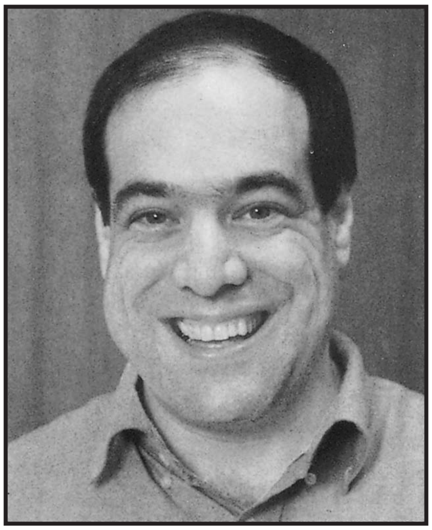
Promoting Interactivity in Physics Lecture Classes

By David E. Meltzer and Kandiah Manivannan



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Several innovative methods directed toward improving physics instruction in the introductory courses (both algebra- and calculus-based) have been developed recently. These include microcomputer-based laboratories,[1] integrated lab/lecture "studio" setups,[2] computerized animations and simulations employed in lectures,[3] and the use of electronic devices for linking students and instructors in the lecture hall.[4] However, the large number of students in introductory physics lecture classes makes it difficult to promote a higher level of student-faculty interaction and active student participation in the learning process during class time. At our institution, faced with limited resources and logistical constraints (e.g., no teaching assistants and little computer hardware), we have been working to develop methods that may be readily applied in the setting of lecture classes with a hundred or more students, and which are not dependent on simultaneous reorganization of the laboratory course. Our techniques are specifically aimed at converting a traditional lecture class, which may have either small or large attendance, into something that is closer in spirit to a seminar or a tutorial. We present here a number of the methods that we have been using and some of the thinking that underlies their development.

The Goal

The traditional lecture format consists of a rapid-fire presentation of ideas with little time or opportunity allowed for students to grapple with and comprehend concepts during class time. The detailed—and rather complex—thought processes that are required to master the key physical concepts tend to be glossed over or overlooked.[5,6] Instead, students become adept at recognizing certain problem types and patterns, and matching the pattern to an appropriate equation that may yield a numerical solution.[7] Studies have documented that, for instance, basic concepts in Newtonian mechanics are not learned very well even by most students who obtain good grades in traditional courses.[8,9]

We aim to *require* students to think about, discuss, work through, and solve problems *during class time* that bear directly on key conceptual issues.[10] (One consequence of this is a reduction in the sheer quantity of topics that may be presented during class.) The instructor plays more the role of a guide who promotes thinking and questioning by leading and focusing the discussion. (Quite similar methods have been pioneered during the past several years by Eric Mazur at Harvard University.[11]) We have in mind the "athletics instruction" paradigm: the "coach" doesn't just lecture and draw diagrams, but offers instantaneous critiques and feedback as the "player" attempts to perform the desired skill.

Methods Used

We utilize techniques for acquiring immediate feedback from all of the students in the class. Through these methods, the instructor is transformed from a "provider of information" into a tutorial leader who is constantly interacting with students, asking questions, hinting at answers, and helping students to move forward in their understanding. There are several interconnected phases in the instructional process, not all of which necessarily take place on the same day. The majority of class time is occupied by students working through conceptual questions and numerical problems, either with each other or in a constant back-and-forth dialogue with the instructor. The central elements of the process are as follows:

I. De-emphasis of Formal Lecture

In our large lecture classes we do not generally deliver a formal lecture in the traditional manner. Instead, we introduce concepts and solve sample problems for several minutes, at which point we pause and present either a question or a problem for the students to work on and discuss with each other. Although we might present an overview lecture in which the major ideas in a chapter are introduced and their interconnections sketched out, we would then return to these concepts one by one for approximately five to 15 minutes each.

II. Group Problem Solving

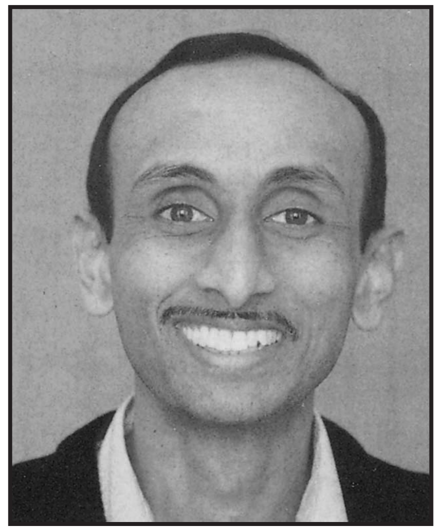
We give students time to work together on problems, typically in groups of two, three, or four neighboring students, and these groups are often encouraged to confer with each other. As the students discuss and work through these problems, the instructor frequently circulates throughout the room examining students' work when they indicate that they have a result and offering assistance to those who request it. Periodically, the instructor may go to the board and offer hints and partial solutions to the whole class as they continue to work. Then, when it appears that the majority of the class is well on the way to solving the problem, the instructor will often go to the board and sketch the solution, addressing aspects of the problem that proved particularly troublesome.

