# FORMATIVE ASSESSMENT IN PHYSIOLOGY TEACHING USING A WIRELESS CLASSROOM COMMUNICATION SYSTEM

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Systems physiology, studied by biomedical engineers, is an analytical way to approach the homeostatic foundations of basic physiology. In many systems physiology courses, students attend lectures and are given homework and reading assignments to complete outside of class. The effectiveness of this traditional approach was compared with an approach in which a wireless classroom communication system was used to provide instant feedback on in-class learning activities and reading assignment quizzes. Homework was eliminated in this approach. The feedback system used stimulated 100% participation in class and facilitated rapid formative assessment. The results of this study indicate that learning of systems physiology concepts including physiology is at least, as if not more, effective when in-class quizzes and activities with instant feedback are used in place of traditional learning activities including homework. When results of this study are interpreted in light of possible effects of the September 11, 2001 terrorist attacks on student learning in the test group, it appears that the modified instruction may be more effective than the traditional instruction.

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Biomedical engineers often study what is termed "systems physiology," that is, physiology approached from a control systems standpoint. This is an analytical way of learning the homeostatic foundation of basic physiology. In many systems physiology courses, students attend traditional lectures and are given both homework assignments and reading assignments to complete outside of class.

Numerous publications have attested to the effectiveness of active learning compared with the passive learning that occurs when a student merely sits and listens to a lecture (4, 6, 9, 14, 15, 16, 17). The basic idea of active learning is to transform learners from essentially passive recording devices, storing with variable degrees of accuracy in memory and on paper the auditory and visual stimuli perceived in a lecture, into critical decision makers who analyze and synthesize concepts during the class period. Asking questions of the student "audience" during lectures is an attempt to stimulate a little active learning, but with the low response rate typical of a large class, it is a generally ineffective attempt. Mechanisms that ensure participation by all students in active learning exercises are desirable. Several such mechanisms are the commercial products "Personal Response System" (PRS; Educue LLC, Alplaus, NY, www.educue.com), "Classtalk" (Better Education, www.bedu.com), "Classroom Performance System" (CPS; eInstruction, Denton, TX, www.eInstruction.com), "TI-Navigator" (Texas Instruments, Dallas, TX, www.ti.com), and "Interactive Presenter" (Dolphin Interactive, http://www.ballotbox.fi/index.html). Noncommercial versions also have been used (20). The PRS, CPS, and TI-Navigator products all use wireless technology to allow students to respond to questions posed in class. Such classroom communication systems have been used for education in physics (8, 10, 19) and a variety other disciplines (1, 22) although no previous reports of their use for physiology instruction appear to have been published in English-language literature.

These classroom communication systems offer many advantages. The ability of these systems to rapidly collect a large volume of responses via signals not visible to the human eye gets every student to respond to every question without being inhibited by the fear of "looking stupid" to their peers. The ability of these systems to rapidly analyze, display, and store the responses provides timely formative assessment to guide both the instructor and the students. The benefits of full participation and rapid feedback are numerous, including being able to correct misunderstandings rapidly and keeping every student engaged in the learning process. Wireless communication systems offer the additional benefit of allowing easy movement during class, such as might occur when students gather in working groups.

Time spent out of class is also important to the learning process and is often spent completing written homework assignments. Homework can be used as an opportunity to practice skills introduced in the classroom, to expand on material covered in class, to prepare for an upcoming class, and to synthesize and develop new ideas and expressions. Although homework has long been a staple of college-level coursework, conflicting results have been published about its effectiveness. It has been associated with higher grades in mathematics (7, 23) and Spanish (5) at the college level. However, homework has also been shown not to increase achievement in mathematics at the college level (24). In a major review of 84 homework experiments conducted between 1904 and 1984, Foyle and Bailey (11, 12) found that, in more than one-half of the experiments, student achievement was as good with other methods as it was with homework, especially at the college level. The nature and effectiveness of instructor feedback on homework assignments have also been called into question. Paschal (no relation) et al. (18) found that evaluated homework was more effective than ungraded homework. Various other studies have indicated that the nature of the feedback, e.g., only a portion of the assignment being graded (2) or being graded for completeness vs. accuracy (21), makes no difference in later outcomes. Even in those situations where homework is beneficial, its utility is typically hampered by the long time required to grade and return assignments, especially for courses with large enrollments and/or lengthy assignments.

