AMERICAN JOURNAL of PHYSICS

Another reason that physics students learn by rote

Andrew Elby

Citation: Am. J. Phys. **67**, S52 (1999); doi: 10.1119/1.19081
View online: http://dx.doi.org/10.1119/1.19081
View Table of Contents: http://ajp.aapt.org/resource/1/AJPIAS/v67/iS1
Published by the American Association of Physics Teachers

Another reason that physics students learn by rote

Andrew Elby
Physics Department, University of Maryland at College Park, College Park, Maryland 20472-4111 and Thomas Jefferson High School for Science and Technology, 6560 Braddock Road, Alexandria, Virginia 22312

(Received 9 February 1999; accepted 14 May 1999)

Using written questionnaires, I surveyed introductory physics students about how they study and about how they would advise a hypothetical student to study if she were trying to learn physics deeply with no grade pressure. The survey teases apart students' ''epistemological'' beliefs about learning and understanding physics from their more course-specific beliefs about how to earn high grades. The results indicate that students perceive ''trying to understand physics well'' to be a significantly different activity from ''trying to do well in the course.''

I. INTRODUCTION

This article explores why physics students, even those who work hard, often study in ways considered unproductive by physicists.[1] Despite the repeated pleas of their instructors, many students memorize formulas and problem-solving algorithms, instead of trying to develop a deeper conceptual understanding.

Previous research has uncovered one of the reasons for this. Sometimes, rote-based study habits stem from naive *epistemological* beliefs—beliefs about the nature of physics knowledge and learning.[2,3] For instance, as Hammer[4] discusses, some epistemologically naive students think that physics knowledge consists of weakly-connected pieces of information. These students may believe that knowing facts, formulas, and algorithms constitutes a full understanding of the material. When told that a deep understanding is important, the student might not understand what that means. By contrast, more sophisticated students conceive of physics knowledge as a unified, coherent, richly-interconnected whole. These students know that rote learning cannot lead to real understanding.

Although epistemological beliefs explain many aspects of students' study behavior, they do not tell the whole story. In this study, I try to tease apart students' epistemological beliefs from their more course-specific beliefs about getting good grades. My questionnaire focuses on the differences between how physics students study and how they would advise a hypothetical student to study if she were trying to learn physics deeply, with no grade pressure. Students' advice to the hypothetical student reflects their epistemological beliefs about what it means to learn and understand physics.[5] By contrast, their own self-reported study habits reflect a combination of habits, epistemological beliefs, and course-specific beliefs about how to get high grades.

The results indicate that most students perceive learning physics deeply to be a significantly different activity from trying to do well in the course. Specifically, students report spending more time focusing on formulas and practice problems and less time focusing on concepts and real-life examples than they would spend if grades didn't matter. In this paper, I use the word ''distortion'' to denote these differences between the student's self-reported behavior and the behavior they suggest to the hypothetical student who cares only about understanding. Most students who substantially distort their study habits believe that failure to do so would result in lower grades. Furthermore, students' grades do not correlate with the extent of these study-habit distortions; high- and low-achievers all ''play the game.''

After describing my methodology and presenting these results in detail, I will discuss why students (reportedly) distort their study habits.[6]

II. METHODOLOGY

A. Overview of study

In the summer and fall of 1996, I surveyed 106 introductory college physics students (mean age = 22, female = 37%) near the San Francisco Bay. Most of the students (98) were drawn from six different community colleges. At four of the colleges, students were taking first-semester physics; at one college, students were in second-semester physics; and at one college, they were in third-semester physics. The remaining eight students were in a first-semester summer-school course at a research university, a class that enrolls many community college students. Participation was voluntary, and subjects were paid $3. They were assured that their instructors would not see their responses. The survey was administered during the second half of the course, after students had taken at least one midterm.

