Exploring an Electronic Polling System for the Assessment of Student Progress in two Biomedical Engineering Courses

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Abstract

Monitoring students' understanding as part of course lectures has the potential to increase student engagement, facilitate modification of instruction so it targets learners' needs, and increase students' overall learning of the course materials. Classroom Communications Systems (CCS) provide a method for students to respond immediately to questions posed by a professor in class. The results are aggregated and reported to the instructor and the students in the form of a histogram (see http://www.bedu.com for more information on commercially available CCS). We have introduced one of these electronic polling systems into two biomedical engineering courses: biomechanics and physiological transport phenomena. Fifty-seven CCS questions were asked in the biomechanics class. Students in this class were separated into 3 groups on the basis of the number of CCS questions they answered during the semester: low (<26, N=13), mid (26-44, N=10), and high (>44, N=15) participation groups. Comparisons were made between the three groups for total course performance, overall examination averages, final exam grade and average homework grade. In every case, low-participation students performed significantly lower than high or mid participation students. No differences were found in performance between the mid and high participation groups. We conclude that performance in all aspects of the course is related to class participation. The primary reason for non-participation in CCS activities was absenteeism. There were only rare cases when students, present in the classroom, did not answer a CCS question. There was a slight, but not significant, difference in the rate of correct responses to CCS questions between the 3 groups. Therefore, when low-participation students are present, they appear to understand the material as well as mid- or high-participation students. This would suggest that the reason low-participation students do poorly in the course is because they miss significant portions of the material that is presented in class, not because they are unable to understand the material. We believe the CCS system engages students during class by providing them with timely feedback, and assisting the instructor in setting the pace for introducing new material. This paper describes the result of this initial investigation for using CCS in engineering education and discusses research we are conducting on the next generation of CCS for higher education.

Introduction

Classroom Communications Systems (CCS) are methods that can provide useful formative assessment to students and timely information about student comprehension to instructors. All CCSs provide mechanisms which perform the following basic functions: 1) delivery of an appropriate question to the entire class (or selected subgroup); 2) retrieval of individual student responses to the question; 3) Sorting, compilation and display of student responses; and 4) discussion of student responses. CCS can exist in many different forms. We are all familiar with the simplest form of a CCS in which an instructor poses an oral statement to the class and asks for a show of hands of first those who agree, then those who disagree with the statement. The "vote" is tallied and a discussion ensues. Although this is reasonably effective in generating discussion, it suffers from the fact that the student responses are not anonymous. Consequently, there are many students who do not raise their hands, either because they are unsure of the answer or they don't want others to know their response. One way to ensure anonymity is to have students answer the question on an index card. The instructor then collects the cards, sorts them and reports the responses. Although this process ensures anonymity, it can be very time-consuming, particularly in large classes.

Technological advances in recent years have led to the development of a number of different electronic devices for CCS designed for large lecture halls. One of the earliest is Classtalk, which consists of small palmtop computers or calculators (Texas Instruments and Hewlett Packard) that connect to the teacher's computer with cables at each seat [2-7]. As students enter the lecture hall one member from a group selects a computer from a cabinet and connects it to the cable at his or her seat. The professor then poses a question, the groups deliberate, and they submit either a multiple choice or short answer response. Recently, Texas Instruments created a system called Navigator that uses wireless hubs located strategically throughout a classroom. This works well in many engineering schools where the calculator is a ubiquitous device. Other manufactures use infrared (IR) technology to provide wireless connectivity with the instructor's computer. Each student can use an inexpensive handheld device with a 12 key pad to respond to a professor's question. For this study we used the Personal Response System (PRS) by Better Education[1].

These CCS systems have been used in multiple domains, but some of the earliest uses have been in the area of physics, mathematics and chemistry. Mazur was an early pioneer of the system at Harvard and has great success with it in his physics class. Students' conceptual understanding of Newtonian mechanics increased significantly when they used the PRS system compared to students taught in a more traditional method[5-7]. The use of these systems continues to grow. A group at the University of Massachusetts has been forming a community of users that share many techniques and potential questions.

