

# The Need for Improved Physics Education for Teachers: FCI Pretest Scores for Graduates of High-School Physics Courses - Is it Finally Time To Implement Curriculum S? \* ‡

Richard R. Hake; Physics Dept., Indiana University, <[rrhake@earthlink.net](mailto:rrhake@earthlink.net)>

---

\*Partially supported by NSF Grant DUE/MDR-9253965.

‡The reference is: R.R. Hake, “The Need For Improved Physics Education of Teachers: FCI Pretest Scores for Graduates of High-School Physics Courses - Is it Finally Time To Implement Curriculum S?”  
*Physics Education Research Conference 2000: Teacher Education*, Univ. of Guelph, August 2-3, 2000;”  
on the web at <<http://www.physics.indiana.edu/~hake/>>. (Note that hot linked URL’s are in <**bold**>).

© Richard R. Hake, 8/10/00. Permission to copy or disseminate all or part of this material is granted provided that the copies are not made or distributed for commercial advantage, and the copyright and its date appear. To disseminate otherwise, to republish, or to place at another website (instead linking to <<http://www.physics.indiana.edu/~hake>>) requires written permission.

# OUTLINE

I. The Normalized Gain $\langle g \rangle$ .....	3
II. Actual Gain vs Pretest Scores for 62 Introductory Physics Courses .....	5
III. Pretest Scores and <i>Hypothesized <math>\langle g \rangle</math>'s</i> for Indiana University Premed Graduates of High-School Physics (HSP) Courses .....	6
IV. <i>Hypothesized Actual Gain vs Pretest Scores for Indiana University</i> Premed Graduates of High-School Physics (HSP) Courses .....	7
V. Other Evidence of the Need for Improved Physics Education of Teachers .....	9
VI. The Solution - A Curriculum S ? .....	13
<i>References and Footnotes</i> .....	15 - 18

## I. The Normalized Gain $\langle g \rangle$

### A. Definition of “Normalized Gain”\*

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.,

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

---

\* 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://www.physics.indiana.edu/~sdi/>>.

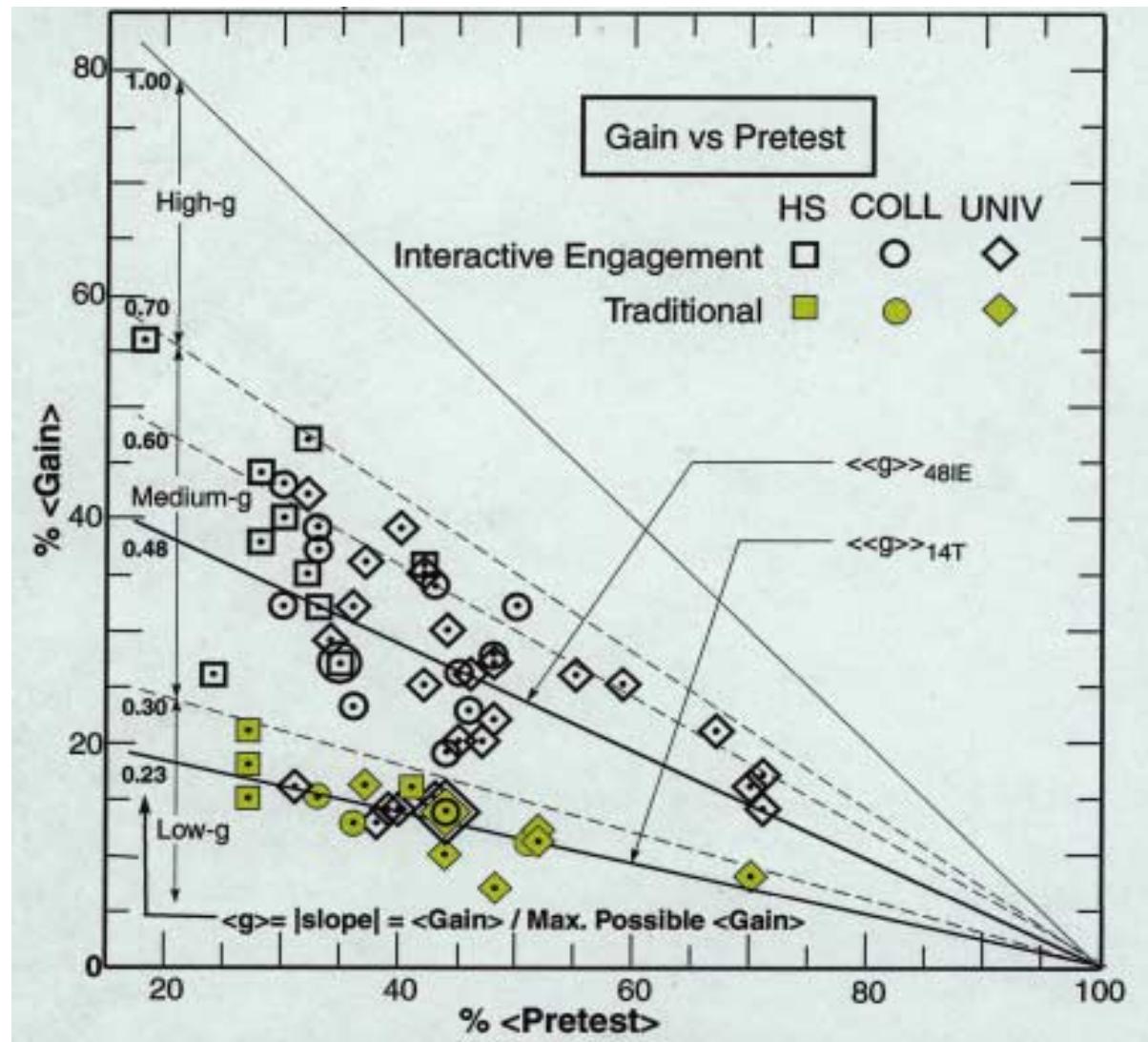
## B. Experimental Justification of $\langle g \rangle$ as a Comparative Measure of Course Effectiveness

