

Heidi L. Lujan and Stephen E. DiCarlo

Advan Physiol Educ 30:17-22, 2006. doi:10.1152/advan.00061.2005

You might find this additional information useful...

This article cites 55 articles, 11 of which you can access free at:

<http://ajpadvan.physiology.org/cgi/content/full/30/1/17#BIBL>

This article has been cited by 1 other HighWire hosted article:

Learning styles of first-year medical students attending Erciyes University in Kayseri, Turkey

Z. Baykan and M. Nacar

Advan Physiol Educ, June 1, 2007; 31 (2): 158-160.

[\[Abstract\]](#) [\[Full Text\]](#) [\[PDF\]](#)

Medline items on this article's topics can be found at <http://highwire.stanford.edu/lists/artbytopic.dtl> on the following topics:

Management .. Problem Solving

Communication .. Teachers

Criminology .. Education (Criminology)

Education .. Learning Activities

Education .. Educational Games

Education .. Educational Strategies

Updated information and services including high-resolution figures, can be found at:

<http://ajpadvan.physiology.org/cgi/content/full/30/1/17>

Additional material and information about *Advances in Physiology Education* can be found at:

<http://www.the-aps.org/publications/advan>

This information is current as of March 25, 2008 .

Too much teaching, not enough learning: what is the solution?

Heidi L. Lujan and Stephen E. DiCarlo

Department of Physiology, Wayne State University School of Medicine, Detroit, Michigan

Submitted 21 September 2005; accepted in final form 11 December 2005

Lujan, Heidi L., and Stephen E. DiCarlo. Too much teaching, not enough learning: what is the solution? *Adv Physiol Educ* 30: 17–22, 2006; doi:10.1152/advan.00061.2005.—The curriculum is packed with so much content that teachers resort to telling students what they know and students simply commit facts to memory. The packed curriculum leaves little time for students to acquire a deep understanding of the subject or to develop life-long skills such as critical thinking, problem solving, and communication. However, learning is not committing a set of facts to memory, but the ability to use resources to find, evaluate, and apply information. This paper addresses these concerns by discussing “how we learn” and reviewing the literature on what works to improve learning. It is clear that active processing of information, not passive reception of information, leads to learning. That is, students must construct their own understanding of concepts, relationships, and procedures. Teachers can encourage this process by carefully considering the type and organization of information as well as instructional strategies. Specifically, teachers should reduce the total amount of factual information students are expected to memorize, reduce our use of the passive lecture format, and devote much more effort to helping students become active, independent learners and problem solvers. Collaborative learning activities, interactive models, educational games, and establishing a culture of inquiry/scholarship are critical for achieving these goals.

inquiry; scholarship; collaborative learning

“THERE IS A GREAT DIFFERENCE between teaching and learning. There is too much teaching and not enough learning” (24, 67). Teaching is not telling students what we know but showing students how we learn (69). Learning is not committing a set of facts to memory, but the ability to use resources to find, evaluate, and apply information. However, the curriculum is packed with so much content that, to “cover the content,” teachers resort to telling students what they know and students simply commit facts to memory. The packed curriculum leaves little time for students to acquire a deep understanding of the subject or to develop life-long skills such as critical thinking, problem solving, and communication. Therefore, we should unpack the curriculum and reduce the amount of factual information students are expected to memorize. In addition, we should help students become active, independent learners and problem solvers (67).

One way to achieve this goal is to reduce our use of the passive lecture format. Before the development of the printing press, the only way to transmit information was by word of mouth. However, with printed materials and electronic resources, other means of information delivery are now available. In fact, with the explosive development of the Internet and other technologies, teaching resources have seen a revolution that rivals the invention of the printing press in 1460

(44). Why, then, does lecturing remain the predominant form of teaching in postsecondary and health care professional education (18, 27, 45)? It is true that lecturing facilitates the sharing of information with a large number of students and that lecturing may be effective in transmitting factual information (21, 35, 60). However, lecturing merely exposes students to content, and exposure is not sufficient for learning. Active processing of information, not passive reception of information, leads to learning (3, 17, 69). That is, students must construct their own understanding of concepts, relationships, and procedures. Teachers can encourage this process by carefully considering the type and organization of information as well as instructional strategies (28, 49). However, lecturing should not be the instructional strategy of choice.