III. Use of "Flash Cards"

Each of our students has a set of six cards ($8\frac{1}{2} \times 5\frac{1}{2}$ in) labeled A, B, C, D, E, and F that are used to signal the instructor their answers to questions. Multiple-choice questions related to a particular concept are presented, either by overhead projection or written on the board. These questions usually precipitate lively class discussion regarding the different choices. Students within a group will debate with each other; sometimes one group challenges another group's decision. After a time of thought and discussion, students are asked to give a response by holding up one of their flash cards. (The final multiple-choice option may be "Don't Know" or "Not Sure" to encourage all students to participate.)

We have used the cards in three different ways: (1) all students hold up their flash cards simultaneously (this method best preserves the anonymity of the individual responses); (2) students hold up their cards as soon as they think they have the answer; (3) all "A" responses are solicited, then all "B's," and so on (omitting the "Don't Know" option). The instructor surveys the flash cards and reports the breakdown of responses. If there is substantial support for two or more choices, students are encouraged to give arguments in favor of their response; this frequently leads to further discussion and debate. We try to use flash-card questions very frequently, sometimes as many as ten times in a single class period.

Flash-Card Questions. Questions employed with the flash cards emphasize qualitative and proportional reasoning, solution strategies for problems (such as free-body diagrams), order-of-magnitude estimates, and vector concepts of magnitude and direction. (Many such examples are in the Workbook by Reif.[12]) Specific quantitative responses are de-emphasized, but are still solicited to culminate the analysis of a particular problem. We stress questions such as: "Is quantity *A* greater than, less than, or equal to zero? Greater than, less than, or equal to quantity *B*?" "If *A* is doubled, would *B* be doubled, quadrupled, or unchanged?" "Does vector *C* point north, south, east, or west? Is its magnitude closer to 10, 100, 1000, or 10^6?" The challenge for the student thus becomes one of determining which parameter or relationship is applicable to a particular question, and understanding its meaning, in contrast to simple numerical substitution or algebraic manipulation. (We sometimes have students practice with straightforward "plug-in" exercises as preparation for the more challenging qualitative questions.)



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In addition to preparing multiple-choice responses in advance, we have also allowed them to develop in tandem with class discussions. Students are asked to propose various answer options, and then the class "votes" on the options using the flash cards.

Flash-Card Feedback. Flash-card responses provide feedback to the instructor on two key parameters: (1) student misconceptions regarding the topic under discussion, and (2) pace of student understanding in the class as a whole. The instructor gets some feel for the degree of student comprehension by how quickly and confidently they are able to show their cards. Flash-card responses also offer students a means of testing the level of their understanding of the topic under discussion. Moreover, students see that others hold the same misconceptions. If the number of incorrect responses is high—for example, 30% or more—the instructor takes additional time to discuss that particular question before moving on.

For instance, after introducing the definition of acceleration, and discussing examples, the following question (taken from a widely used test bank[13]) was asked: *A ball is thrown vertically upward from the surface of the Earth. Consider the following quantities: (1) the speed of the ball; (2) the velocity of the ball; (3) the acceleration of the ball. Which of these is (are) zero when the ball has reached the maximum height? (A) 1 only; (B) 2 only; (C) 1 and 2; (D) 1 and 3; (E) 1, 2, and 3.* There were 60 students in the class; the numbers of students supporting each response were 0, 0, 15, 20, and 25, respectively. A spirited and intense discussion among the students followed (with guidance from the instructor), and continued for over 20 minutes. (Flash cards may also be used to gauge improvement in student understanding that results from class discussion.)

Sample Problem. It is possible to take a fairly complicated problem, involving several different concepts, and break it down into conceptual elements. We work through the problem piece by piece, with constant interaction and feedback from the students through the use of the flash cards.