The written questionnaire, refined after a 1995–96 pilot study on ten university students and nine high school students, asks subjects how they allocate their study time between concepts, formulas, practice problems, and real-life examples.[7] For instance, the survey asks,

> When you study for a test, what best characterizes your attitude towards becoming very familiar with the formulas (equations)?
>
> (a) Since they're not really what's tested, they're not very important, worth under 5% of my study time.
> (b) They are a little important, but not nearly as important as certain other things (such as the problem-solving techniques or the qualitative concepts). Worth between 5% and 10% of my study time.
> (c) Being very familiar with the formulas is fairly important, worth 10% to 20% of my study time.
> (d) Being very familiar with the formulas is quite important, worth 20% to 30% of my study time.
> (e) Being very familiar with the formulas is very im-

portant, worth 30% to 40% of my study time.
(f) Being very familiar with the formulas is essential, worth over 40% of my study time.

The survey asks essentially the same question about concepts, real-life examples, and practice problems, with the same options (a) through (f):

> Some qualitative concepts you may have covered in this course include the tendency of objects to continue moving in a straight line at constant speed unless a push or pull changes the motion; and the idea that when I push on a desk, the desk automatically pushes back on me. When you study for a test, what best characterizes your attitude toward understanding the qualitative concepts?

> In lectures and textbooks, you often see examples of physics concepts applied to real-life situations. For instance, many textbooks describe how a spinning ice skater increases her rate of rotation by pulling in her arms, and explain this phenomenon in terms of angular momentum conservation and rotational inertia. When you study for a test, what best characterizes your attitude toward understanding real-life applications of physics such as the spinning ice skater?

> When studying, some students like to do extra practice problems besides the homework problems. What's your attitude toward doing extra practice problems?

In addition, the survey has students explain their preferences by describing the advantages and disadvantages of studying in different ways and by answering focused questions about their study habits. I lack the space in this short paper to analyze the results of this written data.

The survey then asks subjects to imagine

> Diana, a student just like you, with the same abilities, background knowledge, and time constraints.

> Diana's grade in the course doesn't matter; in fact, she's taking the course pass–fail. So, she does not need to worry about grades. *Her goal is simply to understand physics more deeply*...

The questionnaire asks how Diana should allocate her study time between concepts, formulas, practice problems, and real-life examples, again using the six choices listed above. Respondents also explain why Diana should study in this way.

Although the above questions briefly define ''concepts,'' ''real-life examples,'' and ''practice problems,'' different subjects undoubtedly interpreted those categories in slightly different ways. My study, however, focuses on the extent of the *discrepancy* between how a student studies and how she would have Diana study. For this reason, small disagreements about the meaning of ''concepts'' do not invalidate my results, as long as the subject has the *same* definition in mind when describing her own study habits and Diana's study habits.

B. Interpretation of survey responses

In this subsection, I outline what kinds of beliefs are probed by the two halves of the survey.

We cannot conclude that students allocate their time as they specify. More likely, students' self reports reflect a combination of their actual behavior and their perceptions about what's important to study. Since my paper is largely about students' perceptions, this apparent methodological flaw doesn't invalidate the results.

Students' written explanations for their study-time allocations indicate a combination of epistemological and practical concerns.[8] Some typical examples include,

> *The practice problems help [you] to learn how to apply the formulas and concepts that will appear on the test which will affect your grade.*

> *If I can understand the theory behind the concept then the formulas and practice problems become much easier...I enjoy reading about the historical and real-life examples, but, when pressed for time, I usually concentrate on what will get me the grade.*

> *Concepts are the least difficult to understand. Actual problems and how they are solved are typical of exam questions.*

These and other responses indicate that students' self-reported study habits reflect a combination of epistemological beliefs (e.g., ''concepts are easy,'' or ''practice problems help you understand the formulas'') and partially nonepistemological beliefs about the exams (e.g., studying historical and real-life examples will not be rewarded, and formulas will appear on the test).

