PEER INSTRUCTION

Increase student engagement and active participation during class using peer instruction.

Peer instruction involves the following steps:

1 **INSTRUCTOR ASKS CLASS QUESTION**

2 **STUDENTS ANSWER INDIVIDUALLY**

3 **INSTRUCTOR LOOKS AT STUDENT RESPONSES**

4 **DID MAJORITY OF CLASS RESPOND CORRECTLY?**

- a **YES:** Great! Most of the class understands concept. Continue with lecture.
- b **NO**
  - i. Peer instruction: Allow students to discuss and justify their answer to their neighbours
  - ii. Answer editing: Students answer again
  - iii. Instructor looks at student responses
  - iv. Did the majority of class respond correctly?
    - 1 Yes: Great! Most of class understands concept. Explain the correct answer and continue with lecture.
    - 2 No: Repeat process starting at peer instruction, and consider providing hints to help students with choosing the correct answer.

Infographic provided by the SKHS Culture of Learning subcommittee

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Peer instruction: Getting students to think in class

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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.

CP399, *The Changing Role of Physics Departments in Modern Universities*: Proceedings of ICUPE,
edited by E. F. Redish and J. S. Rigden

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.

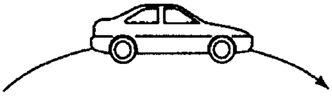
3. "Impulse" is
    1. not covered in the reading assignment.
    2. another name for force.
    3. another name for acceleration.

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?

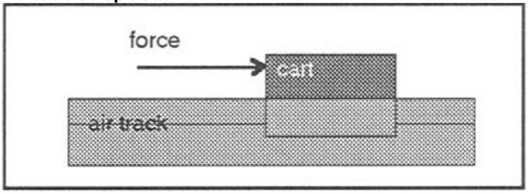
1. No, its speed is constant.
2. Yes.
3. It depends on the sharpness of the curve and the speed of the car.

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%).

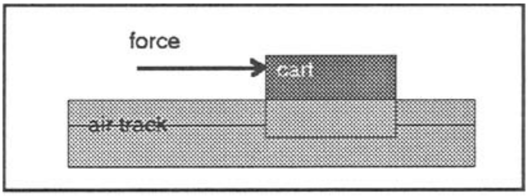
providing wrong answers after the discussion, I would probably spend extra time discussing the correct answer.

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.

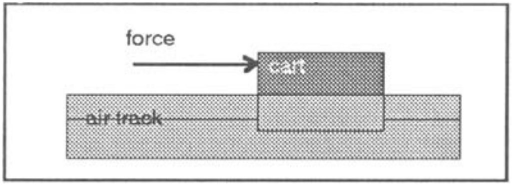
Choice 3 is correct. Response statistics before (after) discussion: 1: 10% (1%), 3: 90% (99%). Confidence: pretty sure: 64% (95%), not quite sure: 34% (4%), just guessing: 2% (1%).

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.

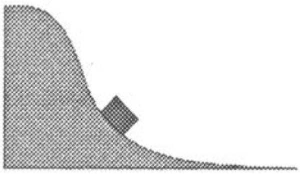
Next, returning to the basic purpose of classical mechanics, I show the dual utility of Newton's second law: given the forces on an object, one can use this law to determine the motion of that object. As examples, I cite the existence of the normal force, the forces on celestial bodies, and so forth.

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%.

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Peer instruction enhanced meaningful learning: ability to solve novel problems

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Cortright, Ronald N., Heidi L. Collins, and Stephen E. DiCarlo. Peer instruction enhanced meaningful learning: ability to solve novel problems. *Adv Physiol Educ* 29: 107–111, 2005; doi:10.1152/advan.00060.2004.—Students must be able to interpret, relate, and incorporate new information with existing knowledge and apply the new information to solve novel problems. Peer instruction is a cooperative learning technique that promotes critical thinking, problem solving, and decision-making skills. Therefore, we tested the hypothesis that peer instruction enhances meaningful learning or transfer, defined as the student's ability to solve novel problems or the ability to extend what has been learned in one context to new contexts. To test this hypothesis, our undergraduate exercise physiology class of 38 students was randomly divided into two groups: *group A* ($n = 19$) and *group B* ($n = 19$). A randomized crossover design in which students either answered questions individually or during peer instruction was used to control for time and order effects. The first factor that influences meaningful learning is the degree of mastery of the original material. Importantly, peer instruction significantly enhanced mastery of the original material. Furthermore, the student's ability to solve novel problems was significantly enhanced following peer instruction. Thus pausing two to three times during a 50-min class to allow peer instruction enhanced the mastery of the original material and enhanced meaningful learning, i.e., the student's ability to solve novel problems.

active learning; cooperative learning; problem solving skills; knowledge transfer; student attitudes

EMPLOYMENT OPPORTUNITIES IN the future will require greater ability to work together to solve novel problems, because much of the knowledge that will be employed in the students' future careers is not known today and therefore must be learned after graduation (24). Furthermore, not all that is known can be taught in 4 yr and not all that is taught can be learned or remembered. Some of what is taught is erroneous and other material will soon be obsolete (24). Students must be capable of working together, gathering evidence, learning from it, and applying the information to novel situations. Without the proper training of the work force for the future, effects on professional research and development, economy, society, and our standard of living will be detrimental. Therefore, it is in the best interest of the nation to raise the level of education of all its citizens in an effort to meet the demands of a challenging society and remain competitive in the scientific and world arenas. However, much of what we do in classes with large numbers of students conflicts with these goals. These activities do not prepare students for solving novel problems because many of these activities encourage memorization of detailed information. Memorization occurs when the learner makes little or no effort to relate new information to existing knowledge or novel situations. In contrast, meaningful learning (5, 13, 14) occurs when the learner interprets, relates, and incorporates new information with existing knowledge and applies the new information to solve novel problems. Meaningful learning requires multiple opportunities for the student to be actively engaged in the reasoning and application of concepts (5, 13, 14).

Lymna's Think-Pair-Share (11) and Mazur's Peer Instruction (12) provide opportunities for students to be actively engaged in the reasoning and application of concepts (3). Think-Pair-Share occurs two to three times during a lecture when the instructor asks a question or poses a problem. Students spend a minute or two alone thinking about an answer or solution (Think). Subsequently students pair up (Pair) to discuss their answers with each other (Share) (3). Mazur used a very similar approach (12). Two to three times during a lecture the students solve a physics problem, mark down their answer, and rate how confident they feel about the correctness of their answer. For the pair phase, Mazur allows students 1 min to convince their neighbor of their answer. After discussing the problem with classmates, students may revise the answer and again rate their confidence in their second answer. There was a dramatic increase in the confidence level and percentage of correct answers after students discussed the concepts (12).

