-reform literature[1-14,19-21] and experiment with interactive-engagement methods in their classes.

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*Richard Hake is an emeritus professor of physics at Indiana University, who now resides in California and can be reached at <hake@ix.netcom.com>. A fellow of the APS, he has published over 60 papers in condensed matter physics. For the past decade he has been involved in a research and development program to improve introductory physics education, supported in part by NSF Grant DUE/MDR-9253965.*