By contrast, the second half of the survey tries to tease out students' epistemological beliefs about learning and understanding physics. Their written responses confirm that epistemology, unsullied by grade consciousness, drives their study suggestions for Diana:

> *If [Diana] just wants to understand physics, she'll learn the qualitative concepts so she can understand real life problems.*

> *The practice problems won't do her as much good as studying the real life examples and the qualitative concepts which in part would lead her to a deeper understanding.*

> *Knowing practical applications of physics can be more important than just a grade, so she should study the formulas and variables more (sic).*

Conceivably, the structure of the survey invites students who previously equated ''understanding physics'' with ''getting a good grade'' to recognize and even exaggerate the difference. Furthermore, to preserve self-esteem in the face of poor grades, some students may latch onto the distinction. This effect could partially explain why students report distorting their study habits so much. But it does not explain why students systematically distort their study habits *in certain directions*. Also, the fact that high-achievers and low-achievers distort their study habits *equally* (see Sec. III B) suggests that the ''self-esteem'' effect is not too important.

III. RESULTS

In this section, I'll present the major results. Students systematically ''distort'' their study habits. They spend more time focusing on formulas and practice problems and less time focusing on concepts and real-life examples than they would have Diana spend. Most students who substantially distort their study habits believe that failure to do so would result in lower grades. Another large set of students believes that a deep understanding can lead to good grades, but that a more rote understanding can also lead to good grades.

Table I. Students' study-time allocations for themselves and for Diana. $N = 106$.

Category	Average bin student reports for self	Average bin student chooses for Diana	Difference
Concepts	4.29	4.78	-0.49^{a}
Formulas	4.53	3.84	0.69^{a}
Real-life examples	3.34	4.51	-1.17^{a}
Practice problems	3.44	3.25	0.19

[a]Statistically significant ($p<0.01$).

A. Patterns of distortion

Recall the six ''bins'' students used to express the percentage of time they spend, or would have Diana spend, studying a given category (concepts, formulas, real-life examples, or practice problems):

(1) Under 5%
(2) 5% to 10%
(3) 10% to 20%
(4) 20% to 30%
(5) 30% to 40%
(6) Over 40%

For each category, Table I shows the average bin that students chose to describe their own study habits, and then the average bin they chose to describe how they would have Diana study. The last column shows the difference between the other two columns. Because self-reports are often unreliable, we cannot map bin selections onto precise time-allocation percentages. Rather, we should view the ''difference'' column as a rough indicator of the perceived *difference* between what it takes to do well and what it takes to achieve a deeper understanding. Asterisks indicate statistical significance.

Students report spending more time on quantitative categories such as formulas and practice problems, and less time on qualitative categories such as concepts and real-life examples, than they would have Diana spend. To a large extent, these distortions stem from their views about exams. When asked how well Diana would do in the course, as compared to the student herself, many students wrote comments such as,

> *Our grades are based on tests which ask us formulas, etc., that Diana may spend less time studying than us.*

> *Because [Diana] is not familiar with practice problems and formulas, she will not use them effectively or quickly enough to be able to complete the exam on time.*

> *She didn't get used to the problems which are similar to the test. She may miss calculations.*

> *Spending more time on real-life situations instead of ''ideal'' testable questions, and reading supplementary materials rather than concentrating on formulas, will make her a little less prepared for the tests.*

B. Extent of the distortions

To make a rough estimate of the total percentage by which a student reportedly distorts her study behavior, we can analyze the data as follows. First, map bins onto percentages. So, bin 1 (0%–5%) corresponds to 2.5%, bin 3 (10%–20%) corresponds to 15%, and so on. (Bin 6, ''over 40%,'' got mapped to 45%, introducing a ''ceiling effect'' discussed below.) Next, calculate the student's concepts distortion percentage—the difference between the percentage of time she reportedly spends on concepts and the percentage of time she would have Diana spend. Then, add the absolute values of her distortion percentages for concepts, formulas, real-life examples, and practice problems. Finally, divide by 2, to avoid double counting. This gives the *total distortion percentage*—the percentage of a student's study time that she reportedly spends differently from the way she would have Diana study.