In addition, we must create a joy, an excitement, and a love for learning. We must inspire and engage students and show them how we learn rather than tell them what we know. When we are truly successful, our students will be impatient to study, reflect, contemplate, and really learn (24). This article presents a review of the literature and evidence supporting the need for these suggestions as well as specific practical examples and resources for achieving these goals.

PASSING EXAMS WITHOUT UNDERSTANDING

How often has a colleague, from an upper-division course, inquired if you covered a specific topic in your class? Your colleague was concerned because the students in his/her class (a class after yours) acted as if they never heard of the topic? Or, how often have you just completed a series of lectures on a subject only to encounter students who were unable to discuss even the simplest concepts you covered? From these experiences, we were convinced that our students were memorizing the content and passing exams without understanding the material. Memorization occurs when the learner makes little or no effort to relate new information to existing knowledge or novel situations. Or, memorization is what we resort to when what we are learning makes no sense. For example, please read and study the following paragraph for 3 min (30). After reading and studying the paragraph for 3 min, without referring to the paragraph, please answer the following questions:

Last Fernday, George and Tony were in Donlon peppering gloopy saples and cleaming, burly greps. Suddenly, a ditty strezzle boofed into George’s grep. Tony blaired, “Oh George, that ditty strezzle is boofing your grep!”

Please Answer the Following Questions:

1. When were George and Tony in Donlon?
2. What did the ditty strezzle do to George’s grep?
3. What kind of saples did George and Tony pepper?
4. What was Tony’s reaction?
5. What do you imagine happened next?

Address for reprint requests and other correspondence: H. L. Lujan, Wayne State Univ. School of Medicine, 540 E. Canfield Ave., Detroit, MI 48201 (e-mail: hlujan@med.wayne.edu).

6. Based on the incidents in this story, do you think George and Tony will want to return to Donlon? Why or why not?

Please check your responses with the correct answers below.

Correct Answers:

1. Last Fernday
2. Boofed into George's grep
3. Gloopy saples
4. Tony blaired, "Oh George, that ditty strezzle is boofing your grep!"
5. Almost any answer will receive partial or complete credit.
6. Almost any answer will receive partial or complete credit.

Assign 17 points for each correct response and assign partial credit (1–16 points) for each partially correct response. Using this format, did you receive a passing grade (e.g., did you "pass" this exam)?

Most students receive enough points to "pass" this exam. However, because the paragraph was nonsense, there was no meaningful learning or learning with understanding. Thus our students may be passing exams without understanding the material.

WHAT CAN BE DONE TO INCREASE UNDERSTANDING?

We must 1) reduce the amount of factual information students are expected to memorize, 2) reduce our use of the passive lecture format, and 3) help students become active, independent learners and problem solvers (67).

Reducing the amount of factual information students are expected to memorize. We must reduce the amount of factual information that students are expected to memorize because students do not remember, or, more importantly, understand much of what they memorize. For example, Miller (40) reported that students forget much of what they learn in anatomy and biochemistry courses before they graduate. In addition, after a short time, students who had high grades in a subject knew no more about that subject than students who had lower grades (40). Similarly, Swanson and colleagues (65) documented very low retention of basic science information by fourth-year medical students. Furthermore, Richardson (53) reported that, compared with naïve students, experienced students who completed an elementary physiology course did not have a greater knowledge level of physiology or perform better in an upper-division physiology course. In short, a prior course in physiology did not enhance performance on a precourse test or on a postcourse test (53). It is also well documented that science-based undergraduate education has no effect on academic performance by medical students (22). Finally, we documented that retention of acquired knowledge is short lived (16).

Thus, we don't remember or understand much of what we learn in the classroom, and even if we did it would not help us in our future careers 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 (69). Furthermore, only a small portion of what is known can be taught in four years, and not all that is taught is learned or remembered. Some of what is taught is erroneous, and other material will soon be obsolete. Therefore, students must be capable of working together and gathering evidence, evaluating it, and learning from it. However, much of what we do in classes with large numbers of students conflicts with our goals. These

activities do not prepare students for solving novel problems because many of these activities encourage memorization of detailed information. As a result, retention of acquired knowledge is short lived, and grades do not correlate with problem-solving abilities (15, 16).

For example, in many schools, students think classes involve an endless list of independent, unrelated facts: a series of unrelated phenomena where faculty encourage memorization of detailed information. For example, consider the seeming unrelated letters in the following row. It would be difficult to memorize this row of letters; however, even if we did, we would not remember the letters for long, and it would have no meaning.