The PRS system provides the instructor and the students with several major advantages. First, this process encourages students to reflect on the concepts that have just been presented and allows them to think about how they might explain or apply these new ideas. This requires that they become less passive during class and more generative. The second benefit emerges from this generative process. If students find that they can't answer the question, then they can ask the professor clarifying questions, rather than discovering that they don't understand the material while doing homework. A third benefit to the students is the opportunity to see that they are not alone in their misconceptions. A fourth benefit is that the process is anonymous, which should encourage student participation. A fifth benefit, which results from anonymous student participation, is that the professor receives immediate feedback from the entire class showing the level of understanding for the class as a whole on selected concepts. Therefore, through the use of well-designed questions and multiple-choice responses, a professor can diagnose where students may be going astray and modify the instruction appropriately. A sixth benefit is that it gives an instructor entry into students' thinking processes, and this can be used as an instructional tool. For example, the result of a survey of students' responses can be used as a discussion-starter. The professor can ask a student who responded a certain way to explain why they chose their particular response. This allows the professor to probe their reasoning and guide the students toward a more refined understanding of the concepts.

Designing Questions for Classroom Communication Systems

There are many valid reasons for soliciting student responses during a course lecture. In this study we designed PRS questions that fall into the following categories : 1) questions that stimulate interest in a new topic, 2) questions designed to assess preconceptions or knowledge of a topic before it was formally discussed in the course, 3) questions designed to assess a student's understanding of concepts recently introduced via lectures, homework assignments, etc., and 4) other questions, unrelated to specific course material. Questions in the last category were generally related to housekeeping issues, such as a vote on whether or not to move an exam to a different date.

Asking questions that challenge a student's intuition can be an excellent method to generate interest in a new topic and to focus on critical features about the application of this new information. For example, Figure 1 shows the second in a series of questions designed to stimulate interest by raising a student's awareness of the severity of accidental falls in the elderly. Figure 1 illustrates that only a small percentage of the class intuitively selected the correct result. The sequence of questions ultimately leads the students to the identification of a potential market for products that can either prevent the elderly from falling or protect them from injury when they do fall.

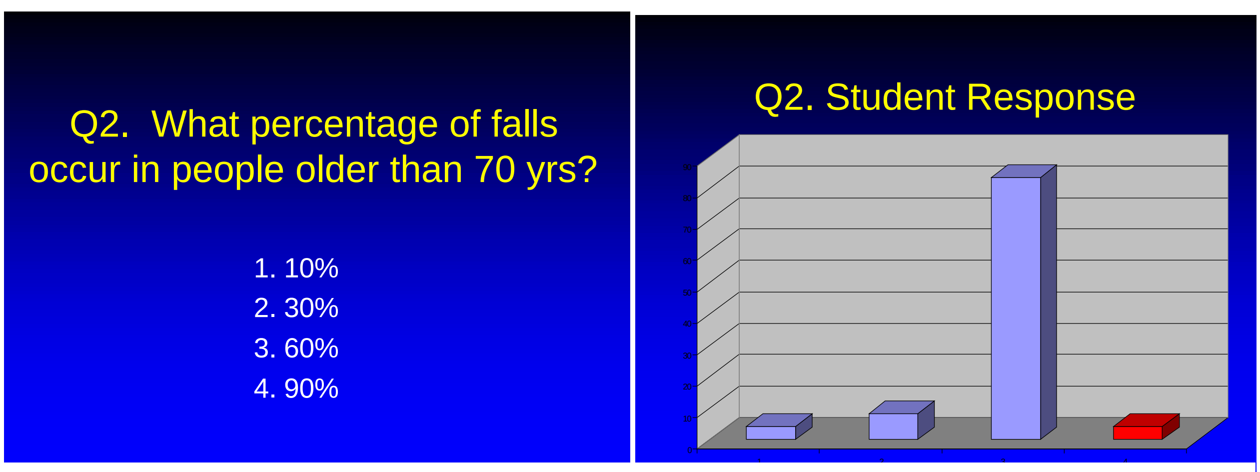

Figure 1 - An example of a question used for stimulating interest. The correct answer is 90%.