We recently reported that peer instruction increased medical student performance on quizzes (20). Similarly, we recently reported that collaborative testing, a similar peer instruction procedure, increased medical student performance on quizzes (19) and undergraduate student performance on exams as well as increased student retention of previously learned information (6). Specifically, performances on quizzes and retention of previously learned information were significantly higher when students completed exams in groups than when they completed exams individually. These results document that peer instruction enhances exam performance as well as student retention of previously learned information. Thus peer instruction significantly enhanced mastery of the original material. This is important because the first factor that influences meaningful learning is the degree of mastery of the original material. However, it is unknown if peer instruction enhances meaningful learning. Therefore, we tested the hypothesis that peer instruction enhances mastery of the original material as well as meaningful learning, i.e., the student's ability to solve novel problems.

MATERIALS AND METHODS

Design. All procedures were reviewed and approved by the Intuitional Review Board and informed consent was obtained from all students before beginning the study. We borrowed concepts of the Lymna and Mazur peer instruction activities to promote student

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involvement in the learning process and test the hypothesis that peer instruction enhances mastery of the original material as well as meaningful learning (11, 12). Students were divided by the instructor into two permanent equal groups: *group A* ($n = 19$) and *group B* ($n = 19$). Students from the groups were positioned on opposite sides of an aisle that physically divided the classroom in half. It was important that the groups be heterogeneous: diverse in gender, ethnic background, and academic ability. Heterogeneous grouping typically enhances the likelihood of success and permits students to work constructively with varied individuals who bring different strengths and approaches to tasks. Positive interactions with diverse individuals also prepare students for the real workplace and for society. When a group was involved in peer instruction, the students were positioned in clusters of ~4 students. We wanted to have 3–4 students per cluster because this size is large enough to include students of diverse opinions, experiences, and learning styles to assist with the problem solving. In addition, if a group member is absent, the cluster can continue to function smoothly. A group of four is not so large that a student can "hide"; thus all students must carry the load. Finally we used permanent groups so that the students remained together long enough to establish positive working relationships and to develop team building. Classes consisted of two to three short presentations on key points. Each short presentation was followed by a one-question multiple choice quiz. The questions on the quizzes ranged from simple recall to comprehensive questions. The students from both groups were allowed 1 min to formulate the answer. Subsequently, the students from *group A* only were allowed 1 min to discuss their answers with their peers. This process encouraged critical thinking, problem solving, and decision making skill as well as provided a way to assess the level of understanding. Students from the other group, *group B*, were not allowed to consult with peers. After the first exam, students from *group B* followed the peer instruction procedures when responding to questions, and students from *group A* were not allowed to consult with peers. We analyzed these responses to determine the effectiveness of peer instruction on the student performance on quizzes (mastery of the original material).

For the last third of the course, virtually identical procedures were followed to determine the effect of peer instruction on meaningful learning; however, all of the questions involved novel situations. The students were required to interpret, relate, and incorporate new information with existing knowledge and apply the new information to solve novel problems. Students were not exposed to the novel situation; however, they received the material required to solve the novel problem. We analyzed these responses to determine the effectiveness of peer instruction on meaningful learning (the ability to solve novel problems). All problem-solving questions were prepared by an instructor (S. E. DiCarlo) at a different institution who was not formally active in the class. The questions were developed based on the course outline provided by the class instructor (R. N. Cortright). For examples of the problem-solving questions, readers are referred to two recent publications (4, 16). Figures and questions related to the cardiovascular and respiratory sections were taken from these papers.

Procedures. This peer instruction, active learning technique was implemented during the Exercise Physiology class (EXSS 3805) at East Carolina University (Greenville, NC). The class consisted of 38 students. The course, offered through the Department of Exercise and Sport Science (EXSS) must be completed in the third or fourth year in order for EXSS majors to meet the graduation requirements in: *1*) Physical Activity and Fitness (BS), *2*) Physical Education (BS), *3*) Exercise and Sport Science (BA), or *4*) Exercise Physiology (BA). Students from other basic science departments could also enroll. The class was lecture based, with laboratories scheduled throughout the semester. The peer instruction technique was used for all classes. Each class of 50 min was divided into two to three short presentations of 15 to 20 min each. Each presentation was followed by a one-question multiple choice quiz on the subject discussed. All students were allowed 1 min to think and to record their answers (see below). Subsequently students from one group only were allowed 1 min to discuss their answers with classmates. Students were then allowed to change their first answer if desired, and both answers were recorded. Finally, the instructor and students discussed the answer.

To record the student responses, we included five colored sheets of paper labeled A (red), B (white), C (blue), D (green), and E (yellow) in the students' lecture notes. Students use these colored letters to answer questions during the class (7). For example, students answer the question by holding up the appropriate colored letter. All students hold up their choice of colored letter at the same time. These procedures increase class participation as well as allow us to immediately determine whether students understand a particular concept by observing the sea of colors. If the majority of students answer correctly, we feel comfortable moving on. However, if a significant number of students answer incorrectly, the concept is reviewed. Students enjoy this activity and appreciate the opportunity to assess their own understanding as well as participate in class. Furthermore, students report that these activities help to hold their attention. Finally, we get an immediate idea of student learning and record the responses.

After determining the effect of peer instruction on the mastery of original material, we determined the effect of peer instruction on meaningful learning. A randomized, crossover design was again applied to evaluate performance on problem-solving questions. One novel problem-solving question was introduced to each class. Students were allowed ~10 min to answer each question. Students alternated from peer instruction groups (*group A*) to nonpeer instruction groups (*group B*) every class period. Each student participated in an equal number of questions as *group A* or *group B*. Content area was diverse including metabolism, cardiovascular, and respiratory physiology. All students experienced equal numbers of problem-solving questions from all content areas across the study period. Each problem-solving question was worth two points and assessment of meaningful learning was based on the number of points gained for each individual question when operating as *group A* or *group B* participants.

Analysis. All results are presented as means ± SE. To determine the effect of peer instruction on student performance on multiple choice questions (mastery of original material), we used a Student's paired *t*-test to compare raw scores obtained when all students answered the questions as individuals with raw scores obtained when the students answered the questions in collaboration with others (peer instruction).