Figure 1 shows the distribution of total distortion percentages for the students in this study.[9] The median is 25%. For the middle half of students (25th to 75th percentile in this distribution), the distortions ranged from 19% to 35%. Although students in different classes report distorting their study habits by different amounts, my sample size is too small to conclude that these differences are statistically significant.

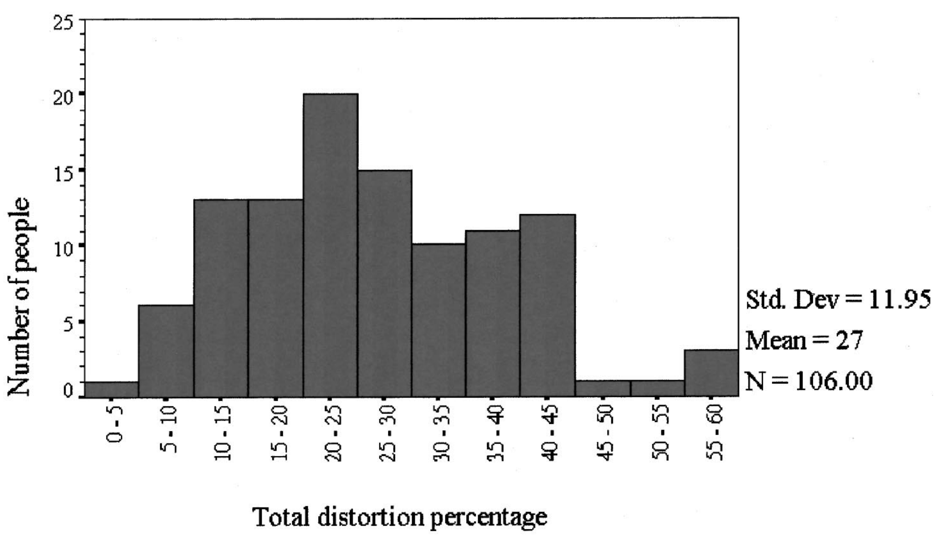

Fig. 1. Distribution of total distortion percentages. A student's ''total distortion percentage'' quantifies the difference between her own study time allocations and the allocations she recommends to a hypothetical student who is pursuing a deep understanding of physics, with no grade pressure.

Table II. How well would Diana do, compared to you?

Of the students who report distorting their study habits by less than 20%...	• 30% say Diana would get a higher grade than they would. • 36% say Diana would get about the same grade. • 34% say Diana would get a lower grade than they would.
Of the students who report distorting their study habits by 20% to 35%...	• 35% say Diana would get a higher grade than they would. • 26% say Diana would get about the same grade. • 39% say Diana would get a lower grade than they would.
Of the students who report distorting their study habits by more than 35%...	• 11% say Diana would get a higher grade than they would. • 27% say Diana would get about the same grade. • 62% say Diana would get a lower grade that they would.

Due to the ceiling effect mentioned above, Fig. 1 represents a lower bound on students' total distortion percentages for the following reason. By mapping bin 6 (''over 40%'') onto 45%, I assumed that ''over 40%'' means 40% to 50%. For instance, when a student reported spending 30% to 40% of her time on concepts (bin 5), but recommended that Diana spend over 40% of her time on concepts (bin 6), I calculated a concepts distortion percentage of 10%. However, if ''over 40%'' actually meant 55% or 60%, then my calculated distortion percentage understates the actual distortion. For this reason, Fig. 1 may understate students' total distortion percentages.[10]

Individual students vary greatly in the extent to which they distort their study habits; the standard deviation is 12%. But there is no significant correlation ($r=-0.045$) between performance (as measured by grades) and total distortion percentage. In other words, higher-achievers and lower-achievers report distorting their study habits by about the same amount, on average. These results suggest that most students perceive ''pursuing good grades'' to be a different activity from ''pursuing a deep understanding of physics.''