Similarly, helping students identify their preconceptions can help them realize their lack of understanding or misunderstanding, and can provide the instructor with valuable information about methods that might tailor instruction to suit the needs of that specific class. An example of a question designed to assess student preconceptions is given in Figure 2a. Students knew the definition of mechanical advantage, but had little experience in applying it to living systems. Most students missed this question. They felt that since the horse is bigger than the armadillo it must provide a greater mechanical advantage. After answering this question, students were provided with the anthropometric data shown in Figure 2b and were asked to compute the mechanical advantage for the forelimb of each animal. Finally, the original question was repeated, and this time nearly the entire class answered correctly (Figure 2c).

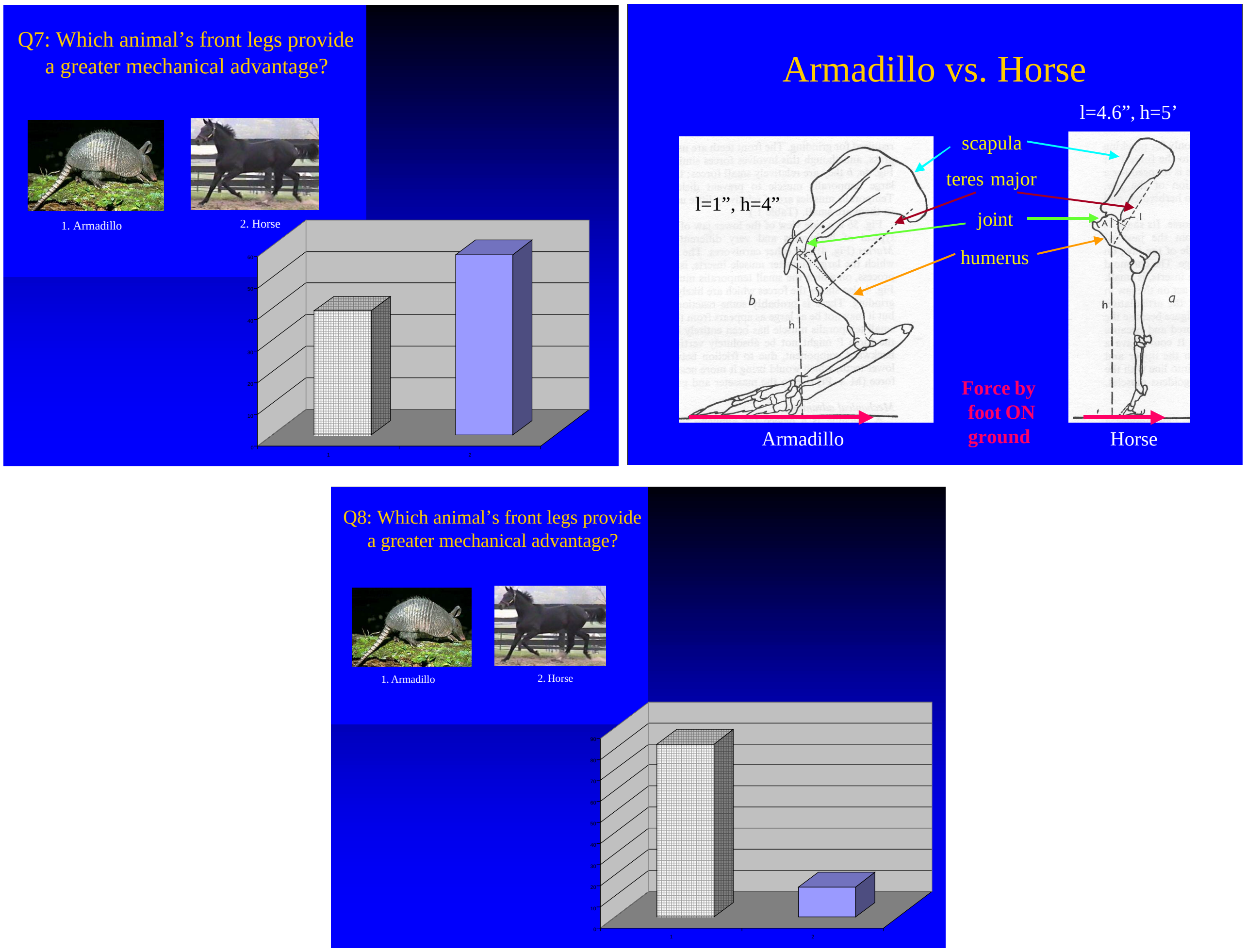

Figure 2. a) top, left: original question (preconception). b) top, right: anthropometric data. c) bottom: repeat original question.

