Peer Instruction: Getting Students to Think in Class

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The first time I taught introductory physics, I spent much time preparing lecture notes, which I would then distribute to my students at the end of each lecture. The notes became popular because they were concise and provided a good overview of the much more detailed information in the textbook.

Halfway through the semester, a couple of students asked me to distribute the notes in advance so they would not have to copy down so much and could pay more attention to my lecture. I gladly obliged, and the next time I was teaching the same course, I decided to distribute the collected notes all at once at the beginning of the semester. The unexpected result, however, was that at the end of the semester a number of students complained on their questionnaires that I was lecturing straight out of my lecture notes!

Ah, the ingratitude! I was at first disturbed by this lack of appreciation but have since changed my position. The students had a point: I was indeed lecturing from my lecture notes. If they had read the textbook, they might also have noticed that my lecture notes closely followed the material in the book. Later research showed that my students were deriving little additional benefit from hearing me lecture if they had read my notes beforehand. Had I lectured not on physics but, say, on Shakespeare, I would certainly not spend the lectures reading plays to the students. Instead, I would ask the students to read the plays before coming to lecture and I would use the lecture periods to discuss the plays and deepen the students' understanding of and appreciation for Shakespeare.

Year after year, I had written on the blackboard that pressure is defined as force per unit area—a definition that is printed in the book and in my lecture notes. Year after year the students copied it from the blackboard into their notebooks. What a waste of time, both for the students and the teacher! What inefficiency! And the students and I believed this lecturing constituted 'teaching.' What a fallacy!

In most introductory science courses we require the students to buy textbooks of encyclopedic dimensions and then we use lecture time to present what is printed in the text. At best, the textbook is there to clarify the material introduced in lecture. Small wonder, then, that the attendance at introductory science lectures is relatively low compared to lectures in the humanities. And small wonder that student opinions of introductory science lectures are very poor.

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In these days of overhead projectors, video cassette recorders, multimedia computers, and the world-wide web, books may strike some as outdated teaching aids. Yet the truth is that, at least in introductory science, we have never really used textbooks to their full potential. We write the material on the blackboard and students copy it into their notebooks. If we are lucky they can follow the first fifteen minutes of lecture. If they lose the thread somewhere—and this is bound to happen sooner rather than later—note taking becomes completely blind: "I'll think about it later." Unfortunately the thinking is not always happening, and many students resort to memorization of the equations and algorithms copied in their notebooks. Many bad study habits are a direct result of the lecture system.

The surprising similarity between lecture and sermon suggests that the lecture dates back to quite ancient times. There is no doubt that the lecture system predates the invention of the printing press. After all, before the mechanization of book printing, lectures were the only efficient method to transmit knowledge. The ideas of theologians and scholars were dutifully reproduced by scribes. In the 13th century, as the center of intellectual life moved from courts and monasteries to universities, professional scribes became the principal creators of books. As it had been since the ancient Egyptians, the printed word was the only way to accurately preserve human knowledge. While book printing in Europe dates back to the middle of the fifteenth century, it was not until the middle of the nineteenth century that fast, mechanized book printing turned print into a mass medium. So at least until then, lectures and note-taking were necessary for the transmission of knowledge.

The main reason we are still using this method is habit: we tend to teach the way we were taught. Since my teachers lectured to me, I lectured to my students, and so will they eventually lecture to their students. Yet everyone will agree that for getting information listening is not as efficient as self-paced reading. While listening is largely a passive activity, reading more easily engages the mind and it allows more time for the imagination to explore questions. Besides, an author has more time than a lecturer to choose the best possible wording to convey an idea.

Am I suggesting that we stop teaching altogether? That we simply ask students to read books instead of coming to lecture? Certainly not. What I am suggesting is that in the sciences, as is done in the humanities, the first exposure to new material comes from reading printed material before the lecture period. Lectures can then be used to give students a sense of what is most important in the material they have read, to relate this material to previously studied material, to check conceptual understanding, to paint a broader picture, to relate theories to observations, to provide a different perspective, or even to lecture on points not covered in the reading.