N₁₀ S₃ & I₁ G₁₃ R₆ E₉ I₅ A₁₂ N₂ E₁₄ P₄ G₁₁ E₇

1 2 3 4 5 6 7 8 9 10 11 12 13 14

However, our responsibility is to take these seemingly independent, unrelated facts and place the facts into an appropriate context. All of us have content knowledge, we understand our subject; however, few of us have pedagogical knowledge, an understanding of how to place the material into a context that promotes meaningful learning (learning with understanding). Meaningful learning (14, 36) occurs when the learner interprets, relates, and incorporates new information with existing knowledge and applies the new information to solve novel problems. For example, please place the letter, using the corresponding number, into the space matching the number. Having completed this task, what does this exercise emphasize? This exercise emphasizes the futility of memorizing seemingly independent facts and illustrates the importance of placing facts into the appropriate context. These seemingly unrelated letters have significant meaning, and the learner will remember the letters when we apply our pedagogical knowledge.

To reinforce this concept, please consider the following example. Please take 10 s to memorize the following row of letters:

O H L B A F N C I B D S N F W

Without looking at the letters, please recall as many letters as possible. Please write the number of letters you recalled in the following space: _____.

Now, please take an additional 10 s to memorize the following row of letters:

N F L C B S F B I D N A W H O

Without looking at the letters, please recall as many letters as possible. Please write the number of letters you remembered in the following space: _____.

Did you recall more letters from the first row or second row of letters? Although the letters in the two rows are identical, all students recalled more letters from the second row. This exercise emphasizes the importance of relating what is unknown to what is known, placing the material into context, and using our pedagogical knowledge (32, 39). This is critical because one of the most important factors influencing learning is what the student already knows. The student must consciously and explicitly link new information to concepts they

already possess. In this way, existing concepts are identified and new linkages are formed between concepts.

Reducing our use of the passive lecture format. We must reduce our use of the passive lecture format because the passive lecture format is *boring*, mind numbing for students and monotonous for teachers. Students' attention in lecture classes wanes dramatically after 10–15 min (48, 64), and there is a weak correlation between lecture attendance and course grades (23). These studies suggest that students do not learn by simply sitting in a classroom listening to the teacher, memorizing assignments, and spitting out answers. Students must talk about what they are learning, write about it, relate it to past experiences, and apply it to their daily lives (10). Students who are actively involved in learning retain information longer than when they are passive recipients of instructions (16). Furthermore, students prefer active learning strategies to the traditional lecture (4). Active involvement also improves students' conceptualization of systems and how they function and increases students' levels of retention (20, 41, 58). Therefore, all teachers are encouraged to reduce or eliminate the passive lecture format!

Helping students become active, independent learners and problem solvers. We must help students become active, independent learners and problem solvers because it is clear that active processing of information and not just passive reception of that information leads to learning. That is, we understand and remember the information we think about! Specifically, learning with understanding requires time. Faculty must be realistic about the amount of time required to learn complex concepts and provide the 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; the complex cognitive activity of information integration requires time.

Active learning strategies reach all types of learners in the visual, auditory, read/write, kinesthetic, and tactile schemes. With active learning strategies, visual learners are targeted by the presence of models and demonstrations. Auditory learners are reached through discussion during peer instruction (15, 51),

debates (59), games (2, 38, 42, 46), and answering questions. Manipulating models (7, 54, 62) and role playing (29) satisfy kinesthetic and tactile learners.

An example that clearly demonstrates that active processing of information and not just passive reception of that information leads to learning is shown in Table 1. From this exercise, when did you recall more words: when you actively processed the information or when you passively received the information (5, 32)?

It is generally thought that students have better retention and understanding of knowledge when taught by active as opposed to passive methods (32, 34, 35, 37, 52). If this is true, the curriculum must be changed to active methods that provide educational experiences designed to develop life-long learners and students who are capable of solving novel problems: in short, self-educators (67).

WHAT CURRICULAR CHANGES WORK?