C. The perceived rewards of distorted study habits

The survey asks students to estimate what grade Diana would get (if she were receiving a letter grade), assuming she completes the assignments ''as dutifully as you do.'' Specifically, students indicate whether they think Diana would receive a higher grade, a lower grade, or about the same grade as the student herself receives. Table II summarizes the results.

Of the students who report distorting their study habits by less than 20%, only a third think that Diana would do worse than they would. By contrast, of the students who report distorting their study habits by over 35%, nearly two-thirds think that Diana would do worse. So, the more severely a student distorts his study behavior, the more likely he is to view these distortions as necessary for achieving top grades.

Nonetheless, a substantial number of students—27% of the total—say that Diana would outperform them. This seems mysterious; if Diana's study habits lead to better grades, then why not use her strategies? Fortunately, students' written responses help to clear up the mystery. Many of the students who think Diana would do better attribute the difference to test anxiety:

> *When taking tests, [Diana] wouldn't be so anxious as somebody worrying if they get all the problems correct, so she wouldn't be too pressured, and relax.*

> *Diana would do better than me because the pressure of getting a good grade won't matter for her so she can relax a little more than me...*

> *By not worrying about the grade, it can sometimes help [Diana] focus better than studying and worrying about what kind of a grade you get.*

Another reason students might ''overemphasize'' formulas and problem-solving algorithms, even though they think Diana would match or beat their performance, is habit. For many students, rote learning strategies become deeply ingrained in middle school and high school. Some students may feel unable or unwilling to change their habits substantially. Unfortunately, my data neither support nor refute this hypothesis; further research is needed.

Encouragingly, a few students who said Diana would do better indicate that striving for understanding may be the best way to go:

> *Since [Diana] spent her time furthering her understanding of physics and I spent my time solving page after page of problems, she probably would wiz through the test and I would get hung-up and struggle with concepts.*

Also, a few students wrote that Diana's superior understanding of the material would lead to better grades in the long run, although in the short run she might have difficulties.

Now I will discuss the students who indicated that they and Diana would get approximately the same grade. As Table II shows, many of these students distort their study habits minimally. Predictably, almost all of these minimal-distorters say that they and Diana would earn the same grade simply because they and Diana study in similar ways. More interesting insights come from the students who distort their study habits by more than 20%, but still think Diana would do as well as they would:

> *[Diana] would probably get the same grade but she would leave the class with a much better understanding of physics. There is a difference between memorizing the info for an exam and learning the info. I tend to memorize, simply to get through the exam.*

> *[Diana] would have a good understanding of the concepts, and a little formula use; while I have a good understanding of formula use and a little understanding of concepts.*

Apparently, many students view acquiring a deep understanding of physics as a sufficient but not necessary condition for doing well on tests.

D. Summary

Most students report studying much differently from the way they would advise someone to study in pursuit of deep understanding, because they perceive that ''distorted'' study habits lead to better—or at least comparable—grades. High-achieving and low-achieving students distort their study habits equally, on average. Students spend more time focusing on quantitative activities involving formulas and practice problems, and less time focusing on qualitative activities involving concepts and real-life examples, than they would have Diana spend.

These results do not contradict earlier studies pointing towards the importance of epistemological beliefs.[2,4,11] In fact, another paper based on this data shows that students have a wide range of epistemological beliefs about how Diana should study, and that students' grades correlate strongly with these beliefs.[12] But here, my point is that students spend disproportionate time focusing on formulas and problem-solving algorithms, even when they ''know better,'' partly because they believe that exams reward this behavior.

IV. WHY DO STUDENTS DISTORT THEIR STUDY HABITS? SOME SPECULATIONS

Are students correct in their perception that physics exams reward—or at least, fail to punish—''distorted'' study habits? David Hammer[11] describes a student (''Ellen'') who started off the semester pursuing a conceptual understanding. But she quickly became overwhelmed by the pace of the course, and reverted to rote learning in order to get through the assignments and exams. She earned a high B. In traditionally-taught courses, Ellen's experience may be common.