- a. The correlation of the average normalized  $\langle g \rangle$  with  $\% \langle \text{pre} \rangle$  for the 62 survey courses of my survey 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.

## II. Actual Gain vs Pretest Scores for 62 Introductory Physics Courses



62 courses (N = 6542)

48 IE (N = 4458):  $\langle g \rangle_{(48 \text{ IE})} = 0.48 \pm 0.14\text{sd}$

14 T (N = 2084):  $\langle g \rangle_{(14 \text{ T})} = 0.23 \pm 0.04\text{sd}$

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

### III. Pretest Scores and $\langle g \rangle$ 's for Indiana University Premed Graduates of High-School Physics (HSP) Courses

For the Indiana University "pre-med" courses

[*Am. J. Phys.* **66**(1), 64-74 (1998)]:

1994 Spring: a.  $\langle \% \text{pre} \rangle(43 \text{ no HSP}) = 32\%$

b.  $\langle \% \text{pre} \rangle(123 \text{ HSP}) = 42\%$

$$\langle g \rangle(\text{hypothesized}^*) = \langle g_{\text{h}} \rangle = (42\% - 32\%) / (100\% - 32\%) = 0.15$$

1995 Spring: a.  $\langle \% \text{pre} \rangle(45 \text{ no HSP}) = 37\%$

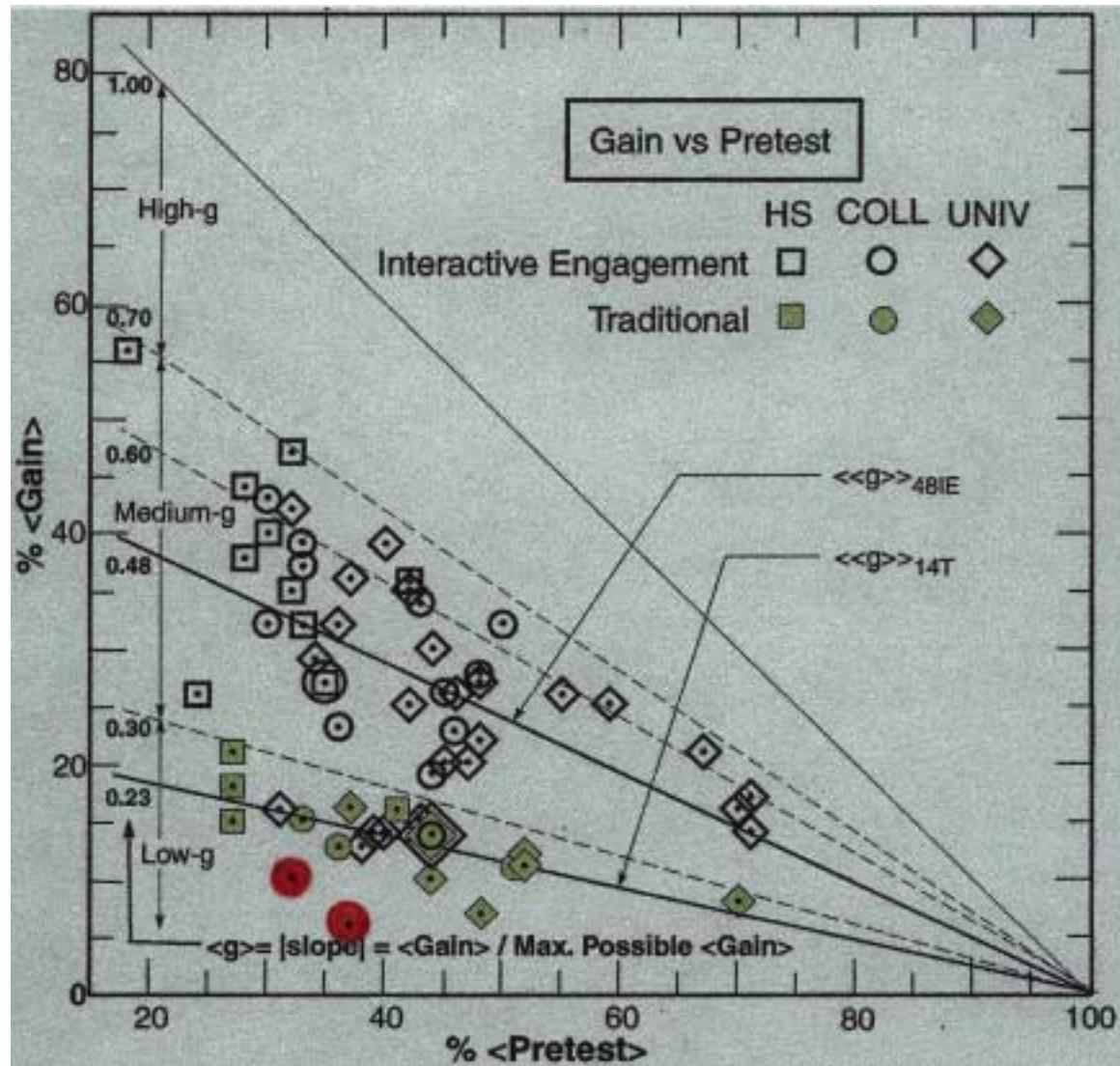
b.  $\langle \% \text{pre} \rangle(164 \text{ HSP}) = 43\%$

$$\langle g \rangle(\text{hypothesized}^*) = \langle g_{\text{h}} \rangle = (43\% - 37\%) / (100\% - 37\%) = 0.10$$

---

\* We assume that the "b" group graduates of HSP, *before* they took HSP, would have averaged about the same as the "a" group.

#### IV. Hypothesized Actual Gain vs Pretest Scores (RED CIRCLES ●) for Indiana University Premed Graduates of High-School Physics (HSP) Courses



A. Indiana Univ. premeds who are graduates of HSP achieved *hypothesized*  $\langle g \rangle$ 's for their HSP courses that are even lower ( $\langle g_h \rangle = 0.15, 0.10$ ) than the average  $\langle\langle g \rangle\rangle$  (14 T) =  $0.23 \pm 0.04$ sd for 14 the traditional courses of the survey. (It might be worthwhile to examine "hypothesized  $\langle g \rangle$ 's" ( $\langle g_h \rangle$ 's) at other universities.)