Peer instruction WORKS! Lymna's Think-Pair-Share (31) and Mazur's Peer Instruction (33) are peer instruction activities that provide opportunities for students to be actively engaged in the reasoning and application of concepts. 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). Mazur used a very similar approach. Two to three times during a lecture, 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 (33). Similarly, we recently reported that peer instruction increased medical student performance on quizzes (51) and increased meaningful learning (15). Specifically, each class of 50 min was divided into three to four short

Table 1. Active processing of information and not passive reception of that information

Please take 15 Seconds to Learn the Following Pairs of Words by <u>Repeating</u> Each Pair of Words <u>Several Times</u> (for example, Dog - WINDOW; Say - Dog, window, dog, window . . .)		Please Take 15 Seconds to Learn the Following Pairs of Words by <u>Visualizing</u> the Two Objects <u>Interacting</u> (for example; Dog - WINDOW; Picture a dog jumping through a window)	
CANDLE - <u>DANCER</u>	DOLLAR - <u>ELEPHANT</u>	ENVELOPE - <u>SLIPPER</u>	JAIL - <u>CLOWN</u>
DANDELION - <u>FLEA</u>	CAR - <u>HONEY</u>	FRECKLES - <u>APPLE</u>	IVY - <u>MOTHER</u>
BREAD - <u>GLASS</u>	LIPS - <u>MONKEY</u>	TREE - <u>OCEAN</u>	SHEEPSKIN - <u>CANDLE</u>
MIRROR - <u>RABBIT</u>	PENCIL - <u>LETTUCE</u>	CANDY - <u>MOUNTAIN</u>	BOOK - <u>PAINT</u>
LAMB - <u>MOON</u>	SOAP - <u>MERMAID</u>	SCISSORS - <u>BEAR</u>	LIZARD - <u>PAPER</u>
FOOTBALL - <u>LAKE</u>	HOUSE - <u>DIAMOND</u>	CUSTARD - <u>LUMBER</u>	HAMMER - <u>STAR</u>
Without looking at the paired words above, please recall the words paired with the following words:		Without looking at the paired words above, please recall the words paired with the following words:	
CANDLE _____	DOLLAR _____	ENVELOPE _____	JAIL _____
DANDELION _____	CAR _____	FRECKLES _____	IVY _____
BREAD _____	LIPS _____	TREE _____	SHEEPSKIN _____
MIRROR _____	PENCIL _____	CANDY _____	BOOK _____
LAMB _____	SOAP _____	SCISSORS _____	LIZARD _____
FOOTBALL _____	HOUSE _____	CUSTARD _____	HAMMER _____
How many words did you recall? ____.		How many words did you recall? ____.	

When did you recall more words: when you actively processed the information or when you passively received the information (5, 32)?

presentations of 10–15 min each. Each short presentation was followed by a one-question multiple-choice quiz on the subject discussed. Students were allowed 1 min to think and 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 collected. Finally, the instructor and students discussed the answer. Results from these studies documented that pausing two to three times during a 50-min class to allow peer instruction of concepts enhanced the students' level of understanding and ability to synthesize and integrate material. Specifically, peer instruction enhanced the mastery of original material and meaningful learning.

Collaborative testing WORKS! Educators often view quizzes simply as a basis for grades. Too often, little emphasis is placed on using quizzes to help teachers teach and students learn. However, quizzes are not only a grading device but also a teaching technique (43). For educators, the process of constructing quizzes helps in putting the course in perspective. Quizzes also provide feedback regarding what students have and have not learned. For students, quizzes provide an opportunity to demonstrate what they have learned and to discover the scope and depth of their knowledge. However, some of the pedagogical value of quizzes is lost due to a lack of immediate feedback. It would be educationally sound for students to discuss the individual questions immediately after completing the quiz.

The pedagogical value of quizzes is also reduced because students usually complete the quiz individually. In this setting, students work in isolation from classmates and are given individual achievement tests to assess their level of learning. Furthermore, "unassisted" student learning is pedagogically unsound, because all school learning is assisted and promoted by the instructional efforts of a wide variety of individuals within and outside the school (26). Conversely, when students learn with others, they have the emotional and intellectual support that allows them to go beyond their present knowledge and skills and accomplish shared goals (61). In the cooperative learning setting, students become more engaged in learning by discussing material, facilitating understanding and encouraging hard work. In addition, cooperative learning has positive effects on race relations, self-esteem, and a willingness to cooperate in other settings (63).