In this study, however, I administered most of the surveys to classes taught by professors involved with the ''TYC21'' (an NSF-funded community college coalition) reform effort. Even those students report significantly distorting their study habits. So, we cannot attribute distorted study habits entirely to the traditional teaching styles characteristic of many introductory physics courses. Something more subtle must be going on. In the rest of this section, I will speculate about why students distort their study habits.

As Schoenfeld[13] and others report, secondary school often rewards rote understanding. Consequently, many college (and high school) physics students enter the classroom with the deeply-entrenched view, supported by years of experience, that rote learning will be rewarded. It would be strange for these students to abandon these long-held beliefs solely because an instructor tells them to. Furthermore, the first few graded assignments that physics students typically encounter are homework problems selected from the textbook. A student can approach these problems by: (i) struggling to obtain a real understanding, *or* (ii) scanning the textbook for relevant formulas and problem-solving algorithms. Since (i) and (ii) often lead to similar homework grades, students who use (ii) get reinforced in their belief that rote study habits will be rewarded. If a student's prior and current experiences point towards the effectiveness of rote learning, he or she is perfectly rational to disbelieve the instructor's claim that only deep understanding will be rewarded.

Along the same lines, some introductory physics exam questions can be solved by rote application of problem-solving algorithms. Of course, a deep understanding of physics also ''works.'' [14] But many students take home the lesson that rote understanding works well enough. To avoid this pitfall, many instructors put especially challenging problems on exams, problems harder than those encountered on the homework. When students flub these questions, do they attribute their troubles to the inadequacy of rote understanding? If so, then the test, though demoralizing in the short term, has served a purpose. But many students instead take home the lesson that the test was unfairly difficult or that they're just not good at physics.[15] The test does not necessarily affect their attitude toward rote learning.

To counter these problems, instructors might try assigning more conceptual, less ''rote-able'' homework problems (cf. The University of Washington tutorial homework[16]); giving mini-quizzes very early in the course that exemplify the kind of conceptual understanding needed to succeed; and writing ''medium-difficulty'' test questions that cannot be solved by rote, but which nonetheless strike students as doable, had they studied differently. Further research is needed to determine if these techniques lead to changes in students' study habits.

V. CONCLUSION

Some previous work about students' study habits has focused on their epistemological beliefs about the nature of physics knowledge.[4] Those studies show that some students learn by rote partly because they have a naive conception of what it means to understand physics. In this study, however, I focused on another cause of these study habits. Students perceive ''trying to understand physics deeply'' to be a different activity from ''pursuing good grades.'' Specifically, students study much differently from the way they'd advise someone to study in pursuit of deep understanding. They spend extra time focusing on formulas and practice problems, at the expense of concepts and real-life examples. Many students believe that a deep understanding is not sufficient, or at least not necessary, to obtain high grades.

Instead of blaming students or instructors, I speculate that we should view this phenomenon as arising from an interaction between the habits and beliefs students bring to their introductory college physics classes and their initial experiences in those classes.

This work also has implications for instructors and researchers who use the Maryland Physics Expectations Survey (MPEX) or similar questionnaires to investigate their students' beliefs.[17] By design, MPEX probes a combination of students' *epistemological* beliefs about learning/understanding physics and students' *expectations* about their physics course. This paper shows that students' expectations about how to do well are often out of sync with their epistemological beliefs. Failure to take this distinction into account could lead to overly simplistic interpretations of MPEX results.

ACKNOWLEDGMENTS

I'd like to thank Bruce Birkett, Andy diSessa, David Hammer, Bruce Sherin, Jason Zimba, and an anonymous referee for their helpful comments.