In the Sample Problem given here, the essential steps leading to the solution are dealt with in questions 1 through 8. (Each successive question is presented only after the preceding one has been answered and discussed.) After the class completes these successfully, they proceed to the quantitative phase in questions 9 and 10. In question 9, the instructor will first point to one of the cells in the table—for instance, the cell referring to "Weight force/*x* direction"—and ask the class to hold up the flash-card letter of the appropriate response. In this way, all the cells in the table will be filled in, one by one. Finally, students may be asked to complete the problem by finding the answer to question 10 and checking it with those seated next to them, or with other student groups.

Sample Problem

A 25.0-kg block has been sliding on a frictionless, horizontal ice surface at 2.00 m/s. Suddenly it encounters a large rough patch where the coefficient of kinetic friction is 0.05. How far does the block travel on this rough surface? *[Questions 1 through 10 refer to the motion on the rough surface.]*

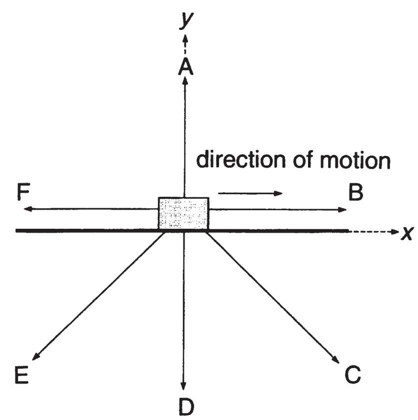


Fig. 1.

1. How many *different* forces are now acting on the block? (Ignore air resistance.)
   A. 0 B. 1 C. 2 D. 3 ← E. 4 F. 5

2. What is the direction of the weight force? *(See Fig. 1.)*
   A. B. C. D. ← E. F.

3. What is the direction of the normal force?
   A. ← B. C. D. E. F.

4. What is the direction of the frictional force?
   A. B. C. D. E. F. ←

5. Is the block accelerating?
   A. Yes ←
   B. No
   C. Not enough information

6. What is the acceleration in the *y* direction?
   A. Greater than zero
   B. Less than zero
   C. Equal to zero ←
   D. Not enough information

7. What is the acceleration in the *x* direction?
   A. Greater than zero
   B. Less than zero ←
   C. Equal to zero
   D. Not enough information

8. How many forces are directly causing the acceleration in the *x* direction?
   A. 0 B. 1 ← C. 2 D. 3 E. 4 F. 5

9. Put the appropriate letters in each box of the table:

	x direction	*y* direction
Weight Force	*[C]*	*[B]*
Normal Force	*[C]*	*[A]*
Friction Force	*[D]*	*[C]*
Total	*[F]*	*[C]*

[Correct answer options are indicated by letters in brackets.]

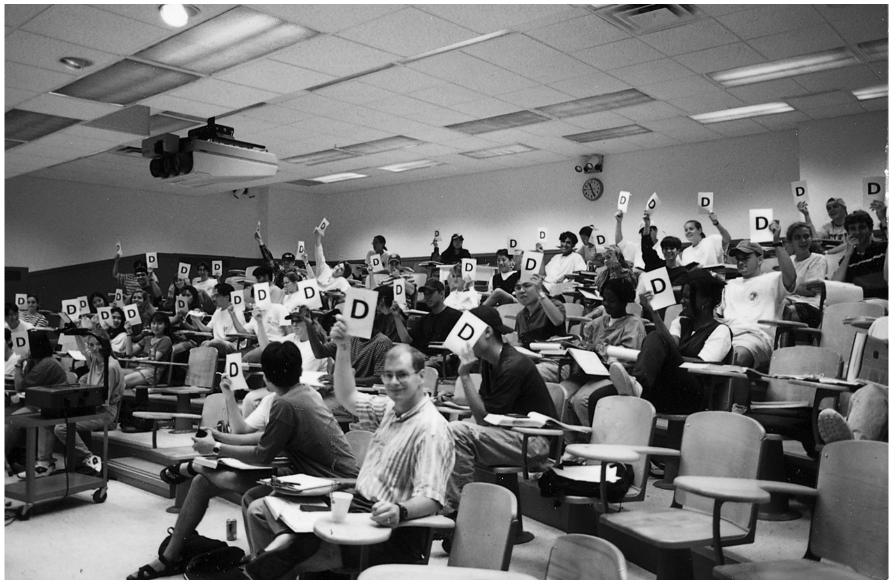
A. + 245 N
B. − 245 N
C. 0 N
D. − 12.25 N
E. + 12.25 N
F. ma_x

10. Find the *x* component of the acceleration, and use it to determine the distance traveled. *[− 0.49 m/s^2; 4.08 m]*

IV. Assessment

We encourage students to prepare for, attend, and participate attentively in class by offering frequent in-class assessment measures that contribute to students' overall grades. In addition to the traditional exams and quizzes, we have used several methods of having students solve quiz questions by working together in groups. Reference to notes, or to both notes and textbook, may be allowed. Students work in groups of two, three, or four, and groups may be allowed to confer with each other. Individual students may be permitted to "dissent" from a group response, handing in one of their own instead.