The PRS system was used primarily to pose questions designed to assess students' understanding of recently introduced concepts. In BME 101, for instance, 46 of the 57 questions were so classified, including that shown in Fig 2c. Student responses to these questions were used to determine whether or not the class should move on to the next topic or module. In some cases, nearly all of the students appeared to grasp the concept with ease (Figure 3), but in others the majority of students had substantial difficulty with a concept (Figure 4). In those cases the concept was reviewed extensively and a class discussion was initiated. For instance, the sign convention for shear stress in Figure 4 was clearly misunderstood by a majority of the class. Rather than move on to the next topic, which would have happened in the absence of a PRS system, the definition of positive shear stress was reviewed and several additional examples were worked out in class. Although it is difficult to quantify how the interventions influenced student interest and understanding, it is safe to say that without the PRS system the students would not have had the opportunity to have gone back over materials they had difficulty with until after the next examination.

In some cases the same question was asked both before and after the introduction of relevant course material. In most cases the distribution of answers was shown immediately after the question was answered, with no indication of the correct answer. After the results were displayed the instructor often attempted to determine why students selected one of the foils, and pointed out specific misconceptions. In some cases, the distribution of answers was withheld until after students attempted to convince other members of a small group of the merits of their answer. Following the discussion, the same question was asked again, and the distributions for both the original and repeated question were displayed.

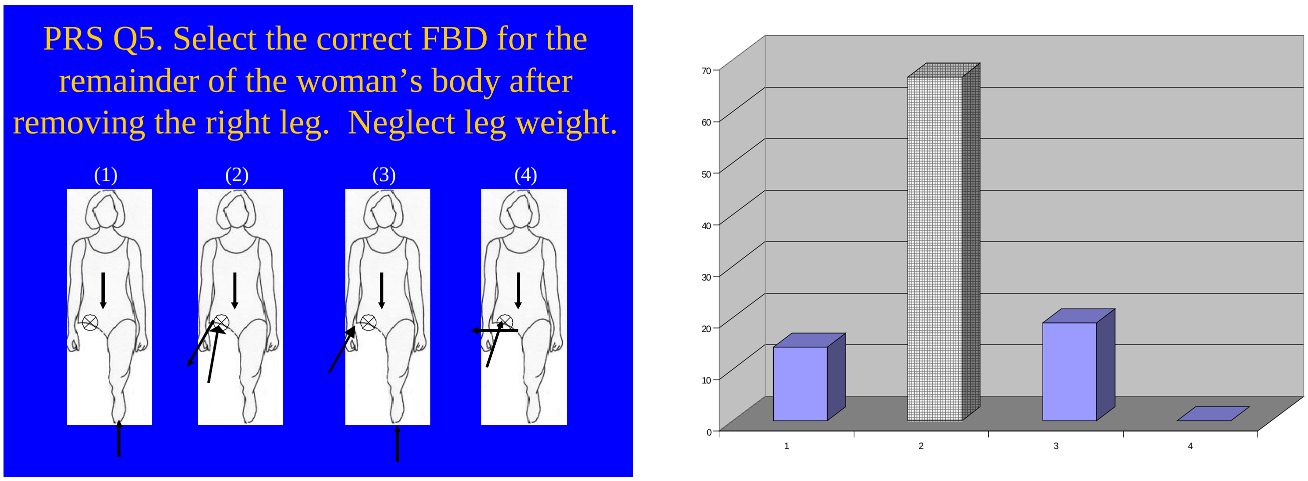

Figure 3. Understanding the concept of a free body diagram.