To determine the effect of peer instruction on meaningful learning (the ability to solve novel problems) we used a Student's paired *t*-test to compare raw scores on novel problem-solving questions obtained when all students answered the questions as individuals compared with raw scores obtained when the students answered the novel problem-solving questions in collaboration with others (peer instruction). Statistical significance was established a priori as $P < 0.05$.

A questionnaire (Table 1) was used to evaluate the peer instruction procedures. The questionnaire evaluated the goals and objectives, specific procedures, students' attitudes, and personal preferences as well as summary of recommendations. The students completed the evaluation at the end of the course. Results from the questionnaire were analyzed using descriptive statistics and are expressed as means ± SE.

RESULTS

Figure 1 presents the effect of peer instruction on student performance on multiple choice questions (mastery of original material). The daily average number of students who participated in peer instruction (answered questions in clusters) was 16.3 ± 0.2. The daily average number of students who answered questions individually was 17.1 ± 0.4. The students who interacted with their peers and those who did not answered 2–3 questions per class throughout the first two-thirds of the

Table 1. *Student evaluation of peer instruction*

Questions	Results
1. The purpose of and rationale behind the educational process was fully explained.	4.6 ± 0.09
2. The process was not too lengthy or complex in its format.	4.6 ± 0.11
3. An opportunity to assess an individual's understanding through questions and answers was provided.	4.6 ± 0.09
4. Peer instruction increased my confidence.	4.4 ± 0.11
5. Peer instruction allowed me to go beyond my previous level of knowledge.	4.3 ± 0.12
6. Peer instruction facilitated my learning of the material.	4.3 ± 0.11
7. Every member "pulled their weight" (contributed to the learning process).	4.1 ± 0.14
8. The level of discussion during peer instruction was high.	4.4 ± 0.12
9. I appreciated the immediate feedback afforded by peer instruction.	4.6 ± 0.10
10. It was difficult to convince students of correct answers.	3.1 ± 0.20
11. Peer instruction enhanced my understanding and ability to synthesize and integrate material.	4.4 ± 0.10
12. Peer instruction provided a more positive relationship among students.	4.6 ± 0.10
13. Peer instruction provided a more positive relationship between students and faculty.	4.6 ± 0.09
14. Peer instruction provided a more constructive classroom learning environment.	4.6 ± 0.09
15. Peer instruction provided the opportunity to discuss incorrect answers and fill in knowledge gaps and therefore improve understanding of the material.	4.6 ± 0.09
16. My level of involvement during the discussions was high.	4.2 ± 0.13
17. This method of learning was as effective as any other I have encountered.	4.4 ± 0.10
18. This process was educationally attractive due to the novelty of this style and format.	4.5 ± 0.10
19. I would recommend this process for other content areas.	4.6 ± 0.09
20. I enjoyed peer instruction	4.7 ± 0.08

Results are expressed as means ± SE. Students were given the following instructions to respond to the questions. Circle the number that most accurately defines the way you feel regarding each statement: 1, strongly disagree; 2, tend to disagree; 3, neither agree nor disagree; 4, tend to agree; 5, strongly agree.

course for a total of 34 questions. Without peer instruction, the students answered questions correctly 44 ± 5% of the time. In contrast, when students were allowed to collaborate with fellow classmates, they answered the questions correctly 59 ± 6% of the time. This 27% improvement of the raw scores was statistically significant ($P = 0.02$).

Figure 2 presents the effect of peer instruction on meaningful learning (the ability to solve novel problems). The students who interacted with their peers and those who did not answered one problem-solving question per class throughout the last one-third of the course for a total of six questions. When students were allowed to interact with their peers, the level of performance on novel problem-solving questions was significantly greater (47 ± 5 vs. 24 ± 2%, $P = 0.04$) than when they completed novel tasks in the traditional format.

The questionnaire used to evaluate the peer instruction procedures and the students' responses are presented in Table 1. Thirty-four of the 38 students completed the questionnaire; this represents an 89% response rate. Among 20 responses, the students reported that the purpose of and rationale behind the educational process was fully explained (*question 1*, 4.6 ± 0.09). It was clear that the students understood the educational goals and figured out ways to achieve the goals. By understanding the goals, the students were observed becoming more efficient and effective with the discussions. In addition, it was clear that the students understood the nature and value of the activity, which prevented many of the concerns faculty may have about peer activities. Thus when establishing cooperative peer activities, it is important that clear instructions are presented. Students reported that peer instruction facilitated their learning of the material (*question 6*, 4.3 ± 0.11). It was clear that there were many concepts that could not be learned quickly. The time allowed during peer instruction provided the opportunity for students to master several complex concepts. As the authority, the instructor often summarized the lesson and validated the learning that occurred. Students reported that every member "pulled their weight" (contributed to the learning process) (*question 7*, 4.1 ± 0.14). We observed all students "pulling their weight" as well as students monitoring group behaviors. Students were observed listening, providing constructive feedback, and reflecting on their learning. We observed students developing leadership, decision making, communication, and conflict resolution skills while gaining mutual respect of peers. The peer instruction activities fostered positive interdependence (*question 12*, 4.6 ± 0.10) and individual accountability (*question 7*, 4.1 ± 0.14), because the activity was carefully structured. Students reported that the level of discussion during peer instruction was high (*question 8*, 4.4 ± 0.12). Indeed, students were observed focused and seriously engaged in the discussion. It was clear that the students learned more and better by becoming actively involved with the material. However, activity in and of itself does not result in higher learning. The students invested in the discussion and we observed a high level of involvement from the students (*question 16*, 4.2 ± 0.13), which helped the students make what they were learning meaningful. The students reported that peer instruction provided a more positive relationship between students and faculty (*question 13*, 4.6 ± 0.09) and among students (*question 12*, 4.6 ± 0.10). Interaction between teacher and students and students and students is one of the most powerful factors in promoting learning. The students reported that they enjoyed peer instruction (*question 20*, 4.7 ± 0.08). It was clear that the students were motivated, eager to learn, and having fun. This created a wonderful classroom environment where student's confidence (*question 4*, 4.4 ± 0.11), learning (*questions 3*, 4.6 ± 0.09 and *5*, 4.3 ± 0.12) and involvement (*question 16*, 4.2 ± 0.13) were high.