This part of the educational process can be modeled as a student producing an output—a homework solution set—which becomes an input to the professor or teaching assistant, who in turn produces an output—the graded homework—that is fed back to the student so that he/she can modify his/her performance. In such a feedback control system, long delays in the feedback loop lead to large oscillations and inefficiencies in performance of the system. In the context of student learning through homework completed out of class, later turned in, and even later returned with corrections, these delays lead to oscillations and inefficiencies in the learning process. As an example, consider the student who, while working on homework, arrives at an understanding of physiological concepts that is incorrect. Without instant feedback, this misconception can become somewhat fixed in memory and remain uncorrected until perhaps a week later when the graded homework is returned. Then the misconception must be "unlearned" and the correct understanding learned. This is an inefficient process, due primarily to the delay between completion of the assignment and return of the graded work. Such long delays seriously limit the value of graded homework as a formative assessment tool. Some computerized methods have been presented to reduce this delay (3, 13), but the impact of reduced delays in homework feedback does not appear to have been studied.

An additional out-of-class learning activity is reading assignments. Given the volume of information to be studied in a physiology course, out-of-class reading assignments are often used to supplement material covered in class. Such assignments expand on what is covered in class and, depending on timing in relation to lecture topics, can serve to either prepare students for a lecture class or reinforce what has been covered in a lecture. Unfortunately, without an intermediate accountability mechanism, some students do not complete reading assignments until just before a major grading event such as an exam, if they complete the reading at all.

The objective of the work reported here was to incorporate a wireless communication system into physiology instruction for increased formative assessment in class, to add more active learning to the classroom instruction, and to improve the way that out-of-class time is used. These changes were implemented and preliminary comparisons to previous traditional instruction are presented here.

## MATERIALS AND METHODS

The context of this study was the first one-third of a systems physiology course taken by all undergraduate biomedical engineering majors at Vanderbilt University, usually in the fall of the junior year. The 69 students taking the course in the fall of 2000 received traditional instruction (control group), whereas the 63 students taking the course in the fall of 2001 received modified instruction (test group). The instructor, class meeting days and times, and classroom were identical for both years. The instructor has taught this course for several years, so there was no "novice instruction" effect regarding the material between the two years, although the use of a wireless communication system was new to the instructor in the second year.

The main study period included the first eight 75-minute class periods of each semester, which covered the topics of control systems diagrams, feedback, cross-membrane transport, membrane potentials, action potentials, synaptic transmission, neuroreceptors, the peripheral nervous system, and the central nervous system, along with a guest lecture on functional magnetic resonance imaging of brain function. The guest lecture was given both years by the same person using essentially the same slides each year but with discussion points and multiple-choice questions inserted by the course instructor in 2001. In both years, the instructor also gave a brief presentation on writing winning test answers.

The same reading materials were used in both years. Students were assigned to read a 20-page handout on biological control systems, feedback, etc., modified by the instructor from a previous instructor's unpublished work (Dr. David Robinson). Students were also assigned readings from chapters three through seven from *Human Physiology: From Cells to Systems* (4th ed.) by Lauralee Sherwood (20a). The specific selections of textbook readings were slightly more focused in 2001 than in 2000.

### Traditional Instruction Method (2000)

The traditional instruction in 2000 included lectures with *1*) lecture notes supplied online through the course Web site before class sessions, *2*) three homework assignments, and *3*) reading assignments as noted above. Homework assignments were graded by a graduate teaching assistant and an undergraduate grader together, using an answer key drafted by the teaching assistant and revised by the instructor. There was roughly a one-week turn-around time between submission and return of graded homework. Homework answer keys were posted online. Homework assignments from the entire fall 2000 semester, eight in all, counted for 15% of the semester grade.

### Modified Instruction Method (2001)

Four types of modifications were implemented in 2001. First, a PRS (US Patent 6,289,222; EduCue, Alplaus, NY) was utilized to gather, analyze, and instantly report student responses to in-class questions. Second, in-class challenge-based activities and multiple-choice questions were added. Third, four in-class quizzes on reading assignments were instituted. Fourth, homework assignments were eliminated. Lecture notes very similar to those used in 2000 were posted online through the course Web site before class sessions. Quiz answer keys were posted online. Quizzes from the entire semester, nine in all, plus two homework assignments not associated with the period of comparison for this study, counted for approximately 14% of the semester grade. In-class activities had a very minor direct contribution to the semester grade.