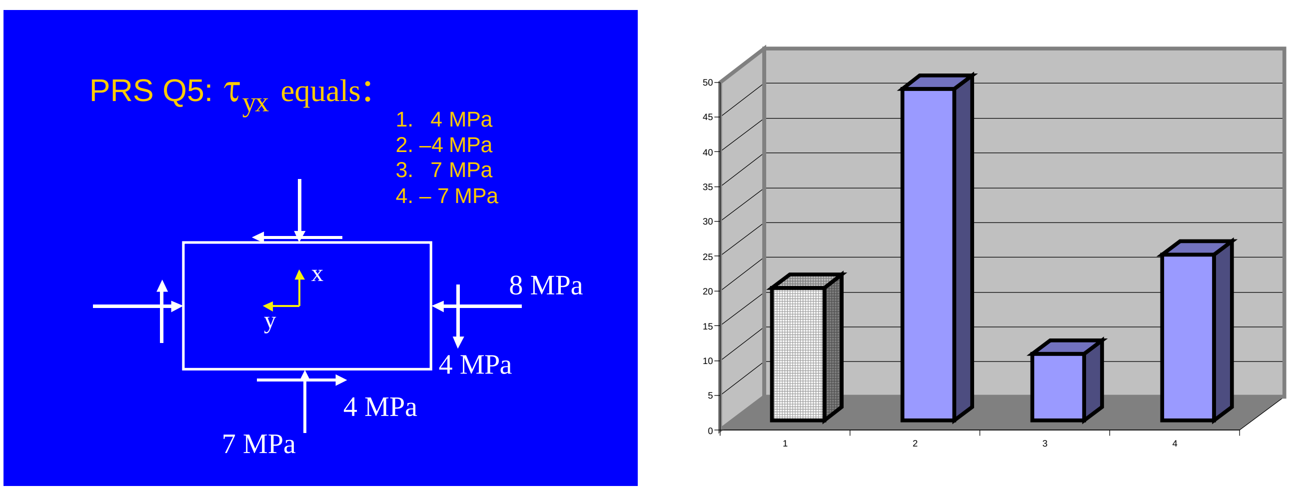

Figure 4. Difficulties with understanding the sign convention for shear stress.

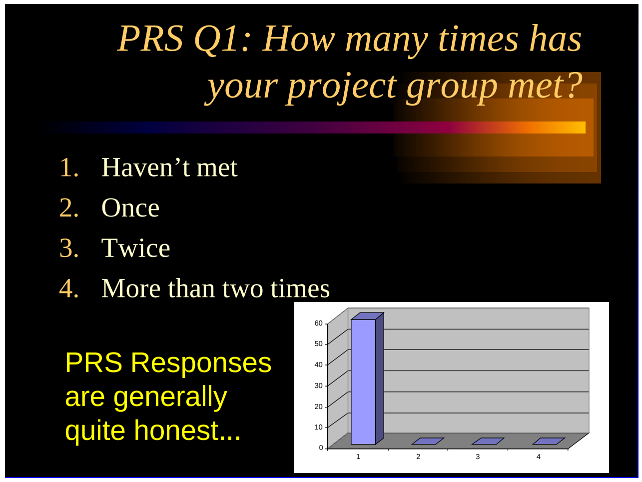

Figure 5. An additional use for the PRS system.

Finally, the PRS system can be used for general classroom administration such as voting on due dates for assignments and gathering information about the students. An example of this "other" category of questions posed with the PRS system is shown in Figure 5. After repeatedly suggesting that students get together to discuss their projects, students were asked in class how many times their group had met. Every student reported that they had not yet met with other members of their group. The same question was asked the next week and the response showed that all groups had met at least once. This illustrates a couple of points about the PRS system. First, students appear to answer PRS questions honestly. Second, the PRS system can be used to help motivate students. Since the PRS response is anonymous it was used to tally votes on a number of other issues, such as shifting the date of an examination

Methods

A Classroom Communications System was used regularly in two undergraduate biomedical engineering courses: introductory biomechanics (BME 101) and physiological transport (BME 210). Both are required courses in the biomedical engineering curriculum at Vanderbilt University. Students normally take biomechanics during their sophomore year and transport in their junior year. The course objectives in biomechanics are to provide fundamental principles and biological applications of statics, dynamics, and strength of materials. The course objectives in physiological transport are to provide fundamental principles and biological examples of fluid mechanics, mass transfer, and heat transfer.