DISCUSSION

In this study, we examined the effectiveness of peer instruction, a pedagogical method that promotes student participation in class and increases student interaction with each other and with the instructor, on student performance on quizzes (mas-

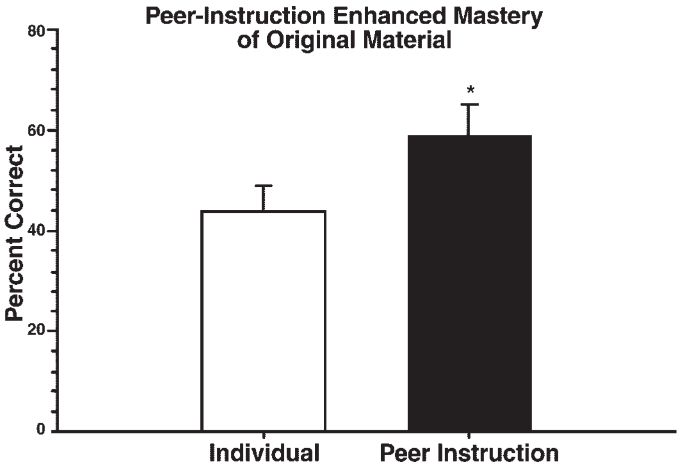

Fig. 1. Effect of peer instruction on student performance on multiple choice questions (mastery of original material). The daily average number of students who participated in peer instruction (answered questions in clusters) was 16.3 ± 0.2 (means ± SE). The daily average number of students who answered questions individually was 17.1 ± 0.4. Without peer instruction (Individual), the students answered questions correctly 44 ± 5% of the time. In contrast, when students were allowed to collaborate with fellow classmates (Peer Instruction), they answered the questions correctly 59 ± 6% of the time. This 27% improvement in raw scores was statistically significantly (*$P = 0.02$). Values are means ± SE.

tery of original material). In addition, we examined the effectiveness of peer instruction on meaningful learning, defined as the learner interprets, relates, and incorporates new information with existing knowledge and applies the new information to solve novel problems. Results from this study confirm previous reports documenting that peer instruction and collaborative group test taking enhanced student performance on quizzes. Specifically, previous studies (6, 15, 19, 20, 21) have documented that student performance on examinations is significantly higher when students completed the same exam in groups than when they completed the examinations individually. The new finding from this study is that peer instruction enhanced meaningful learning. That is, peer instruction provided a learning experience that lead to transfer, defined as the ability to extend what has been learned in one context to new contexts (2, 22). Quality learning experiences should lead to transfer. All learning experiences can appear equivalent when measures of learning are focused on the ability to repeat previously taught facts. However, quality learning experiences (learning with understanding) can be identified when tests of transfer are used. Thus because peer instruction leads to transfer, this study documents that peer instruction provides a quality learning experience.

Mastery of the subject is essential for meaningful learning (e.g., for the successful transfer of knowledge to solve novel problems). Without an adequate level of initial learning, transfer cannot be expected (5). Thus transfer is affected by the degree to which students learn with understanding rather than merely memorize sets of facts (5). Learning with understanding requires time to allow for practice. Faculty must be realistic about the amount of time required to learn complex concepts and provide the practice time to achieve the goal. Students need to take time to explore underlying concepts and to generate connections to other information. Students must have time to "grapple" with specific information relevant to the topic. Thus learning cannot be rushed; the complex cognitive activity of information integration requires time (5). It is important to recognize that time alone will not result in the benefit seen with peer instruction. Rather it is the practice and the feedback provided by peer instruction that enhances the mastery and transfer of knowledge. As stated more succinctly by a quote attributed to world-renowned physiologist and medical historian Horace Davenport, "There is a great difference between teaching and learning. There is too much teaching and not enough learning." (9, 23). In this context, I taught George, my cat, to fetch the remote to my sound system; however, he has failed to learn this task. Importantly, peer instruction provides the time for students to test existing knowledge and apply it to novel situations in a safe, supportive, environment. This quality learning experience allows students to evaluate their concepts and experiences while providing feedback about their progress.

A questionnaire (Table 1) was used to evaluate the peer instruction procedures. The questionnaire evaluated the goals and objectives, specific procedures, students' attitudes, and personal preferences as well as summary and recommendations. The students completed the evaluation at the end of the course. The questionnaire documented that the students developed a better understanding of the material and in the process gained more self confidence (*questions 4* and 6). Furthermore, the questionnaire documented that peer instruction resulted in more positive relationships among students (*question 12*) and between students and faculty (*question 13*), more positive psychological well being (*questions 4-6*), and a more constructive classroom-learning environment (*question 14*).

The results of the questionnaire are important because the students also reported that they enjoyed the procedures (*question 20*) and would recommend this process for other content areas (*question 19*). It is well documented that motivation affects the quality of the learning experience and that high levels of motivation increase learning with understanding (8). According to the ancient Greek scholar Plato, "Bodily exercise,

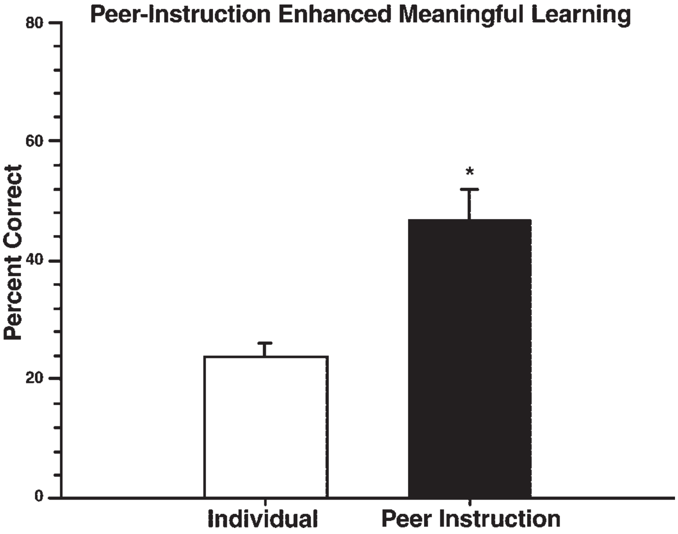

Fig. 2. Effect of peer instruction on meaningful learning (the ability to solve novel problems). When students were allowed to interact with their peers (Peer Instruction), the level of performance on novel problem-solving questions was significantly greater (47 ± 5 vs. 24 ± 2%, *$P = 0.04$) than when they completed novel tasks in the traditional format (Individual). Values are means ± SE.

when compulsory, does no harm to the body; but knowledge which is acquired under compulsion obtains no hold on the mind." (17). Peer instruction motivates students! Furthermore, learning with understanding and transfer requires the student to actively choose and evaluate strategies, consider resources, and receive feedback.