FIG. 1.
**Personal Response System (PRS) device (EduCue, Alplaus, NY). Each unit has a unique serial number linked to a specific student. When responding to a question, students have the option of preceding their numeric response with a confidence level (H, high; L, low; default, medium).**

The PRS stimulated 100% participation by students present in responding to in-class questions, provided instant feedback to students and faculty, and automated quiz grading. When entering the classroom, each student would pick up a small device similar to a television remote control (Fig. 1). Each PRS device had a unique serial number and was assigned to a specific student. Multiple-choice questions were computer projected onto a screen at the front of the room, and the answering period was started. Students then pressed the number of their answer choice on their PRS devices. The device sends an infrared signal to receivers at the front of the classroom. When the answer is received, the students' names, but not their answer selections, are displayed on the screen (Fig. 2*A*). When all students had submitted their answers, generally within a one-minute period, the answering period was closed, and a bar graph showing the percentage of students selecting each answer was displayed (Fig. 2*B*). The question and answer choices were then discussed before the class moved on to the next question or other instructional activity. Student-specific data were stored by the PRS software in a spreadsheet for later automated grading or analysis. The PRS can also be used in an anonymous mode.

In-class exercises included simple calculations, synthesis of ideas, and modeling exercises. The question or task was displayed on screen, the students were given time to formulate an answer, and then the PRS was used to poll all the students in the room about their answers. The PRS was used to inform the instructor and the students of the collective performance on in-class activities. Some examples of in-class activities follow. Note that, for the second question, students were given time to create their own systems diagram. After a few minutes, three possible answers were displayed, and students were asked to select the one most like the diagram they drew.

**In-class question 1.** If the Nernst potential for sodium is +60 mV, for potassium is −90 mV, and for chlorine is −74 mV and if, for some reason, $P_{Na+} \gg P_{K+}, P_{Cl-}$, which of the following will be the most likely value of the membrane potential?