"Class Quizzes" are based solely on flash-card responses. If more than 50% of the class gives the correct response, each student in attendance receives credit for a 100% score on that quiz; otherwise, all receive a score of zero. "Group Quizzes" involve written responses that are handed in, with each person in the group getting the same grade. In "Challenge Quizzes," which generally involve more difficult questions, *each student* in a group is required to state how many points (up to 100% of the maximum possible quiz score) they want to "gamble" on their group's written response. Correct responses are awarded the number of points wagered, while incorrect responses result in a *loss* of that same number of points from the students' overall grade. (Typically, weaker students are not willing to put any points at risk.) When we use a multiple-choice format for the quizzes, students are often asked to report their responses by using the flash cards (after the quizzes have been collected). This allows instant feedback and discussion of the quiz problems.



Our Findings

Traditional Lecture Presentation Communicates Little to Students. We have found that many relatively simple concepts that are traditionally "covered" in a few minutes of lecture time turn out to be profoundly confusing to students even after extended thought and discussion. *[Example: The only force (ignoring air resistance) acting on a projectile during its flight is gravity, and the horizontal component of the projectile's acceleration is zero.]* Ideas that instructors may consider too trivial for more than a passing reference have been found to stump many students when they are asked to make use of them in problems. *(Example: Find the total momentum of a pair of objects sitting at rest.)* Results of using the interactive methods suggest that traditional methods of cursory treatment of important concepts during lecture yield little student understanding.

Instructors Must Have a Clear Concept of What They Intend Students to Learn. If the instructor's goal is for students to be trained to recognize certain types of quantitative problems, find the appropriate equation that may be used to solve the problem, and then use it to obtain a correct quantitative answer to a nearly identical problem presented to them—then these interactive methods may not be appropriate. If, however, the goal is for students to obtain a thorough understanding of certain basic concepts so that they may be able to devise novel solution methods for relatively *unfamiliar* problems in a variety of contexts, traditional methods do not appear to be very effective and the interactive methods may hold greater promise.

Outcome of Using Interactive Learning May Depend on Students' Level of Preparation. We have used these techniques both at Southeastern Louisiana University and at the University of Virginia at Charlottesville. The subjective response of the (typically much better prepared) students at UVa was more positive than of those at SLU. There is little doubt that the educational background of the students taking a particular introductory physics course is likely to have a significant effect on the outcome of interactive learning methods.

Students Accustomed to Traditional Methods May Be Suspicious of and Hostile Toward Interactive Learning.[14] Many students are accustomed to educational methods that emphasize memorization and formulaic learning. As a result, a significant number of the students in some of our classes showed a great distaste for—and were even resentful of—the inherent uncertainty and confusion that is an essential phase of the process of actively struggling to master difficult concepts. "Why can't you just tell us the answer?!" was a characteristic remark. Some students commented that the use of the flash cards was "a waste of time."

Interactive Methods Have Little Hope of Success If Used Only in Isolated Situations. Students who are accustomed exclusively to traditional memorization-based methods are unlikely to be receptive to highly interactive, concept-driven learning. Students who have little experience in pursuing *extended, time-consuming thought processes* to master difficult concepts—involving question-and-answer dialogue and discussion—tend to find such processes difficult, distasteful, frustrating, and confusing.

Conclusion

Interactive methods such as those described here focus on the goal of having substantial effective learning take place *during class time*. The objective is to ensure that students do not simply listen passively to the words spoken by the instructor, but that they become intensely involved in learning and applying targeted concepts. The physics lecture as a forum for "covering" large numbers of topics is sacrificed. What takes its place is an environment that becomes an expression of the instructor's skill in guiding and leading students through the complex thought processes required to understand and apply physics concepts. It is intended that these experiences in conceptual learning—particularly those few moments when the students can say, "Aha, *now* I see..."—will form a basis for students' out-of-class study that is at least as effective as the traditional lecture.

Acknowledgment

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