By actively involving students in peer instruction activities, the student's attention span may be greatly increased. It has been reported that students in a lecture-based college classroom are not attentive ~40% of the time (18). During sustained lectures, student attention decreases with each passing minute. Furthermore, sustained lectures appeal only to auditory learners and tend to promote lower level learning of factual information. Finally, sustained lecturing assumes that all students learn the same information at the same pace (10). Thus by incorporating peer instruction, active learning activities may increase student's attention.

Faculty are often reluctant to incorporate active learning activities in the class. The reasons most often advanced for not including these active learning activities include not being able to cover as much content in the time available and the excessive preparation time required for devising strategies promoting active learning (1). In terms of preparation time, minimal extra time is required for this active approach. Furthermore, the minimal extra time pays dividends in understanding and retention of material (6). As stated by Mazur (12), using time for peer instruction greatly improves student's level of understanding with relatively little effort and no capital investment.

Although little additional time is required in preparation for the peer instruction activities, the instructor has several important roles during the process. For example, the instructor must model appropriate social skills, including listening and providing constructive feedback or eliciting more in-depth responses through probing questions. The instructor must also reinforce these positive behaviors by publicly commenting on the ways students use them effectively.

In conclusion, pausing two to three times during a 50-min class to allow peer instruction of concepts enhanced the student's level of understanding and ability to synthesize and integrate material. Specifically, peer instruction enhanced the mastery of original material and meaningful learning. It is possible to create an effective active learning environment with relatively little effort by implementing peer instruction technique. We would be wise to heed the words of British mathematician, logician, and philosopher Alfred North Whitehead who said, "So far as the mere imparting of information is concerned, no university has had any justification for existence since the popularization of printing in the fifteenth century." (25).

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Peer instruction enhanced student performance on qualitative problem-solving questions

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Giuliodori, Mauricio J., Heidi L. Lujan, and Stephen E. DiCarlo. Peer instruction enhanced student performance on qualitative problem-solving questions. *Adv Physiol Educ* 30: 168–173, 2006; doi:10.1152/advan.00013.2006.—We tested the hypothesis that peer instruction enhances student performance on qualitative problem-solving questions. To test this hypothesis, qualitative problems were included in a peer instruction format during our Physiology course. Each class of 90 min was divided into four to six short segments of 15 to 20 min each. Each short segment was followed by a qualitative problem-solving scenario that could be answered with a multiple-choice quiz. All students were allowed 1 min to think and to record their answers. Subsequently, students were allowed 1 min to discuss their answers with classmates. Students were then allowed to change their first answer if desired, and both answers were recorded. Finally, the instructor and students discussed the answer. Peer instruction significantly improved student performance on qualitative problem-solving questions (59.3 ± 0.5% vs. 80.3 ± 0.4%). Furthermore, after peer instruction, only 6.5% of the students changed their correct response to an incorrect response; however, 56.8% of students changed their incorrect response to a correct response. Therefore, students with incorrect responses changed their answers more often than students with correct responses. In conclusion, pausing four to six times during a 90-min class to allow peer instruction enhanced student performance on qualitative problem-solving questions.

collaboration; meaningful learning; transfer

THERE HAS BEEN REMARKABLE PROGRESS in our understanding on how people learn. It is now clear that concept construction requires active processing of information. That is, we understand and remember the information we think about (8)! However, processing information requires time. Faculty members must be realistic about the amount of time required to learn complex concepts and provide the time needed to achieve the goal (5). Students need time to explore the underlying concepts and to generate connections to other information. Students must have time to "grapple" with specific information relevant to the topic. Thus, learning cannot be rushed; the complex cognitive activity of information integration requires time (4).

However, students attending our Physiology course are in class 5 h/wk. This computes to ~2.4% of the total hours in a student's week. Herein lies the problem: How do we provide time for information processing during this limited class time (8)? One way is to use qualitative problems (14, 15) in a peer instruction format (12, 13). These problems require a qualitative prediction (increase/decrease/no change) about the response of a physiological system to a perturbation. Qualitative problems require integration of multiple concepts; however, the problems can be answered quickly with single, best multiple-choice questions. These are important considerations because one of the most important factors influencing learning is what the student already knows. The students must link new information to concepts they already possess (8). This process is critical for solving novel problems. Peer instruction is a cooperative learning technique that may promote this process. Therefore, we tested the hypothesis that peer instruction enhances the students' performance on qualitative problem-solving questions. To test this hypothesis, qualitative problems were included in a peer instruction format during our Veterinary Physiology course.

METHODS

Design. We borrowed concepts from Lymna (11) and Mazur (13) peer instruction activities to promote student involvement in the learning process and test the hypothesis that peer instruction enhances student performance on qualitative problem-solving questions.

Procedures. This peer instruction, active-learning technique was implemented during the Physiology class (Fisiología No. 423) at the Facultad de Ciencias Veterinarias, Universidad Nacional de La Plata, La Plata, Argentina. The class consisted of 114 veterinary medical students. The class was lecture based, and the peer instruction technique was used for 10 classes involving cardiovascular, respiratory, and renal physiology. Each class of 90 min was divided into four to six short presentations of 15–20 min each. Each short presentation was followed by a qualitative problem-solving scenario that could be answered with a one-question, multiple-choice quiz. All students were allowed 1 min to think and to record their answers. Subsequently, students were allowed 1 min to discuss their answers with classmates (2–3 students/group). Students were then allowed to change their first answer if desired, and both answers were recorded. Students were instructed to provide reasons for their answers and to convince their peers that their answers were correct. In this format, the students had two roles: as a teacher, explaining the rationale for their answer; and as a student, listening to the reasoning for their peers' answer. Finally, the instructor and students discussed the answer.

The questions were qualitative problem-solving scenarios generated by M. J. Giuliodori using the format provided by Michael and co-workers (see *Appendixes A–C*) (14, 15). The qualitative problem-solving scenarios asked for a qualitative prediction (increase/decrease/no change) about the response of a system to a perturbation; for example, *If the heart is dener-*

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vated, what change, if any, will occur to heart rate (will it increase, decrease, or stay the same)? (14). Specifically, the questions posed conceptual problem-solving scenarios that required the integration of multiple concepts but were answered with single, best multiple-choice questions. In addition, tables were used, instead of multiple-choice questions, when more than one prediction was required (see *Appendixes A–C*); for example, *Predict how cutaneous blood flow, shivering, and sweating will be affected at the onset of a fever* (15).

Statistical analysis. All results are presented as means ± SE, and significance was set at the $P < 0.05$ level. To determine the effect of peer instruction on student performance on qualitative problem-solving questions (see Fig. 1), we used a Student's paired *t*-test to compare responses obtained when the students solved problems as individuals with responses obtained when the students solved problems in collaboration with peers (peer instruction).