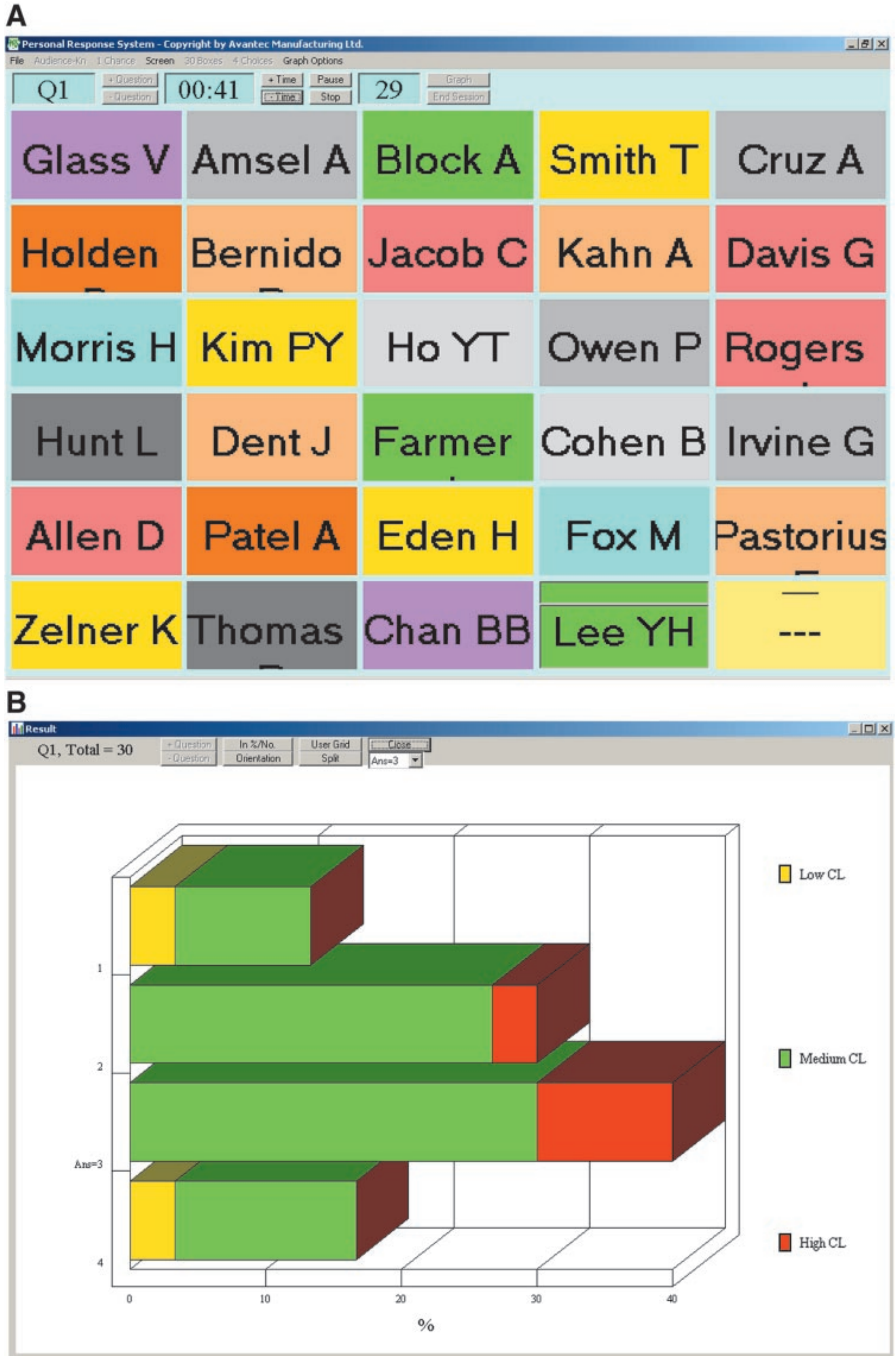
(1) +50 mV

(2) −90 mV

(3) −50 mV

**In-class question 2.** In multiple sclerosis (MS), some nerves become demyelinated. One of the symptoms of MS is difficulty with motor control, especially walking. Basic control of motor function occurs when the motor cortex sends a command signal to the extra-

FIG. 2.
**Display screens for the PRS. *A*: screen shot of response period. The instructor opens up a response period of a selected duration. Students use their PRS device to transmit their choices to a receiver connected to a computer running the PRS software. The system displays the names of respondents as their submissions are received but does not display their answers (names displayed here are fictitious and do not represent students in the reported study). *B*: screen shot showing percentage of respondents choosing each answer. Yellow indicates responses given with low confidence, green denotes a medium (default) confidence level, and red indicates a high level of confidence. Ans =, correct answer.**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Personal Response System - Copyright by Avantec Manufacturing Ltd.
File Audience-Kn 1 Chance Screen 30 Boxes 4 Choices Graph Options
Q1
+ Question
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High CL

fusal muscle fibers (E), which produce a force (f) that acts on a load (L), resulting in a change in the position variable (*x*). Various proprioceptors (P) detect position and feed that information back to the brain to provide input for correction of the command signal. Draw a systems diagram to model this basic motor control system. [*After a few minutes, the following three possible answers* (Fig. 3) *were displayed, and students selected the one closest to their diagram*.]

**In-class question 3.** What type of system element would be added to your diagram from *Question 2* and where to model the changes brought about by MS?

(1) a differentiator just before the proprioceptors (P)

(2) a delay just before the extrafusal fibers (F)

(3) an integrator between F and the load (L)

(4) a delay between the proprioceptors and the brain

(5) 2 and 4

[Answers: *question 1*, (1); *question 2*, (1); *question 3*, (5)].

Quizzes on reading assignments were given at the beginning of four of the eight class periods. Students were given a copy of the quiz on paper so that they could individually allocate their time between the four or five multiple-choice questions. Questions were designed to assess completion and understanding of reading assignments. Two sample questions are shown here.