There are a number of problems with this method. First of all, in most large introductory science classes neither teachers nor students expect any preparation using printed material. Students have come to expect what teachers are accustomed to giving: a lecture. It will take a considerable effort to change this deeply ingrained habit. Second, reading a science text book is quite different from reading a novel. Most students at first tend to read their text books too quickly—without pausing or pondering the meaning of what they have just read. Perhaps the method I am advocating will require a change in the way science textbooks are written. Third, if one doesn't lecture during class time, what *does* one do?

During the past five years I have tried to address these problems by radically changing my teaching strategy. First, I assign the students pre-class reading for each lecture period. To make sure the students carry out this important assignment, I begin each and every lecture period with a five-minute mini quiz on the material they have read. I then divide the remainder of the class time into ten- to fifteen-minute long periods, each devoted to one of the main points of the reading. I might begin each such period with a very brief lecture on a point I wish to get across or with a lecture demonstration. This is followed by a conceptual question, which tests the students' understanding of the idea or point presented. I project these multiple-choice questions, which I call *ConcepTests*, onto a screen and give the students one minute to select an answer. Each student individually must commit to an answer—I do not allow the students to speak to each other during this minute. After the students have recorded their answer, I ask them to try to convince their neighbors of their answer. The ensuing discussions are surprisingly animated. After a minute or so, I again ask the students to select an answer (one can use a show of hands, flashcards, scanning forms, or a computerized voting system). The proportion of students who chose the correct answer always increases after the discussion, suggesting that the students are successfully explaining their reasoning, and in the process teaching are each other. If about half the students select the right answer (with the correct reasoning) before discussion, a minute or so of discussion is sufficient to dramatically improve the level of understanding of the class. No lecturer, however engaging and lucid, can achieve this level of involvement and participation simply by speaking.

I have successfully applied this method to large classes of about 250 students. The results are very encouraging. Attendance is high. What is more, attention and student involvement are high. And the answers to the *ConcepTests* provide instant feedback to the teacher; there is never a gulf between the class' understanding and the teacher's expectation. But best of all, testing shows this teaching style engenders a better understanding of the fundamental concepts and discourages a number of bad study habits such as rote memorization and an exclusive focus on problem solving. The students' energy and enthusiasm during the discussions are contagious: once one has experienced it, it is difficult to revert to lecturing to a passive and mostly silent audience.

I now believe the days of straight lecturing in introductory science courses are numbered—we can no longer afford to ignore the inefficiency of the traditional lecture method, regardless of how lucid or inspiring our lectures are. The time has come to offer our students in introductory science classes more than a mere regurgitation of printed material.

SAMPLE LECTURE

As an example of *Peer Instruction*, let's consider a 90-minute lecture on Newton's laws, the outline of which is:

1. Newton's first law
2. Definitions of force and mass
3. Newton's second law
4. Newton's third law

Before coming to class, students are required to read the lecture notes as well as corresponding sections in the textbook. At the beginning of class, they complete the short reading quiz shown in Figure 1. Note that this quiz tests only whether or not the pre-class reading was done; it does not test understanding of the material because doing so would penalize (and therefore discourage) the student who does the reading but is unable to master the concepts from the reading.

Figure 1. Pre-class reading quiz for lecture on particle dynamics.

1. Which of these laws is not one of Newton's?
    1. To every action there is an opposed equal reaction.
    2. *F=ma*.
    3. All objects fall with equal acceleration.
    4. In the absence of a net external force, objects at rest stay at rest and objects in uniform motion stay in uniform motion

2. The law of inertia
    1. is not covered in the reading assignment.
    2. expresses tendency of bodies to maintain their state of motion.
    3. is Newton's third law.

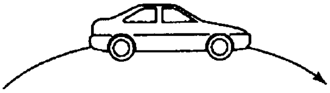
3. "Impulse" is
    1. not covered in the reading assignment.
    2. another name for force.
    3. another name for acceleration.

The correct answers are 1-3, 2-2, 3-1. Response statistics: 1a: 15%, 1b: 2%, 1c: 83%, 1d: 0%, 2a: 1%, 2b: 98%, 2c: 1%, 3a: 82%, 3b: 16%, 3c: 2%. These and subsequent statistics are from a representative semester during which *Peer Instruction* was used.