To determine which students changed their individual response (see Fig. 2), we used a Kruskal-Wallis nonparametric, one-way ANOVA. Once statistical significance was established, post hoc analysis was performed with a Student-Newman-Keuls test. Finally, to compare the positive effects (individual *incorrect* responses changed to peer-instructed *correct* responses) with negative effects (individual *correct* responses changed to peer-instructed *incorrect* responses), we used a Mann-Whitney rank-sum test (see Fig. 3). Significance was set at the $P < 0.05$ level.

RESULTS

Figure 1 presents the percentage of correct responses when the students solved problems as individuals and when the students solved the same problems in collaboration with peers. As individuals, the students responded correctly 59.3 ± 0.5% of the time. In sharp contrast, in collaboration with peers, the students solved the same problem correctly 80.3 ± 0.4% of the time. This 21% increase was statistically significant ($P < 0.001$).

Figure 2*A* presents the percentage of correct individual responses that did not change (correct to same correct) or changed to incorrect responses (correct to incorrect) after peer instruction. In the group of students having correct individual responses (~60% of the total population), 93.5% did not change their response after peer instruction (no effect). However, 6.5% changed their responses to incorrect responses (negative effect).

Figure 2*B* presents the percent of incorrect individual responses that changed to correct responses (incorrect to correct), changed to a different incorrect response (incorrect to incorrect), or did not change (incorrect to same incorrect) after peer instruction. In the group of students having individual incorrect

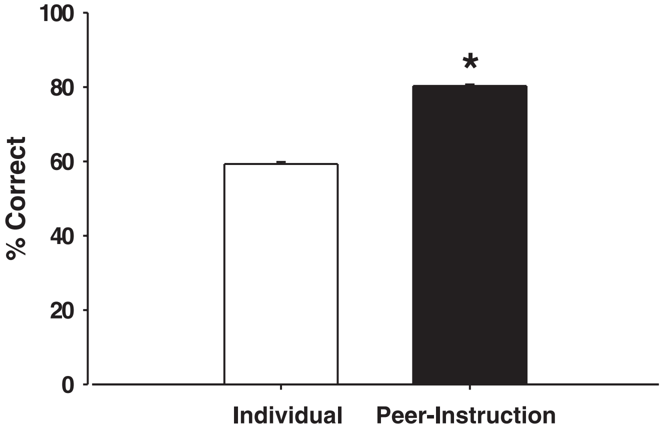

Fig. 1. Effect of peer instruction on students' qualitative problem-solving skills. Without peer instruction (individual), the students solved problems correctly 59.3 ± 0.5% of the time (mean ± SE). In contrast, when students were allowed to collaborate with classmates (peer instruction), the students solved the problems correctly 80.3 ± 0.4% of the time. *$P < 0.001$, individual vs. peer instruction.

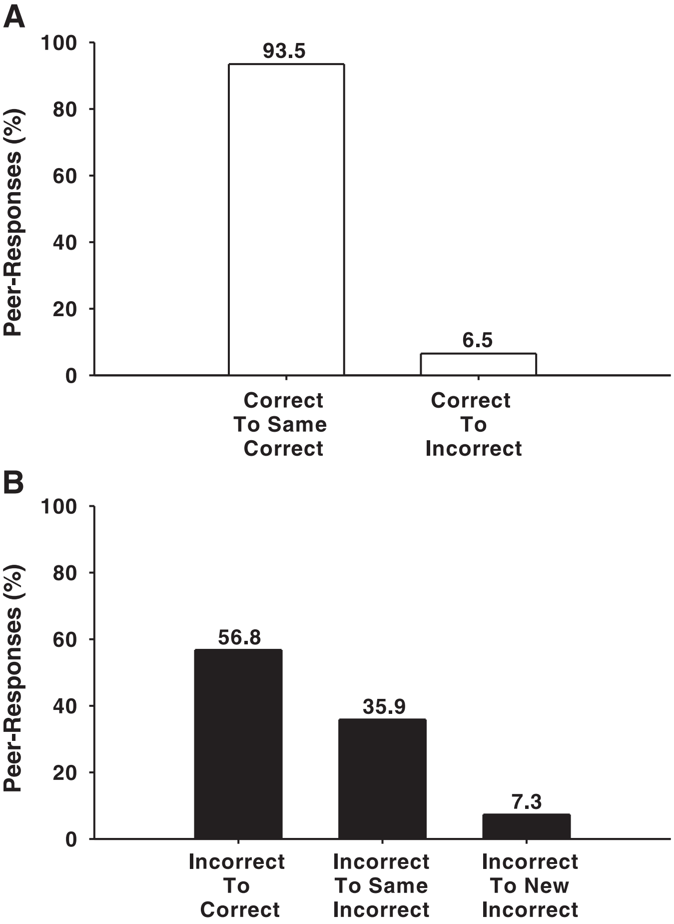

Fig. 2. *A*: percentages of correct individual responses that did not change (correct to same correct) or changed to incorrect responses (correct to incorrect) after peer instruction. In the group of students having correct individual responses (~60% of the total population), 93.5% did not change their response after peer instruction (no effect). However, 6.5% changed their responses to incorrect responses (negative effect). *B*: percentages of incorrect individual responses that changed to correct responses (incorrect to correct), changed to a different incorrect response (incorrect to incorrect), or did not change (incorrect to same incorrect) after peer instruction. In the group of students having individual incorrect answers (~40% of student population), 56.8% changed their initial incorrect response to a correct response after peer instruction (positive effect), 35.9% did not change (incorrect to same incorrect, no effect), and 7.3% changed to another incorrect response (no effect). One-way nonparametric ANOVA revealed significant group effects ($P < 0.001$). Post hoc analysis revealed that fewer students change their responses from correct to incorrect (6.5%) than from incorrect to correct (56.8%, $P < 0.05$). Thus, most correct students (93.5%) did not change their individual responses; however, many incorrect students did (64.1%). Taken together, these data document that it is easier to convince someone who is incorrect than someone who is correct.