**Quiz question 1.** In Fick's law of diffusion, as described in your textbook, the five variables affecting the net rate of diffusion Q are the concentration gradient of the substance ΔC, the distance (membrane thickness) ΔX, the surface area of the membrane A, the permeability of the membrane to the substance P, and the molecular weight of the sub-

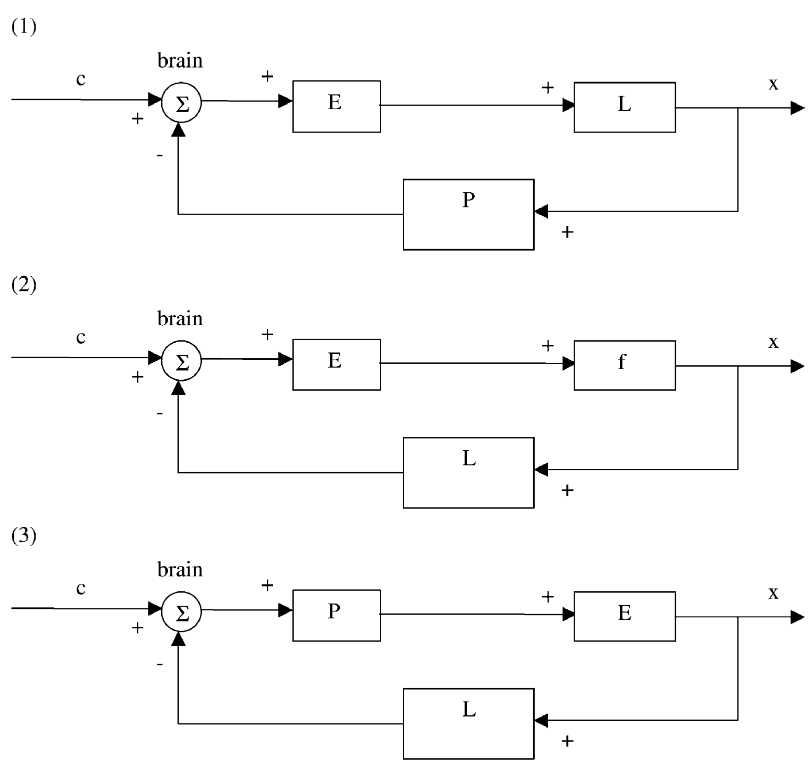


**FIG. 3.**
**Systems diagram model: the 3 possible answers.**

stance MW. Which of these factors, if *increased*, will, in turn, *increase* the net rate of diffusion?

(1) $\Delta C$, MW, $\Delta X$

(2) P, A, MW

(3) $\Delta C$, A, $\Delta X$

(4) $\Delta C$, P, A

**Quiz question 2.** You are ironing the clothes you are going to wear on a date that evening. You begin to daydream about your exciting evening plans, and you stop paying attention to what you are doing. Your finger touches the hot iron and you quickly withdraw your hand. Your response involves the three types of neurons in your body. In what order are these types of neurons involved in the initial response?

(1) efferent neurons, interneurons, afferent neurons

(2) interneurons, efferent neurons, afferent neurons

(3) afferent neurons, efferent neurons, interneurons

(4) afferent neurons, interneurons, efferent neurons

[Answers: *question 1*, (4); *question 2*, (4)].

After about 10 minutes, the PRS was used to submit answers to the first question, and the totaled responses were displayed, and the answers discussed. This process was repeated for the next question, and so on. Both the students and the professor had instant feedback about student understanding of the readings, which the professor used to guide emphasis in the subsequent lecture.

### Assessment and Evaluation

To compare the effectiveness of the two instructional methods, the professor created two exams ("A" and "B"), with questions covering very similar content and selected from the same total content with very similar styles. Then, by use of random selection (coin toss), questions from *exam A* and *exam B* were allocated between the *2000 exam* and the *2001 exam*. Each year's exam had an equivalent number of reasoning, calculation, and memory questions. The exam was administered in the ninth class period of each year and was graded by the professor using the same criteria for each year. In both years, the exam grade was 20% of each student's final semester grade.

In 2001, after the exam, the professor reverted to traditional instruction with lectures, homework, reading assignments, and no quizzes for a period of three weeks (six class periods). Topics covered in this time included musculoskeletal physiology and the beginning of cardiovascular physiology. At the end of this period, students were surveyed regarding completion of reading assignments and preferences for instructional style.

Because achievement before entering the course could affect performance in this study, student grade point averages and numbers of credit hours earned before entry in this course were obtained for all but one student in each cohort (These two students were new to Vanderbilt, and no such data were available for them). The cohorts were then compared. Approval from the local Institutional Review Board was obtained before this information was obtained.