I use the same lecture notes I used when I taught this material conventionally. I describe the scope of classical mechanics and introduce Newton's first law by writing it on the chalkboard. After introducing the first law, I use a computer animation to show that it is really a statement about reference frames. Next, to firmly establish the relationship between forces and acceleration, I project the *ConcepTest* question shown in Figure 2. The students generally do well on this question, and its main purpose is to bolster their confidence. In any case, I don't dwell too long on this topic as Newton's other two laws generally cause far greater difficulties.

Figure 2. *ConcepTest* on Newton's first law.

A car rounds a curve while maintaining a constant speed.



Is there a net force on the car as it rounds the curve?

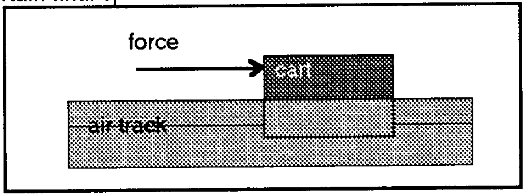
1. No, its speed is constant.
2. Yes.
3. It depends on the sharpness of the curve and the speed of the car.

Choice 2 is correct. Response statistics: 1: 3%, 2: 96%, 3: 1%.

Then I define the concepts of force and mass and formulate Newton's second law. To make sure that the relationship between force, acceleration, and speed is clear, I use the question shown in Figure 3. The statistics under the Figures show how the convince-your-neighbors discussion increases the number of correct responses and bolsters the students' confidence. With nearly 20% of the students

Figure 3. *ConcepTest* on force.

A constant force is exerted on a cart that is initially at rest on an air track. Friction between the cart and track is negligible. The force acts for a short time interval and gives the cart a certain final speed.



To reach the same final speed with a force that is only half as big, the force must be exerted on the cart for a time interval

1. four times as long as
2. twice as long as
3. equal to
4. half as long as
5. a quarter of

that for the stronger force.

Choice 2 is correct. Response statistics before (after) discussion: 1: 16% (5%), 2: 65% (83%), 3: 19% (12%). Confidence before (after) discussion pretty sure 50% (71%), not quite sure: 43% (25%), just guessing: 7% (4%).

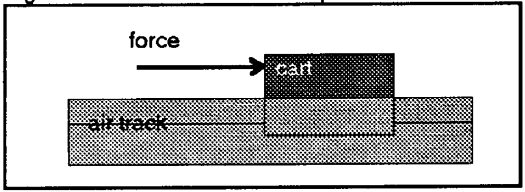
providing wrong answers after the discussion, I would probably spend extra time discussing the correct answer.

An important point in explaining this question is to avoid (at all cost!) using equations. My verbal argument goes as follows: force causes acceleration, which tells how much an object's speed increases in a given interval of time. So if the force is half as large, the acceleration will be half as large. The force thus needs to act for a time interval twice as long to give the cart the same increase in speed.

The next *ConcepTest* (Figure 4) further elaborates on the previous question. Notice how much better he students do this time before the convince-your-neighbors discussion. With 90% providing the right answer before any discussion, there is little room for improvement. Still, the discussion does increase the students' confidence. The percentage of correct answers after discussion is a clear indication that not much further discussion of this question is required.

Figure 4. *ConcepTest* on force.

A constant force is exerted for a short time interval on a cart that is initially at rest on an air track. This force gives the cart a certain final speed.



The same force is exerted for the same length of time on another cart, also initially at rest, that has twice the mass of the first one. The final speed of the heavier cart is

1. one-fourth
2. four times
3. half
4. double
5. the same as

that of the lighter cart.

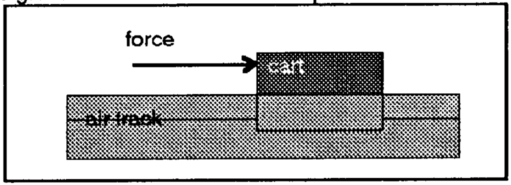
Choice 3 is correct. Response statistics before (after) discussion: 1: 10% (1%), 3: 90% (99%). Confidence: pretty sure: 64% (95%), not quite sure: 34% (4%), just guessing: 2% (1%).

I immediately follow this *ConcepTest* with the one shown in Figure 5. To save time, I do not ask the students to discuss their answers.