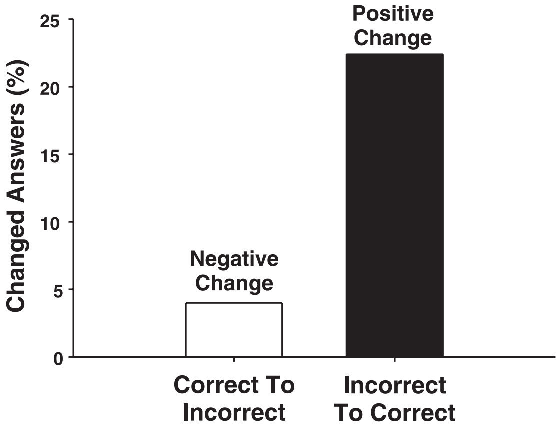

Fig. 3. Effect of peer instruction on the way students changed their responses (positive change vs. negative change). Of the student population, only 4% showed a negative change (individual correct answers to peer-instructed incorrect answers). However, 22.4% showed a positive change (individual incorrect answers to peer-instructed correct answers, $P < 0.001$).

answers (~40% of student population), 56.8% changed their initial incorrect response to a correct response after peer instruction (positive effect), 35.9% did not change (incorrect to same incorrect, no effect), and 7.3% changed to another incorrect response (no effect). One-way nonparametric ANOVA revealed significant group effects ($P < 0.001$). Post hoc analysis revealed that fewer students changed their response from correct to incorrect (6.5%) than from incorrect to correct (56.8%, $P < 0.05$). Thus, most correct students (93.5%) did not change their individual response; however, many incorrect students did (64.1%). Taken together, these data document that it is easier to convince someone who is incorrect than someone who is correct.

Figure 3 compares the positive effects (individual incorrect responses changed to peer-instructed correct responses) with negative effects (individual correct responses changed to peer-instructed incorrect responses). Only 4% of the students had a negative change (individual correct response to peer-instructed incorrect responses). In contrast, 22.4% of the students had a positive change (individual incorrect response to peer-instructed correct responses). Post hoc analysis revealed that the positive effects were higher than the negative effects (22.4% vs. 4.0%, $P < 0.001$).

Students' perceptions regarding the peer instruction activity are presented in Table 1. One hundred four students (of 114 students total) returned the completed questionnaire (91.2% response rate). The students reported that the peer instruction methodology was simple and helped them to better understand the topics. The students reported that the level of discussion was high and the immediate feedback was helpful. Finally, the students enjoyed the methodology and recommended it for other courses.

DISCUSSION

In this work, we examined the effect of peer instruction, a pedagogical tool that increases student interactions with each other and with the instructor, on student performance on qualitative problem-solving questions. The main finding was that peer instruction increased student performance on qualitative problem-solving questions. Specifically, there was a 35% improvement in correct responses to qualitative problems after discussions with peers (absolute gain: 21 percentage units, $P < 0.001$; Fig. 1). Similar results have been reported by other investigators. For example, Crouch and Mazur (7) observed significant increases in conceptual problem-solving skills involving physics scenarios over a 10-yr period of peer instruction experience. Similarly, we (17) recently reported that peer instruction increased medical student performance on quizzes. Furthermore, collaborative testing, a similar peer instruction procedure, also increased medical student performance on quizzes (16, 18). Similarly, peer instruction as well as collaborative testing increased undergraduate student performance on exams and increased student retention of previously learned information (5, 6). Specifically, performances on quizzes and retention of previously learned information were significantly higher when students completed exams in groups rather than when they completed exams individually (5, 6). Importantly, we (5) also documented that peer instruction enhanced meaningful learning (the students' ability to solve novel problems).

The new finding from this study is that peer instruction enhanced student performance on qualitative problem-solving questions. Qualitative problems require the integration of multiple concepts. Thus, peer instruction provides a learning experience that leads to the ability to extend what has been learned in one context to new contexts (2, 20). All learning experiences can appear equivalent when measures of learning are focused on the ability to repeat previously taught facts. However, quality learning experiences require the ability to extend what has been learned in one context to new contexts. Quality learning experiences require time to allow for practice. Faculty members must be realistic about the amount of time required to learn complex concepts and provide the practice time to achieve the goal. Students need time to explore underlying concepts and to generate connections to other information. Students must have time to "grapple" with specific information relevant to the topic. Thus, learning cannot be rushed;

Table 1. *Student perceptions regarding the PI activities*

Questionnaire Items	Responses
1. The methodology of PI was clear and easy to follow.	3.80±0.09
2. The methodology of PI was interesting and enjoyable.	3.84±0.08
3. The methodology of PI helped me to better understand the topics.	3.91±0.09
4. The levels of discussion with peers and instructor were high.	3.75±0.09
5. The immediate feedback given by discussions with peers and instructor was positive.	3.92±0.08
6. Other faculty members should include PI in their courses.	3.72±0.10

Data are shown as means ± SE; $n = 104$ students who returned the completed questionnaire (91.2% response rate) regarding the peer instruction (PI) activities. Responses were on a 5-point scale, where *1* was completely disagree, *2* was disagree, *3* was neither agree nor disagree, *4* was agree, and *5* was completely agree.

the complex cognitive activity of information integration requires time (4). Importantly, peer instruction provides the time for students to test existing knowledge and apply it to novel situations in a safe, supportive environment. This quality learning experience allows students to evaluate their concepts and experiences while providing feedback about their progress.

A previous study (13) has shown that students obtain optimal benefits of peer instruction when the percentage of correct individual responses is between 35% and 70%. Specifically, when the percentage of correct individual responses is too low (<35%) or too high (>70%), there is little improvement. For example, when the percentage of correct individual responses is too low (<35%), most of the students have not obtained sufficient understanding of the concept to have meaningful discussions. In contrast, when the percentage of correct individual responses is too high (>70%), there is less room for improvement (13). In this study, the percentage of correct individual responses (59.3 ± 0.4%) was within the range for optimal improvement (13).

The beneficial effects of peer instruction are due, in part, to two major factors. First, student attention decreases with each passing minute during sustained lectures. Importantly, peer instruction activities increase attention by actively involving students in problem-solving activities. Furthermore, sustained lectures appeal only to auditory learners and tend to promote lower-level learning of factual information (10, 18). Finally, sustained lecturing assumes that all students learn the same information at the same pace (9). Rowe (19) reported that pausing every 15 min during a lecture increased students' attention and retention.

Second, the value of peer instruction derives from the student generating explanations for their answers. Students obtain benefits when they generate their own explanations ("self-explanation") for their new knowledge (3) and when they explain their reasoning to classmates, that is, when the learner acts as a teacher. Thus, "*the best way to learn something is to teach it*," because teaching requires the generations of explanations, both for oneself and for the learner (14). All of us who teach have experienced and understand the true meaning of this concept.