## RESULTS

As shown in Table 1, the students in 2001 scored higher (70.1 ± 10.7%) than the students in 2000 (66.6 ± 12.6%) on the exam. The difference was not significant, as determined by an unpaired (2-sample) *t*-test assuming unequal variances. A histogram of the exam scores (Fig. 4) shows that, in 2001, fewer students earned very low scores (scores less than 50%) than did so in 2000.

Metrics of student performance before entry in the course, summarized in Table 2, showed no difference

**TABLE 1**
**Course performance data**

| | 2000 | 2001 |
|---|---|---|
| Number of students | 69 | 63 |
| Homework average | 82.8% | NA |
| Quiz average | NA | 71.8% |
| Exam average* | 66.6 ± 12.6% | 70.1 ± 10.7% |

NA, not applicable. *No significant difference in exam scores were found between the 2000 and 2001 classes.

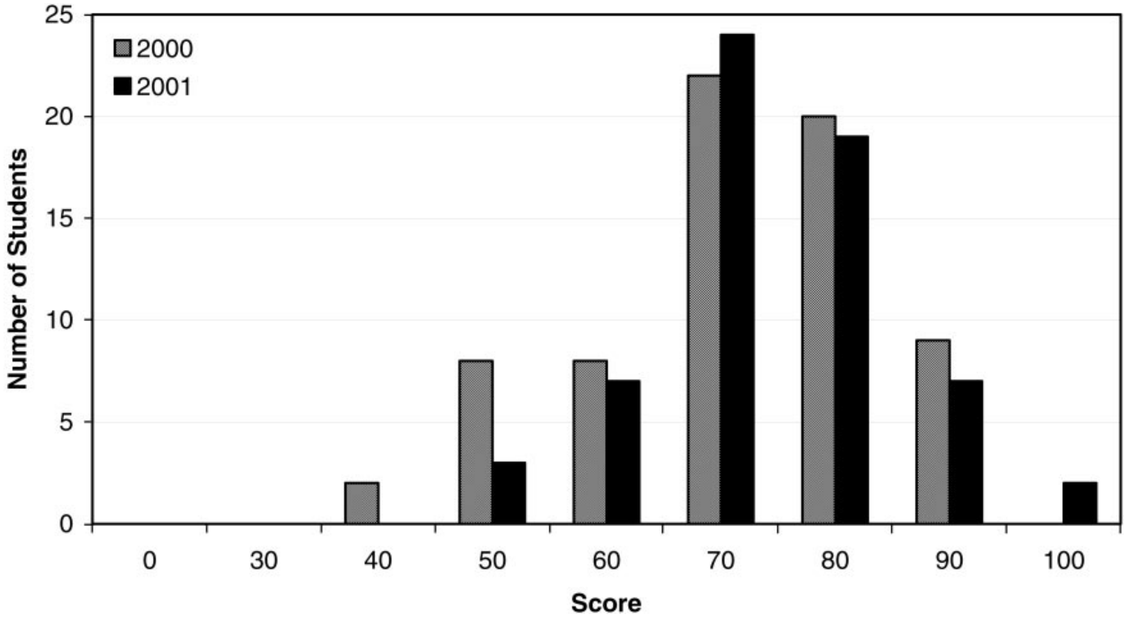


**FIG. 4.**
**Exam scores for students in 200 and 2001. Although the mean score is not significantly different between the two years, note that, in 2001, there were fewer scores below 50% than there were in 2000.**

in the preparedness and past accomplishments of students in the two cohorts, again as measured by an unpaired *t*-test assuming unequal variances.

Survey results in 2001 indicated that 47.5% of students completed all of the systems and neurophysiology reading assignments in time for class when quizzes were given, whereas only 33.3% of students completed the musculoskeletal reading assignments once the modified instruction period ended when no formal accountability tool was used. Three class periods into the next unit (class no. 15), on cardiovascular physiology, no students (0%) had completed the cardiovascular reading assignments.

When surveyed about the system that each student in 2001 thought optimal for learning and time management, a majority chose a combination of reading assignment quizzes, in-class exercises, and no homework. This was the process used for the test group. The next most popular choice was no quizzes on reading assignments with in-class exercises and homework. Detailed survey results are given in Table 3.