The CCS used in both courses for formative assessment was the Personal Response System (PRS)[4]. This system consists of a receiver wired to the instructor's computer and several small wireless devices (infrared transmitter similar to common remote controls for TVs) with 12 button keypads. Students are assigned an individual PRS device at the beginning of the semester. Students use their PRS device to respond to true/false and multiple choice questions asked in class. Unique signals are sent from each wireless remote to a receiver connected to the instructor's computer located at the front of the room. The students use their PRS to enter up to 10 responses, along with their confidence level (low, medium (default), or high) (see http://www.educom.edu for more details). Once all the responses are received, the computer can display a bar graph illustrating the distribution of responses. After class the remote units are collected and placed in a case, which is stored for the next class.

A total of 57 PRS questions were asked in BME 101 and 44 questions were asked in BME 210. Each class was divided into three groups of roughly equal size, based on the number of PRS questions answered. The number of questions answered during the semester was taken as a measure of class participation. Low class participation was associated with answering fewer than 26 of 57 questions in BME 101 (N=13) and fewer than 35 of 44 questions in BME 210 (N=19). The middle group answered 26 to 44 of 57 questions in BME 101 (N=10) and 36 to 41 of 44 questions in BME 210 (N=20). The high-participation group answered more than 44 questions (N=15) in BME 101 and more than 41 questions (N=20) in BME 210. Students in BME 210 were told that class participation would make up 10% of their final grade and that class participation would be measured primarily by the PRS system.

Course performance for each student was evaluated in several ways: 1) Total points accumulated in the course; 2) performance on homework assignments; 3) average exam performance; and 4) final exam performance. Total points in BME 101 were based on the following distribution: 15 points for each of four semester examinations, 25 points based on 18 homework assignments and 15 points for oral and written group project reports. An optional final exam could be taken to replace one of the four semester exam grades. The total points in BME 210 were based on the following distribution: 15 points for each of three semester exams, 15 points based on 15 homework assignments, 15 points based on a written group project report, 15 points based on the final examination, and 10 points based on class participation.

Analysis of variance (ANOVA) was applied to determine if a difference in student performance ($p<.05$) existed between the three levels of student participation. A t-test with unequal variances was used to evaluate the degree of significance between groups. Comparisons were made for each of the student performance measures described above.

Results

Although each student's response was anonymous in the classroom, it was associated with a specific student and recorded by the PRS system. Since the PRS system was used regularly it provided a measure of each student's participation in the classroom. There was a significant difference between student performance based on student participation in these two courses, as summarized in Tables I and II. ANOVA indicated a significant difference between the three groups for every measure of course performance ($p < 0.05$). The Student t-test showed a consistent difference between the low and high participation groups for all performance comparisons. All students in both courses who received final grades of D or F were found to be in the low participation group for that course. No student in the low participation group of 19 students from BME 210 received a final grade of A, while only two of the 13 students in the low participation group in BME 101 received a final grade of A. Nine of the twelve students who answered all PRS questions in BME 210 ranked 13th or higher in the final class rankings.