Collaborative testing is an effective cooperative learning teaching strategy (16, 50). To conduct a collaborative testing experience, students first complete a quiz individually. Once the quiz is completed individually, students complete the same quiz in groups. Specifically, students complete the quiz individually for the first 50 min. Immediately after completing the quiz individually, students are assigned to a group of two or three and work as a team to answer the original questions; 80% of the final quiz score is based on individual results, and 20% of the final quiz score is based on group results. This collaborative group testing has been shown to increase student learning (50) as well as student retention of previously learned material (16).

Educational models WORK! Construction of models of biological processes (7, 54) is an outstanding strategy to enhance active and collaborative efforts as well as improve critical thinking skills (41). Model construction encourages logic, reasoning, and creativity, all of which are components of

the scientific process and are at the heart of problem-based learning (6). Evidence suggests that with the use of activity-based science programs, teachers can expect substantially improved performances in science processes (6). The role of the instructor is crucial for the success of students during the construction of the model. It is important to note that construction alone does not guarantee learning. The important part is not that students manipulate things physically but that they do so for a purpose and engage in discussion about it (66). Therefore, it is important for the instructor to specify the objectives for the lesson, assign the groups, explain the task and goal, and assess the effectiveness of the learning groups and the individual student's achievement. 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.

Educational games WORK! An area of neglect in science education is our role and responsibility to inspire students, to create a joy, an excitement, and a love for learning and to make learning fun. This is important because students must become life-time learners. The use of innovative educational games in the classroom can increase enthusiasm and reinforce previously presented didactic information (2, 13, 25, 42, 46). It is also a positive, interactive, alternative method of teaching and information sharing. In addition, team learning and active peer-to-peer instruction are strongly reinforced by educational games.

By developing and playing educational games, teachers and students add variety and alternatives to the traditional lecture format. Games increase student involvement, motivation, and interest in the material and allow the instructor to be creative and original when presenting topics (8, 9, 11, 47). Games also challenge students to apply the information, thus allowing them to evaluate their critical thinking skills (20). Finally, games create a challenging, constructively competitive atmosphere that facilitates interaction among students in a friendly and fun environment. Card games (46), crossword puzzles (2), and games based loosely on television game shows (25, 42, 55) have been used with remarkable success.

Experimental-based learning WORKS! The concepts and functional significance of many biological processes are often difficult for students to grasp. To help students understand these concepts, simple classroom experiments are often utilized, because, as stated by Albert Einstein, "A pretty experiment is in itself often more valuable than twenty formulae extracted from our minds."

Simple classroom experiments have been used to help students experience the force of ambient pressure and observe the concept of pressure gradients (12), for understanding of pulmonary function testing (56) and compliance (19), and for a variety of other biological processes (57).

Replicating classic experiments during the class is another valuable way to help students appreciate complex concepts as well as demonstrate how we learn. For example, in 1929, Von Neergaard (68) performed some simple but ingenious experiments on lungs obtained from cats. The isolated cat lung was nearly maximally inflated with air, and relaxation or recoil pressure was then recorded as measured volumes of air were sequentially removed from the lung. After a relaxation curve

for the air-filled lung was constructed, the lung was degassed and reinflated to near-maximum volume with a physiological saline solution. A second relaxation curve was constructed as measured volumes of saline solution were sequentially withdrawn. The results indicated that the recoil pressure at a particular lung volume (125 ml) was nearly twice as large in the air-inflated lungs as in the fluid-inflated lung. This simple experiment illustrated the importance of the air-liquid interface and its tendency to retract or recoil. Importantly, this classic, simple, and ingenious experiment can be replicated by substituting balloons for lungs. Similarly, to help students understand pulmonary compliance characteristics and relaxation curves for the chest cage, lung, and combined lung-chest cage, we (19) have previously demonstrated how the curves are generated by substituting a balloon for the lungs and a tennis ball for the chest cage.

From these experiences using demonstrations and simple experiments to help the students learn, we are convinced that most effective means to promote problem solving, critical thinking, and cooperative learning is through active participation in laboratory experimentation and analysis (53). However, experimentation is often neglected in many curricula because of the scarcity of suitable laboratory equipment, space, and experiments. The use of laboratory animals for experimentation is another obstacle, because many schools do not have sufficient funding or facilities to care for live animals. In addition, some teachers may lack the experience of handling laboratory animals. To address these concerns, "virtual" experiments can be used. For example, virtual experiments have been designed to help students understand the theory and application of the electrocardiogram (1) and gastrointestinal (2), endocrine (46), and cardiovascular physiology (13). Virtual experiments expose students to experimental design and procedures; however, the data are provided so that the results can be analyzed and discussed despite the lack of equipment (47). Furthermore, students gain information by analyzing and interpreting data, answering questions, and plotting graphs. The goal of virtual experiments is to instill an appreciation for experimental design, data collection, and analysis and to encourage students to continue their pursuit of science by presenting the material in an exciting, challenging, and inexpensive manner.