B. Low  $\langle g_h \rangle$ 's may reflect:

1. A rapid decrease in  $\langle g \rangle$  in the years following HSP, as might be expected if only incoherent and loosely related bits of physics understanding had been acquired,
2. A low  $\langle g \rangle$  even directly after HSP, or
3. Some combination of "1" and "2".

C. In any case, the results suggest the ineffectiveness of HSP to promote conceptual understanding and the need for improved physics education of teachers in interactive-engagement (IE) rather than traditional (T) classes. Teachers need IE rather than T courses because they:

- (a) "tend to teach the way they were taught,"
- (b) should understand physics concepts.

## V. Other Evidence of the Need for Improved Physics Education of Teachers - TIMSS

- A. 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> >:

The major difference mentioned in the reports is that the U.S. curricular materials are *a mile wide and an inch deep*. By this is meant that the curricula in the U.S. present many topics, but no subject is covered in any depth and there is very little difference in the emphasis between subjects.

Because the study was able to look at students in both 7th and 8th grades, it was possible to see if there are any gains in subject matter competency between these grades. In several countries, students showed gains in some subjects, mostly those that had been covered in some depth in their schools. *In the U.S., by contrast, no subjects showed a gain in knowledge and skill.*

. . .(in my opinion TIMSS tells us that) . . . we are not generally giving students an understanding of physics which supports generalization and manipulation of concepts in new contexts. . . . . *A large fraction of existing high school teachers will soon be retiring; the physics community has a great opportunity.* (My italics.)

B. M. Neuschatz, “What can the TIMSS teach us?” *The Science Teacher* **66**(1), 23-26 (1999).

“In the study.....(the 12th grade portion)..... U.S. students tied for last place in Physics and scored almost as low in advanced mathematics.....*The explanation* ..... *may not be that our students are getting so little of the physics they take, but rather that they are taking so little in the first place*.....the TIMMS study pitted U.S. students against those with twice as much physics study under their belts..... The U.S. still stands out among its industrial partners as exposing a smaller proportion of students to physics in secondary school and encouraging even fewer to attempt a more intensive study of the subject. *The notion put forth by the TIMSS researchers that the syllabi for our courses tend to be ‘a mile wide and an inch deep’ seem to have a good deal of merit.*” (My italics.)

C. NRC, *Global Perspectives for Local Action: Using TIMSS to Improve U.S. Mathematics and Science Education* (National Academy Press, 1999):

“U.S. students’ worst showing was in population 3.....(final year of secondary School.....corresponding to U.S. high school seniors).....*In the assessment of general mathematics and science knowledge, U.S. high school seniors scored near the bottom of the participating nations.* In the assessments of advanced mathematics and physics given to a subset of students who had studied those topics, no nations had significantly lower mean scores than the United States. *The TIMSS results indicate that a considerably smaller percentage of U.S. students meet high performance standards than do students in other countries.”* (My italics.)

**D. R.B. Schwartz**, “Lessons from TIMSS,” *Hands On\** 21(1), 4 (1999):

“If the public debate about the meaning of these results is conducted only between the doomsayers and the ‘Don’t worry, be happy’ crowd, we will all miss an opportunity to benefit from the *important lessons of TIMSS, which are found not in the comparative ranking of the countries but in the extraordinary sub-studies that accompany the administration of the tests.....*

The first study focusing on textbooks, strongly suggests that, *in the absence of clear agreements about what students are supposed to know and be able to do at each grade or cluster of grades, our textbooks err on the side of inclusiveness, treating a large number of topics superficially rather than a handful of topics in depth.....*

The second study examines videotaped classrooms in Germany, Japan, and the U.S., and this is enormously instructive in what it reveals about the focus on pedagogy in the three countries. Simply put, the *American lessons, especially when contrasted with Japanese classrooms, focus much more on procedures and skills, and much less on concepts, deductive reasoning, and understanding.*

Finally, there are detailed case studies of the same three countries.....(showing, for One thing)..... *that we track much earlier than either Germany or Japan...”*  
(My *italics*.)

---

\*TERC - Technical Education Research Center <<http://www.terc.edu>>.