Table I. BME 101 Performance vs. Participation

	Low Participation	Mid Participation	High Participation	Low vs. Mid	Low vs. High	Mid vs. High
Total Points						
Average	63.0	77.2	78.9	*	*	ns
Variance	225.8	3.5	30.42			
N	12	10	15			
Exams						
Average	59.1	75.4	75.7	*	*	ns
Variance	279.1	15.1	23.3			
N	13	10	15			
Homework						
Average	51.4	72.2	78.5	*	*	ns
Variance	812.6	86.5	133.7			
N	13	10	15			
Final Exam						
Average	64.9	79	81.7	*	**	ns
Variance	97.6	86.2	45			
N	9	10	9			

ns - not significant (t > .05) * significant (t < .05) ** highly significant (t < .001)

Table II. BME 210 Performance vs. Participation

	Low Participation	Mid Participation	High Participation	Low vs. Mid	Low vs. High	Mid vs. High
Total Points						
Average	66.4	77.9	83.9	**	**	**
Variance	145.0	30.3	45.9			
N	19	20	20			
Exams						
Average	65.4	73.5	78.9	*	**	*
Variance	198.0	59.0	88.6			
N	19	20	20			
Homework						
Average	64.9	90.5	98.8	**	**	**
Variance	435.9	57.6	57.3			
N	19	20	20			
Final Exam						
Average	53.3	60.2	66.1	ns	*	ns
Variance	263.9	78.9	174.8			
N	19	20	20			

ns - not significant (t > .05) * significant (t < .05) ** highly significant (t < .001)

Discussion

PRS results suggest that there is a strong correlation between class participation and class performance. Those students who came to class regularly and answered PRS questions tended to do well in the two courses that were examined. Virtually all students who attended a lecture also answered PRS questions posed during that class period. Therefore, class participation, as measured with the PRS system, reflected class attendance. We found no significant difference between the percent of PRS questions answered correctly between any of the participation groups. Hence, when low participation students attend class they appear to understand the material just as well as students who attend class regularly. We would speculate, then, that their lower performance on exams and homework may not reflect their ability to master the material, but rather that they may have missed important information by not participating in classroom activities.

Students in the mid-participation group in BME 101 tended to do just as well as those in the high participation group, suggesting that missing just a few classes does not seriously influence performance. However, in BME 210, where the number of students in each group weas larger, there was generally a significant difference between the performance of the mid-participation and high-participation groups.

The variance in all performance measurements for the low-participation group was always higher than the mid-participation or high-participation groups, indicating that this group probably consists of two or more sub-classifications. These might include students who skip class because they feel comfortable with the material, students with extended illnesses, students who are not able to manage their time effectively, students who are not stimulated by the course material or the course instructor, or students who have excessive involvement in other activities.

There are some disadvantages associated with electronic CCS systems in general, and with the PRS system in particular. Often, the receiver is not permanently installed in the classroom, so it must be transported to and from the classroom for each class session. Thus, time must be allotted for setting the system up and breaking it down for each session. The transmitters used by students must also be transported to the classroom, distributed at the beginning of class and collected at the end of class. Although transporting the transmitters to class each day is an inconvenience, no class time is lost because each student is assigned a specific transmitter at the beginning of the semester. They remove their transmitter from a numbered box when they enter the classroom and return it to the same location when they leave. An alternative would be for students to buy their own transmitter and bring it to each class. However, it was decided that this would increase the possibility that some students who actually participated in the class would be unable to answer CCS questions because they forgot or lost their transmitter.

Since these systems are electronic and are delivered via computer, they suffer from all the problems associated with such devices. Transmitter batteries can go dead (this did not happen in either class), transmitters or receiver circuit boards can malfunction (one transmitter stopped functioning), wires between computer and receiver can become disconnected (this happened several times), etc. In addition, the computer software expects the questions to conform to a specific syntax. The PRS system, for instance requires that each question be differentiated from the next by inserting the symbols "><". Failure to do so will generally result in lost student response data. Another serious flaw peculiar to the PRS system is that it will not function unless the computer system detects a floppy drive. Even though the PRS system does not use the floppy drive, it will not function if the floppy drive is replaced with a CD ROM drive in the media bay of a laptop computer. Still another difficulty is the lack of graphics capabilities in most CCS systems. Many of the concepts in engineering are visual in nature, such as free body diagrams, system diagrams, graphs, etc. The PRS system did not have this capability. We had to switch back and forth between Powerpoint slides, which contained the images, and the PRS system, which recorded the student responses.