In conclusion, the curriculum is packed and leaves little time for students to acquire a deep understanding of the subject or to develop life-long skills such as critical thinking, problem solving, and communication. Contributing to the problem is the mistaken notion that instructors must "cover the content" or their students will be unprepared for the future and they will have failed as teachers. In addition, teachers worry about "losing" or "wasting" valuable lecture time for in-class discussion, collaborative problem solving, and inquiry-based activities. However, these activities focus student learning on how to use scientific knowledge to solve important questions. Therefore, we should unpack the curriculum and help students become active, independent learners and problem solvers. Collaborative learning activities, interactive models, educational games, and establishing a culture of inquiry/scholarship are critical for achieving these goals.

ACKNOWLEDGMENTS

The authors thank Margo Bowman and Debra L. Frame (Department of Psychology, Wayne State University) for the active learning demonstration and Todd Zakrajsek (Faculty Center for Innovative Teaching, Central Michigan University) for the passing exams without understanding the material demonstration.

REFERENCES

1. **Anderson J and DiCarlo SE.** "Virtual" experiment for understanding the electrocardiogram and the mean electrical axis. *Adv Physiol Educ* 23: 1–17, 2000.
2. **Bailey CM, Hsu CT, and DiCarlo SE.** Educational puzzles for understanding gastrointestinal physiology. *Adv Physiol Educ* 21: 1–18, 1999.
3. **Bolles E.** *Remembering and Forgetting: Inquiries into the Nature of Memory.* New York: Walker, 1988.
4. **Bonwell CC and Eison JA.** *Active Learning: Creating Excitement in the Classroom.* Washington, DC: George Washington Univ., 1991.
5. **Bower G and Winzenc D.** Comparison of associative learning strategies. *Psychonomic Sci* 20: 119–120, 1970.
6. **Bredderman T.** What research says. Activity science. The evidence shows it matters. *Sci Children* 20: 41, 1982.
7. **Chan V, Pisegna JM, Rosian RR, and DiCarlo SE.** Construction of a model demonstrating neural pathways and reflex arcs. *Adv Physiol Educ* 27: 14–42, 1991.
8. **Chandler MP and DiCarlo SE.** An educational tool for understanding the cardiopulmonary changes associated with aging. *Adv Physiol Educ* 26: 17–36, 1994.
9. **Chen Y and DiCarlo SE.** An educational tool for understanding the cardiopulmonary changes associated with heart failure. *Adv Physiol Educ* 26: 37–53, 1994.
10. **Chickering A and Zelda F.** Seven principles for good practice. *Am Assoc Higher Educ Bull* 7: 3–7, 1987.
11. **Collins HL and DiCarlo SE.** An educational tool for understanding the cardiovascular changes associated with diabetes. *Adv Physiol Educ* 26: 4–31, 1995.
12. **Collins HL and DiCarlo SE.** Simple, inexpensive classroom experiments for understanding basic gas laws and properties of gases. *Adv Physiol Educ* 27: 244, 2003.
13. **Collins HL, Rodenbaugh DW, Murphy TP, Kullics JM, Bailey CM, and DiCarlo SE.** An inquiry-based teaching tool for understanding arterial blood pressure regulation and cardiovascular function. *Adv Physiol Educ* 27: 15–28, 1999.
14. **Committee on Undergraduate Science Education.** Misconceptions as barriers to understanding science. In: *Science Teaching Reconsidered: a Handbook.* Washington, DC: National Academy, 1997.
15. **Cortright RN, Collins HL, and DiCarlo SE.** Peer instruction enhanced meaningful learning: ability to solve novel problems. *Adv Physiol Educ* 29: 107–111, 2005.
16. **Cortright RN, Collins HL, Rodenbaugh DW, and DiCarlo SE.** Student retention of course content is improved by collaborative-group testing. *Adv Physiol Educ* 27: 102–108, 2003.
17. **Craik FIM and Lockhart RS.** Levels of processing: a framework for memory research. *J Verbal Learn Verbal Behav* 11: 671–676, 1972.
18. **DaRosa DA, Kolm P, Follmer HC, Pemberton Beaty L, Pearce WH, and Leapman S.** Evaluating the effectiveness of the lecture versus independent study. *Eval Progr Plan* 14: 141–146, 1991.
19. **DiCarlo SE, Collins HL, and Rodenbaugh DW.** Experiment to help students understand pulmonary compliance. *Adv Physiol Educ* 26: 135–136, 2002.
20. **Elliott DD.** Promoting critical thinking in the classroom. *Nurse Educ* 21: 49–52, 1996.
21. **Gage N and Berliner D.** *Educational Psychology.* Boston, MA: Houghton Mifflin, 1998.
22. **Hall ML and Stocks MT.** Relationship between quantity of undergraduate science preparation and preclinical performance in medical school. *Acad Med* 70: 230–235, 1995.
23. **Hammen CS and Kelland JL.** Attendance and grades in a human physiology course. *Adv Physiol Educ* 26: 105–108, 1994.
24. **Haramati A.** Teaching physiology: filling a bucket or lighting a fire? *The Physiologist* 43: 117–121, 2000.
25. **Howard MG, Collins HL, and DiCarlo SE.** "Survivor" torches "Who Wants to be a Physician?" in the educational games ratings war. *Adv Physiol Educ* 26: 30–37, 2002.