**TABLE 2**
**Prior performance data**

| | 2000 | 2001 |
|---|---|---|
| Grade point average | 2.93 ± 0.53 | 3.04 ± 0.51 |
| Quality credit hours | 57.87 ± 12.96 | 58.61 ± 10.16 |
| Total credit hours* | 67.49 ± 14.99 | 66.07 ± 13.20 |

*Total credit hours equals quality credit hours plus hours earned by advanced placement examinations, transfer credits, and pass/fail courses. No significant differences were found for any of these measures of performance prior to entry in the systems physiology course, illustrating the equivalence of the cohorts.

## DISCUSSION

The exam scores for students participating in the modified instruction in 2001 were slightly higher, but not significantly so, than the scores of students receiving the traditional instruction in 2000. However, a critical confounding event that may have lowered student performance in 2001 and thus reduced the significance of the results was the Sept. 11, 2001 terrorist attacks that occurred on the day of one of the class periods and quizzes in this study. Then, the Student Government Association organized a 9/11 memorial activity and walkout that disrupted another

**TABLE 3**
**Student survey responses 2001**

| | |
|---|---|
| I think the following system is optimal for my learning and my time management: | |
| 1) Quizzes on reading assignments; in-class exercises; homework | 7.0% |
| 2) Quizzes on reading assignments; in-class exercises; no homework | 50.9% |
| 3) Quizzes on reading assignments; no class exercises; homework | 1.8% |
| 4) Quizzes on reading assignments; no class exercises; no homework | 8.8% |
| 5) No quizzes on reading assignments; in-class exercises; homework | 28.1% |
| 6) No quizzes on reading assignments; no class exercises; homework | 3.5% |
| I think the following system is optimal for my learning and my time management: (same question, but with only two choices) | |
| 1) Quizzes on reading assignments; in-class exercises; no homework | 69.0% |
| 2) No quizzes on reading assignments; in-class exercises; homework | 31.0% |

class period in this study. Other potential confounding factors include instructor inexperience using wireless communication systems for classroom instruction and potential biasing of the exam design toward the traditional lecture and homework method of instruction.

The PRS was very beneficial. For the professor, instant feedback identified both misconceptions needing extra attention in class and areas of good understanding needing less time in class. For students, PRS feedback quickly identified misconceptions before they became deeply ingrained, as can be the case with homework completed out of class and not returned for approximately one week. By displaying names and total count of student respondents but not revealing individual answers publicly, the PRS promoted 100% participation and forced students to think about and select answers to the questions asked. Thus the students were more actively engaged in the learning process than when passively listening to a lecture.

In 2001, quizzes on the reading assignments made students much more accountable for the material in the reading assignments. Consequently, most students in 2001 came to class with some knowledge of the material already and thus were potentially better able to understand and assimilate the content covered in class. When such intermediate accountability events were stopped, the same students were less likely to have read the assigned material.

The new approach to instruction changed workloads, with students and the teaching assistant having reduced loads. With no homework to complete, student workload was reduced, allowing more time for students to complete the reading assignments. With no homework, grading workload, normally handled in this course by a teaching assistant (TA), was dramatically reduced. A new responsibility for the TA was to create quizzes, answer keys, and related PRS files under the professor's supervision. However, this was similar to TA responsibilities in previous years to create homework assignments and answer keys, again with the professor's guidance. The professor's class preparation workload increased due to the need to create new in-class activities, although once created such activities can be reused in future years. The PRS system required about 5–10 minutes of setup and breakdown time every class period, although a permanent installation of the system would eliminate this time requirement.

Elimination of homework was but one of four interventions in this study; thus the effect of its omission cannot be isolated. However, these results showing essentially equivalent performance when homework was replaced with in-class learning activities and quizzes with instant PRS feedback are consistent with the meta-analysis findings of Foyle (11) and Foyle and Bailey (12). Given the time savings of the new method for both students and the person(s) responsible for grading and the student preferences expressed in the survey results, it seems clear that homework should be omitted from future offerings of this course.

## CONCLUSION

The results of this study indicate that learning of systems physiology concepts, including control systems and neurophysiology, is at least as and potentially more effective when in-class quizzes and activities with instant feedback via a wireless classroom communication system are used in place of traditional learning activities including passive lectures and homework. This new approach results in time savings for both students and those who grade homework assignments. When the results of this study are interpreted in light of a major confounding factor, it appears that the modified instruction may be more effective than the traditional instruction.

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