With all these questions yielding more than 80% correct responses, I move on to Newton's third law, emphasizing that the two components of a third law force pair never act on the same object. To make this point clear, I discuss the example of a person standing in an elevator. While the normal force exerted by the elevator floor in the person is equal to and opposite the weight of the person when the elevator is at rest, the two are not an action-reaction pair.

Figure 5. *ConcepTest* on force.

A constant force is exerted for a short time interval on a cart that is initially at rest on an air track. This force gives the cart a certain final speed.



Suppose we repeat the experiment, but instead of starting from rest, the cart is already moving in the direction of the force at the moment we begin to apply the force. After we exert the same constant force for the same short time interval, the increase in the cart's speed

1. is equal to two times its initial speed.
2. is equal to the square of its initial speed.
3. is equal to four times its initial speed.
4. is the same as when it started from rest.
5. cannot be determined from the information provided.

Choice 4 is correct. Response statistics: 1: 10%, 2: 3%, 3: 5%, 4: 82%. Confidence: pretty sure: 63%, not quite sure: 35%, just guessing: 2%.

When the elevator is accelerating, these two forces are no longer equal—the difference being responsible for accelerating the person. I make free-body diagrams for the person and the elevator and indicate which force pairs are third law pairs. This presentation is followed by a lecture demonstration, immediately after which I confront the students with the classic question in Figure 6. In spite of

Figure 6. ConcepTest on Newton's third law.

A locomotive pulls a series of wagons. Which is the correct analysis of the situation?

1. The train moves forward because the locomotive pulls forward slightly harder on the wagons than the wagons pull backward on the locomotive.

2. Because action always equals reaction, the locomotive cannot pull the wagons—the wagons pull backward just as hard as the locomotive pulls forward, so there is no motion.

3. The locomotive gets the wagons to move by giving them a tug during which the force on the wagons is momentarily greater than the force exerted by the wagons on the locomotive.

4. The locomotive's force on the wagons is as strong as the force of the wagons on the locomotive, but the frictional force on the locomotive is forward and large while the backward frictional force on the wagons is small.

5. The locomotive can pull the wagons forward only if it weighs more than the wagons.

Choice 4 is correct. Response statistics before (after) discussion: 1: 14% (7%), 2: 2% (2%), 4: 74% (86%),5: 9% (5%). Confidence before (after) discussion: pretty sure: 59% (71%), not quite sure: 36% (26%), just guessing: 5% (3%).

the conceptual difficulty of this question, a surprisingly large fraction of the class answer correctly the first time around. This question always raises a large number of questions—it really gets students thinking—and I usually end up spending time after class explaining it a few more times.

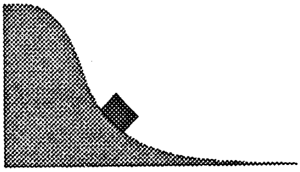
Next, returning to the basic purpose of classical mechanics, I show the dual utility of Newton's second law: given the forces on an object, one can use this law to determine the motion of that object. As examples, I cite the existence of the normal force, the forces on celestial bodies, and so forth.

I finally move to the first force law—that of gravitation. I spend some time making clear the distinction between inertia (an object's tendency to maintain its state of motion) and gravitation (an object's tendency to attract matter): an astronaut on the Moon can easily lift a massive object, but kicking it would hurt as much as it does on Earth.

The last question I use (Figure 7) involves gravitation, but really tests the students' understanding of acceleration. This question offers the opportunity to spiral back and make the connection between the material in previous lectures (kinematics) and that in this lecture. While two thirds of the students provide the right answer, only one third are confident of their answer (the most frequent mistake is to assume that if speed increases, acceleration must increase too).

Figure 7. ConcepTest on gravitation, acceleration, and speed along an incline.

A cart on a roller- coaster rolls down the track shown below. As the cart rolls beyond the point shown, what happens to its speed and acceleration in the direction of motion?



1. Both decrease.
2. The sped decreases, but the acceleration increases.
3. Both remain constant.
4. The speed increases, but acceleration decreases.
5. Both increase.
6. Other.

Choice 4 is correct. Response statistics: 1: 3%, 2: 4%, 3: 8%, 4: 70%, 5: 11%, 6: 4%.
Confidence: pretty sure: 34%, not quite sure: 57%, just guessing: 9%.