26. **Johnson DW and Johnson RT.** *Meaningful and Manageable Assessment Through Cooperative Learning.* Edina, MN: Interaction, 1996.
27. **King A.** From sage on the stage to guide on the side. *Coll Teach* 411: 30–35, 1993.
28. **Klionsky D.** Constructing knowledge in the lecture hall. *J Coll Sci Teach* 31: 246–251, 2001.
29. **Kuipers JC and Clemens DL.** Do I dare? Using role-play as a teaching strategy. *J Psychosoc Nurs Ment Health Serv* 36: 12–17, 1998.
30. **Lavoie RD.** *Understanding Learning Disabilities—How Difficult Can It Be?* Adapted from F. A. T. City Workshop 89. Alexandria, VA: Greater Washington Educational Telecommunications [PBS video].
31. **Lymna F.** The responsive classroom discussion. In: *Mainstreaming Digest*, edited by Anderson AS. College Park, MD: Univ. of Maryland College of Education, 1981.
32. **Matlin MW.** *Cognition.* Hoboken, NJ: Wiley, 2003, vol. 101, p. 176–178.
33. **Mazur E.** Peer instruction: getting student to think in class. In: *The Changing Role of Physics Departments in Modern Universities*, edited by Redish EF and Rigden JS. Buenos Aires, Argentina: Proceedings of ICUPE 399, 1997, p. 981–988.
34. **McDermott LC.** How we teach and how students learn. *Ann NY Acad Sci* 701: 9–20, 1993.
35. **McKeachie WJ.** *Learning and Cognition in the College Classroom. Teaching Tips: Strategies, Research and Theory for College and University Teachers.* Lexington, MA: Heath, 1994, p. 279–295.
36. **Michael J.** The Claude Bernard Distinguished Lecture. In pursuit of meaningful learning. *Adv Physiol Educ* 25: 145–58, 2001.
37. **Michael JA.** Teaching problem solving in small groups. *Ann NY Acad Sci* 701: 37–48, 1993.
38. **Mierson S.** Skits and games to enhance students' learning of physiology. *Adv Physiol Educ* 277: 283–284, 1999.
39. **Miller GA.** The magical number seven plus or minus two: some limits on our capacity for processing information. *Psychol Rev* 63: 81–97, 1956.
40. **Miller GE.** An inquiry into medical training. *J Med Educ* 37: 185–191, 1962.
41. **Modell HI.** Preparing students to participate in an active learning environment. *Adv Physiol Educ* 270: 69–77, 1996.
42. **Moy JR, Rodenbaugh DW, Collins HL, and DiCarlo SE.** Who wants to be a physician? An educational tool for reviewing pulmonary physiology. *Adv Physiol Educ* 24: 30–37, 2000.
43. **Murray JP.** Better testing for better learning. *Coll Teach* 38: 148–152, 1990.
44. **Novak JD.** The promise of new ideas and new technology for improving teaching and learning. *Cell Biol Educ* 2: 122–132, 2003.
45. **Novak J.** Active learning in continuing professional education: the challenge of leadership. *New Direct Adult Continuing Educ* 56: 63–81, 1992.
46. **Odenweller CM, Hsu CT, and DiCarlo SE.** Educational card games for understanding gastrointestinal physiology. *Adv Physiol Educ* 20: 78–84, 1998.
47. **Patil RD, Karve S, and DiCarlo SE.** Intergrated cardiovascular physiology: a laboratory exercise. *Adv Physiol Educ* 265: 20–31, 1993.
48. **Penner J.** *Why Many College Teachers Cannot Lecture.* Springfield, IL: Thomas, 1984.