[1] The existence of this problem is discussed in L. C. McDermott, ''What we teach and what is learned—Closing the gap,'' Am. J. Phys. **59**, 301–315 (1991).

[2] M. Schommer, ''Effects of beliefs about the nature of knowledge on comprehension,'' J. Ed. Psych. **82** (3), 406–411 (1990).

[3]B. Eylon and F. Reif, ''Effects of knowledge organization on task performance,'' Cognit. Instr. **1** (1), 5–44 (1984).
[4]D. Hammer, ''Epistemological beliefs in introductory physics,'' Cognit. Instr. **12** (2), 151–183 (1994).
[5]On surveys, students' responses also reflect how they think they are *supposed* to answer.
[6]This research also led to results, reported elsewhere, concerning the correlations between epistemological beliefs, self-reported study habits, and academic performance. See A. Elby, ''Why do epistemologically sophisticated students perform better in physics classes?,'' unpublished manuscript.
[7]These categories emerged from examining popular textbooks. The pilot version of the questionnaire contained a fifth category, ''historical sketches,'' but it was eliminated, because almost all the pilot-study subjects indicated that they spend negligible time on that category. Subjects had the opportunity to write in other categories, but few did. The pilot study led to the hypothesis that students ''distort'' their study habits towards formulas and away from concepts.
[8]A careful analysis of students' written responses supports these conclusions.
[9]Before calculating these distortion percentages, I normalized Diana's time allocations, which originally added up to 109% on average. (By contrast, students' time-allocation percentages for themselves summed to approximately 100% on average.) Figure 1 is based on this normalized data. It turns out, however, that the distribution of total distortion percentages comes out nearly the same whether or not the time-allocation data is normalized. With normalization, the average total distortion percentage was 26.7 ± 11.95. Without normalization, it was 27.3 ± 12.81. In both cases, the distribution has approximately the same shape.
[10]The fact that nearly 40% of students recommended that Diana spend ''over 40%'' of her time on concepts, and the fact that time allocations for Diana added up to 109% on average, *may* indicate that ''over 40%'' often meant over 50%. But nothing in my analysis rides on this speculation.
[11]D. Hammer, ''Two approaches to learning physics,'' Phys. Teach. **27** (12), 664–670 (1989).
[12]This research also led to results, reported elsewhere, concerning the correlations between epistemological beliefs, self-reported study habits, and academic performance. See A. Elby, ''Why do epistemologically sophisticated students perform better in physics classes?,'' unpublished manuscript.
[13]A. Schoenfeld, ''When good teaching leads to bad results: the disasters of well taught mathematics classes,'' Educat. Psycholog. **23**, 145–166 (1989).
[14]Although, as Hammer's[11] ''Ellen'' demonstrates, the strategy of trying to *obtain* a deep understanding might not be viable for all students in fast-paced courses.
[15]See E. Seymour and N. M. Hewitt, *Talking about Leaving: Why Undergraduates Leave the Sciences* (Westview, 1997). They show that men disproportionately attribute poor performance to the unfairness of the test and instructor, while women disproportionately attribute poor performance to their own lack of ability.
[16]L. C. McDermott, P. S. Shaffer, and the Physics Education Research Group, *Tutorials in Introductory Physics: Homework* (Prentice–Hall, Upper Saddle River, NJ, 1998).
[17]E. F. Redish, J. M. Saul, and R. N. Steinberg, ''Student expectations in introductory physics,'' Am. J. Phys. **66**, 212–224 (1998).

It is amusing the way your best-laid plans go wrong in dealing with a class or an audience. An examination often turns into an examination of the teacher's ability to ask questions clearly.

You never can tell what you have said or done till you have seen it reflected in other people's minds.

Robert Frost, in ''Education by Presence,'' an interview with Frost published in the *Christian Science Monitor*, December 24, 1925. Reprinted in *Robert Frost, Poetry and Prose*, edited by E. C. Lathem and L. Thompson, Holt, Reinhart and Winston, NY.