Many of the current CCS systems are small, inexpensive and very simple to use by both student and instructor. . Part of the simplicity of PRS and many other CCS systems is that they are limited to only multiple choice responses. This has both pros and cons. By presenting students with predefined responses an instructor can perform a diagnosis of students' understanding from the incorrect answer they choose. Also, CCS makes it possible to quickly aggregate data so results can be displayed immediately to the instructor and students. However, even well designed multiple-choice questions only require students to select an answer. It is possible for students to select the correct answer through a process of elimination, by recognition, or by a simple guess, rather than generating a solution on their own. The need to be more generative during problem solving is very important. On a written exam this can be a real draw back, but with the CCS system there are some alternatives that can result in better learning. For example, in the biomechanics course we asked students to first generate a free body diagram, then they were shown 4 or 5 possible solutions and asked to select the one that was closest to the free body diagram that they generated.

One of the biggest challenges for instructors is to phrase CCS questions and potential answers that encourage students to think deeply about the concepts. In many situations the multiple-choice system cannot provide the optimal method for posing questions. A CCS that can capture short answers and a tool to help display and organize the results could open up the range of learning activities that occur in the classroom. For example, students could be asked to brainstorm ideas, send them to the system, and the teacher's station could be used to sort through the results. Another great feature would be for students to submit essays and images using this system. We are working on a system that will provide this functionality using wireless laptops that every engineering student will own within the next 4 years at Vanderbilt.

Conclusion

Although it seems reasonable, if not obvious, to expect a correlation between class performance and class participation, we are unaware of any studies in which this relationship is confirmed for biomedical engineering undergraduates. It is our hope that results from this study will be used to prove to students the benefits of participating in classroom activities. At the same time we hope these results will encourage instructors to consider the use of course communication systems as a way of providing feedback to their students and assessing the effectiveness of their own classroom presentations. Further research needs to be conducted on how these PRS systems increase learning in the classroom that cannot be duplicated outside the classroom, i.e., cases where participation in class is necessary in achieving the course objectives. New research on learning and instruction are illustrating the benefits of learning during classroom instruction over and above simply receiving information from the professor. The classroom experience appears to be a fundamental component to learning.

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Bibliography

1. Schwartz, D. L., Lin, X., Brophy, S., & Bransford, J. D. (1999). Toward the development of flexibly adaptive instructional designs. In Reigeluth (Ed.), Instructional Design Theories and Models: Volume II. Hillsdale, NJ: Lawrence Erlbaum Associates.
2. Dufresne, R.J., Gerace, W.J., et al, "Classtalk: A Classroom Communication System for Active Learning", J. Comput. in H. Ed., Vol 7, pps 3-47, 1996.
3. Mestre, J.P., Gerace, W.J., Dufresne, R.J., & Leonard, W.J., "Promoting Active Learning in Large Classes Using a Classroom Communication System," in E.F. Redish & J.S. Rigden (Eds.), *The Changing Role of Physics Departments in Modern Universities: Proc. Of the Intl. Conf. on Undergraduate Physics Education (pp. 1019-1036), Woodbury, NY, American Instit. Of Physics, 1997.*
4. Wenk,L., Dufresne, R., Gerace, W., Leonard, W., & Mestre, J., "Technology Assisted Active Learning in Large Lectures." In C. D'Avanzo & A. McNichols (Eds.) Student-Active Science: Models of Innovation in College Science Teaching (pp. 431-452), Philadelphia Saunders Publishing, 1997.
5. Mazur Eric, "Understanding or memorization: Are we teaching the right thing", in *Conference on the Introductory Physics Course*, Ed. Jack Wilson, (pp. 113 – 124), Wiley, New York , 1997.
6. Mazur Eric, "Peer Instruction: Getting Students to Think in Class", in *The Changing Role of Physics Departments in Modern Universities, Part Two: Sample Classes*, AIP Conference Proceedings, Ed. Edward F. Redish and John S. Rigden, (pp. 981 – 988), American Institute of Physics, Woodbury, New York , 1997.
7. Mazur, Eric, "*Peer Instruction - A User's Manual*" , 253 pages, Series in Educational Innovation, Prentice Hall, Upper Saddle River, New Jersey, 1997.

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