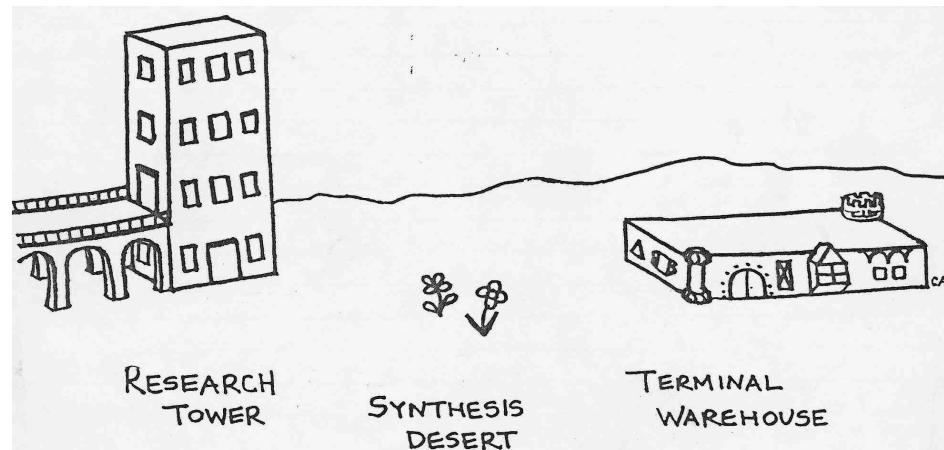
## VI. The Solution - A Curriculum S?



Ken Ford

“From the ..... Second Ann Arbor Conference, November 1962 - came a succinct and memorable recommendation: that two kinds of curricula for physics majors be developed (to meet the needs of two kinds of students). These were named *Curriculum R* and *Curriculum S*. *Curriculum R* (for Research) was the then-current (and still dominant) undergraduate curriculum, whose principal aim is to prepare students for graduate study in physics. *Curriculum S (for synthesis) was to serve students who wanted to study physics as background for something other than physics research: business, law, medicine, teaching, some other scientific study, or just informed citizenship.*

What has happened? Sad to say, *nothing*. *Curriculum R* was already strong and is still strong. *Curriculum S did not exist then and it does not exits now (in the first approximation)*. The accompanying figure shows the present situation, metaphorically.



*Curriculum R* is an austere four-story building, taller than it is wide..... Next door is the *Curriculum S* desert, containing only a few scattered blossoms.....another curriculum has come into being.....*Curriculum T* (for terminal) ..... (with) courses on astronomy, arms control, solar energy, conceptual physics, physics of music, physics and sports, high-fidelity sound, and on and on.....**It is time to look again at Curriculum S.....we need a physics major program suitable for (and attractive to) some of the teachers of the next generation - not just high-school physics teachers, but elementary and middle school teachers as well.** ” (My *italics*, underlining, **bold**, and color.) \*



Walt Kelley's Pogo

*We have met the enemy and he is us (university faculty)!*

---

\*From K. Ford, “Whatever Happened to Curriculum S?” *Phys. Teach.* **25**, 138-139 (1987); see also E.L. Jossem, “Undergraduate Curricula in Physics: A Report on the Princeton Conference on Curriculum S,” *Am. J. Phys.* **32**(6), 491-497 (1964).

## ***References and Footnotes***

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://www.physics.indiana.edu/~sdi/>>.
2. R.R. Hake, "Interactive-engagement methods in introductory mechanics courses," on the Web at <<http://www.physics.indiana.edu/~sdi/>> and submitted on 6/19/98 to the "Physics Education Research Supplement" to AJP (PERS).
3. 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>>.
4. M. Neuschatz, "What can the TIMSS teach us?" *The Science Teacher* **66**(1), 23-26 (1999).
5. NRC, *Global Perspectives for Local Action: Using TIMSS to Improve U.S. Mathematics and Science Education* (National Academy Press, 1999).
6. R.B. Schwartz, "Lessons from TIMSS," *Hands On* (TERC Newsletter) **21**(1), 4 (1999). [TERC - Technical Education Research Center <<http://www.terc.edu>>.]