In this study, only 6.5% of the students with individual correct responses changed their answers after peer discussion to incorrect responses. In sharp contrast, 64.1% of the students with individual incorrect responses changed their answers after peer discussion. Thus, most of the students who changed their responses changed to a correct answer to correct responses (56.8%), whereas a small portion changed to an incorrect answer (7.3%, $P < 0.05$; Fig. 2). Specifically, 22.4% of the student population changed their responses in a positive way (from incorrect to correct answers), whereas only 4.0% of the student population changed their responses in a negative way (from correct to incorrect answers, $P < 0.001$; Fig. 3). Taken together, the magnitude of the peer instruction positive effect was 5.6 times higher than the magnitude of the peer instruction negative effect. Therefore, the beneficial effects of peer instruction on students' performance were observed in the group of students having individual incorrect answers ("weaker students") (Fig. 3). These results are in agreement with reports by Crouch and Mazur (7). These authors reported that it is much easier to change the mind of someone who is wrong than it is to change the mind of someone who has selected the correct answer for the right reasons (13). Thus, there is always an increase and never a decrease in the number of correct answers (solutions) after discussion with classmates.

Faculty members are often reluctant to incorporate active learning activities in class. The reasons most often advanced for not including these active learning activities include not being able to cover as much content and the excessive preparation time required for devising strategies promoting active learning (1). However, as stated by Mazur (13), using time for peer instruction greatly improves the student's level of understanding with relatively little effort and no capital investment. In addition, the instructor has several important roles during the process. For example, the instructor must model appropriate social skills, including listening and providing constructive feedback or eliciting more indepth responses through probing questions. The instructor must also reinforce these positive behaviors by publicly commenting on the ways students use them effectively (5).

Student perceptions regarding the peer instruction activities are in agreement with previous work (5, 6, 16, 17). Students appreciated the interactions with peers and with the instructor. This interaction provided immediate feedback, which is not possible during the traditional lecture format. The students reported that peer instruction facilitated their learning of the topics. In this content, students were seen to be enthusiastically engaged in content-based discussions, giving support to their choices. Finally, students enjoyed this learning experience and recommended it for other courses.

In conclusion, pausing four to six times during a 90-min class to allow peer instruction of qualitative problems enhanced the students' performance on qualitative problem-solving questions.

Appendix A: Samples of Assessed Cardiovascular Questions

1. Predict (increase/decrease/no change) what would happen to the velocity of blood flow through systemic vessels if you provide a medication causing smooth muscle contraction:

A. Increase (correct)
B. Decrease
C. No change

2. Predict (increase/decrease/no change) what would happen to the resting membrane potential in cardiac muscle cells if the extracellular K^+ concentration increases:

A. Increase
B. Decrease (correct)
C. No change

3. Predict (increase/decrease/no change) what would happen to cardiac output if you provide a medication causing smooth muscle relaxation:

A. Increase
B. Decrease (correct)
C. No change

4. Predict (increase/decrease/no change) what would happen to stroke volume, end-diastolic volume, and cardiac output if afterload increased:

	Response
Stroke volume	Decrease
End-diastolic volume	Increase
Cardiac output	Decrease

5. Predict (increase/decrease/no change) what would happen to the volume of blood returning to the heart through the veins if right atrial pressure (central venous pressure) increased:
A. Increase
B. Decrease (correct)
C. No change

6. Predict (increase/decrease/no change) what would happen to tissue fluid formation if you provide a medication causing smooth muscle contraction in veins:
A. Increase (correct)
B. Decrease
C. No change

Appendix B: Samples of Assessed Respiratory Questions

1. Predict (higher/lower/the same) how the tidal volume of a horse immediately after a race would compare with its tidal volume at rest:
A. Higher (correct)
B. Lower
C. The same

2. Predict (increase/decrease/no change) what will be the effect on alveolar ventilation of breathing at higher frequency while keeping the same respiratory volume:
A. Increase
B. Decrease (correct)
C. No change

3. Predict (increase/decrease/no change) what would happen to functional residual capacity in a lung disease leading to emphysema:
A. Increase (correct)
B. Decrease
C. No change

4. Predict (increase/decrease/no change) what would happen to airflow resistance if you provide a medication causing smooth muscle relaxation:
A. Increase
B. Decrease (correct)
C. No change

5. Predict (increase/decrease/no change) what would happen to arterial P_{O_2} in a dog breathing 100% oxygen (oxygen therapy):
A. Increase (correct)
B. Decrease
C. No change

6. Predict (increase/decrease/no change) what would happen to ventilation and perfusion in a dog having its right pulmonary artery blocked:

	Response
Right lung ventilation	Decrease
Left lung ventilation	No change
Left lung perfusion	No change

Appendix C: Samples of Assessed Renal Questions

1. Predict (increase/decrease/no change) what would happen to the glomerular filtration rate, renal blood flow, and glomerular capillary pressure during efferent arteriolar vasoconstriction:

	Response
Glomerular filtration rate	Increase
Renal blood flow	Decrease
Glomerular capillary pressure	Increase

2. Predict (higher/lower/the same) how urine osmolarity would be compared with plasma osmolarity if you provide a medication blocking the $2Cl^{-}$-Na^{+}-K^{+} cotransporter (i.e., furosemide):
A. Higher (correct)
B. Lower
C. The same

3. Predict (higher than 1/lower than 1/equal to 1) the fractional excretion of a drug that is both filtered and secreted (with no reabsorption).
A. Higher than 1 (correct)
B. Lower than 1
C. Equal to 1

4. Predict (increase/decrease/no change) what would happen to the urine concentration capacity in a dog given a low-protein diet:
A. Increase
B. Decrease (correct)
C. No change

5. Predict (increase/decrease/no change) what would happen to plasma Na^{+} concentration, total body Na^{+} content, plasma K^{+} concentration, and total body K^{+} content if you provide a medication with an aldosterone antagonistic effect:

	Response
Plasma Na^{+} concentration	No change
Total body Na^{+} content	Decrease
Plasma K^{+} concentration	Increase
Total body K^{+} content	Increase

6. Predict (increase/decrease/no change) what would happen to urine elimination of tritratable acids if the organic load of metabolic acids increases:
A. Increase (correct)
B. Decrease
C. No change

7. Predict (increase/decrease/no change) what would happen to both the volume and osmolarity of extra- and intracellular fluid compartments if you provide a hypertonic saline solution (i.e., 7.5% NaCl) intravenously:

	Response	
	Volume	Osmolarity
Extracellular fluid compartment	Increase	Increase
Intracellular fluid compartment	Decrease	Increase

GRANTS

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