49. **Powell K.** Science education: spare me the lecture. *Nature* 425: 234–236, 2003.
50. **Rao SP, Collins HL, and DiCarlo SE.** Collaborative testing enhances student learning. *Adv Physiol Educ* 26: 37–41, 2002.
51. **Rao SP and DiCarlo SE.** Peer instruction improves performance on quizzes. *Adv Physiol Educ* 24: 51–55, 2000.
52. **Rao SP and DiCarlo SE.** Active learning of respiratory physiology improves performance on respiratory physiology examinations. *Adv Physiol Educ* 25: 55–61, 2001.
53. **Richardson D.** Active learning: a personal view. *Adv Physiol Educ* 265: 79–80, 1993.
54. **Rodenbaugh DW, Collins HL, and DiCarlo SE.** Construction of a model demonstrating cardiovascular principles. *Adv Physiol Educ* 277: 67–83, 1999.
55. **Rodenbaugh DW, Collins HL, and DiCarlo SE.** Creating a simple Powerpoint multimedia game. *Adv Physiol Educ* 26: 342–343, 2002.
56. **Rodenbaugh DW, Collins HL, and DiCarlo SE.** Spirometry: simulations of obstructive and restrictive lung diseases. *Adv Physiol Educ* 26: 222–223, 2002.
57. **Rodenbaugh DW, Collins HL, and DiCarlo SE.** A simple model for understanding cohesive forces of the intrapleural space. *Adv Physiol Educ* 27: 42–43, 2003.
58. **Rovick AA, Michael JA, Modell HI, Bruce DS, Horowitz B, Adamson T, Richardson DR, Silverthorn DU, and Whitehouse SA.** How accurate are our assumptions about our students' background knowledge? *Adv Physiol Educ* 276: 93–101, 1999.
59. **Scannapieco FA.** Formal debate: an active learning strategy. *J Dent Educ* 61: 955–961, 1997.
60. **Shepard K and Jensen G.** *Handbook of Teaching for Physical Therapists.* Boston, MA: Butterworth-Heinemann, 1997.
61. **Silberman M.** *Active Learning: 101 Strategies to Teach Any Subject.* Philadelphia, PA: Allyn and Bacon, 1996.
62. **Silverthorn DU.** Using demonstrations to uncover student misconceptions: the Law of LaPlace. *Adv Physiol Educ* 277: 281–282, 1999.
63. **Slavin R.** When does cooperative learning increase student achievement? *Psychol Bull* 94: 429–445, 1983.
64. **Stuart J and Rutherford RJ.** Medical student concentration during lectures. *Lancet* 2: 514–516, 1978.
65. **Swanson DB, Case SM, Luecht RM, and Dillon GF.** Retention of basic science information by fourth-year medical students. *Acad Med* 71: S80–S82, 1996.
66. **Tobin K.** *The Practice of Constructivism in Science Education.* Washington, DC: Am. Assoc. for the Adv of Sci., 1993.
67. **Vander AA.** The Claude Bernard Distinguished Lecture. The excitement and challenge of teaching physiology: shaping ourselves and the future. *Adv Physiol Educ* 267: 3–16, 1994.
68. **Von Neergaard K.** Neue Auffassungen über einen Grundbegriff der Atemmechanik. Die Retraktionskraft der Lunge, abhängig von der Oberflächenspannung in den Alveolen. *Z Gesamte Exp Med* 66: 373–394, 1929. English translation in *Pulmonary and Respiratory Physiology: Benchmark Papers in Human Physiology*, edited by Comroe JH Jr. Stroudsburg, PA: Dowden, Hutchinson & Ross, 1976, part 1, p. 2–3.
69. **West KM.** The case against teaching. *J Med Educ* 41: 766–771, 1966.