7. K. Ford, “Whatever Happened to Curriculum S?” *Phys. Teach.* **25**, 138-139 (1987).
8. E.L. Jossem, “Undergraduate Curricula in Physics: A Report on the Princeton Conference on Curriculum S,” *Am. J. Phys.* **32**(6), 491-497 (1964).
9. M. Neuschatz & M. McFarling, *Maintaining Momentum: High School Physics for a New Millennium* (American Institute of Physics, 1999).

### ***Related papers at the Guelph Meeting***

10. S. Mahajan & R.R. Hake, Is It Finally Time for a Physics Counterpart of the Benezet/Berman Math Experiment of the 1930's?" *Physics Education Research Conference 2000: Teacher Education*, Univ. of Guelph, August 2-3, 2000; see also the "Benezet Centre" at <<http://wol.ra.phy.cam.ac.uk/sanjoy/benezet>>: "Students in Manchester, New Hampshire were not subjected to arithmetic algorithms until grade 6. In earlier grades they read, invented, and discussed stories and problems; estimated lengths, heights, and areas; and enjoyed finding and interpreting numbers relevant to their lives. In grade 6, with 4 months of formal training, they caught up to the regular students in algorithmic ability, and were far ahead in general numeracy and in the verbal, semantic, and problem-solving skills they had practiced for the five years before." We conjecture that implementation of the "Benezet Method" in early grades would drastically improve the effectiveness of high-school physics, science, and math instruction. A *Curriculum S* could assist in the education of teachers with the deep understanding of science and mathematics and the pedagogical content knowledge required for implementation of the Benezet Method.

11. J. Epstein, "The '0.7 Barrier' on the FCI -- a suggestion of the underlying problem and a proposal for further research." *Physics Education Research Conference 2000: Teacher Education*, Univ. of Guelph, August 2-3, 2000." See also J. Epstein, "Cognitive Development in an Integrated Mathematics and Science Program," *J. of College Science Teaching*, 12/97 & 1/98, pp. 194-201:

"While it is now well known that large numbers of students arrive at college with large educational and cognitive deficits many faculty and administrative colleagues are not aware that many students lost all sense of meaning or understanding in elementary school.....In large numbers our students.....[at Bloomfield College (NJ) and Lehman (CUNY)].....cannot order a set of fractions and decimals and cannot place them on a number line. Many do not comprehend division by a fraction and have no concrete comprehension of the process of division itself. Reading rulers where there are other than 10 subdivisions, basic operational meaning of area and volume, are pervasive difficulties. Most cannot deal with proportional reasoning nor any sort of problem that has to be translated from English. *Our diagnostic test, which has been given now at more than a dozen institutions shows that there are such students everywhere.....(even Wellesley! - see J. Epstein, "What is the Real Level of Our Students," 1999, unpublished).* (My *italics*.)

In my view, Epstein's work suggests the need for a more Benezet-like approach (ref. 10) to K-12 education.

12. R.R. Hake, “The General Population’s Ignorance of Science Related Societal Issues: A Challenge for the University,” *AAPT Announcer* **30**(2), 105 (2000); on the web < <http://www.physics.indiana.edu/~hake/> >. It is argued that the failure of universities *throughout the Universe* to properly educate pre-college teachers is responsible for our failure to observe any signs of extraterrestrial intelligence.
13. D. Hestenes, “Assessment with the Force Concept Inventory,” *Physics Education Research Conference 2000: Teacher Education*, Univ. of Guelph, August 2-3, 2000.
14. A.M. Zolandz, “Curriculum Survey of High-School Physics Courses,” *AAPT Announcer* **30**(2), 77 (2000).
15. G.E. Gladding, “Physics 100: Preparatory Physics Course,” *AAPT Announcer* **30**(2), 83 (2000): “Despite the University of Illinois’ relatively high admissions standards, nearly 20 percent of accepted students are inadequately prepared to pass our introductory mechanics course.”
16. A.D. Gavrin & M.E. West, “High School Preparation vs College Expectations: Bridging The Gap,” *AAPT Announcer* **30**(2), 129 (2000).