AC 2007-972: USING TECHNOLOGY TO PROMOTE ACTIVE LEARNING IN BIOMEDICAL ENGINEERING

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Using technology to enhance active learning in Biomedical Engineering.

Abstract

This paper evaluates previous uses of Personal Response Systems (PRS) and the pedagogical rationale associated to the different uses. We illustrate the use of PRS systems in two different courses: Systems Physiology and Thermodynamics. We describe the motivation to use PRS as well as the pedagogical methods associated with PRS use in the courses. The main goal of the study is to evaluate the relationships between students' use of PRS and learning outcomes. We used two measures to evaluate students' use of the PRS system. A Response index was calculated as the percentage of questions answered. A second index, Correct Response index was calculated by dividing the number of correct answers by the number of questions attempted. Learning outcomes were assessed using exam grades and final course grade. Students' perceptions relative to PRS use in the course were measured using a questionnaire. We found a positive and significant relationship between PRS Response index and course performance for both courses. We conclude by comparing and evaluating the differences found in the results from both courses.

1. Introduction

National calls for reform in science education [1] recommend a shift in instructional focus to incorporate the student as an active member of the educational process. The National Academy of Engineering is also promoting new initiatives to support innovative work in engineering education [2] Ebert-Mar, Brewer & Allred [3] indicate that learning is a constructive process that requires active participation by not only the teacher but also the student. Active involvement of students in large engineering classes can become a challenge. A possible approach includes "hands-on" experiences in the lab and small interactive classrooms [3]. However, small classrooms are not always possible. As a result, strategies that promote active, inquiry-based and collaborative learning in large classes are likely to have a large impact in the future of science and engineering education.

Personal response systems (PRS) are a type of Classroom Communication System (CCS) consisting of a combination of hardware and software designed to support communication and interactivity in classes. CCS, also known as electronic voting systems (EVS), have been primarily used in science courses within post-secondary education. Such systems provide immediate feedback to students and inform instructors of students' misunderstandings. CCSs typically incorporate four features: presentation of questions using presentation software (such as MS PowerPoint), remote individual transmitters, receivers to capture individual responses, and software to compile and present results. Using the CCS, any student in the classroom is able to respond to multiple choice questions asked by the instructor.

The methods of CCS use in large university classes vary with the pedagogical rationale and educational objectives. Kennedy and Cutts [4] explored different approaches in the use of CCSs. One approach is to incorporate the technology within the standard lecture. Using this method, lecture materials are supplemented with questions posed to students at certain points during the lecture followed by feedback and some discussion on the responses. A second approach is the use as a diagnostic tool in large group tutorials with the aim of determining students' misunderstandings. A third approach is to use the system to assist students with exam preparation using questions similar to those expected in formal assessment. A more developed use of CCS was pioneered independently by Mazur [5] and Dufresne et al [6]. Their approaches, though independently taken, integrate and adapt lecture materials and technology to allow for active learning and peer-based discussion. Mazur's approach requires students to do preparatory work prior to the class. The class is structured around questions posed to the students to probe their conceptual understanding of fundamental concepts. The students first respond as individuals. This is followed by peer discussion in small groups (usually three students) where students attempt to reconcile differences, and this is followed by a second vote. Dufresne's approach is more focused on class-wide discussion based on the responses and misconceptions of students. Although Kennedy and Cutts [4] describe separate approaches to PRS use, it is likely that instructors use a combination of these approaches.

This study reports on an effort to evaluate the relationship between PRS use and learning outcomes in two different courses. Moreover, we evaluated students' perceptions of the PRS systems in both classroom settings. We believe that PRS promotes active learning in the classroom, and, as a result, our main hypothesis was that there would be a positive correlation between PRS use and course grade. We also expected that students who had a higher rate of correct responses would tend to achieve higher grades.

2. Research Methodology

In this section, we begin by describing participants in the study and research goals. Next we describe the context of PRS use in both courses and conclude by describing data collection and analysis.

2.1. Participants

Participants in this study were students in two courses in the Biomedical Engineering Department, a human Systems Physiology course and a Thermodynamics course. A total of 101 students participated in the study. All participants were assigned a PRS unit at the beginning of the quarter, which they used during the lectures.

2.2. Research goals

Our main goal was to evaluate the relationship between PRS use and academic performance for each of the classes and compare and evaluate the results from both settings. An additional objective was to evaluate students' perceptions related to PRS use in the course.

2.3. Context of use of PRS

The instructors used PRS because they believed that it would help them structure their instruction time in ways that were consistent with student learning theories [7]. Both instructors had extensive experience using PRS. PRS use in the class was encouraged, but it did not

contribute to the course grade. We treated the classes as two separate populations since the instructors, the PRS questions, and the course content were different.
Both instructors use the PRS to accomplish the following goals [8]:

- Help students actively construct knowledge in class
- Reveal the extent of misconceptions
- Provide feedback to the instructor on where students are having difficulties
- Demonstrate to students that there are others who do not understand
- Encourage student interaction to promote learning
- Encourage a discussion between class and instructor
- Emphasize important concepts
- Provide a motivational basis for the next phase of lecture
- Help determine the pace of the instruction
- Keep students engaged and focused (and awake)

2.3.1. Physiology

Forty-eight undergraduate students taking the Physiology course participated. The course is taught in the Biomedical Engineering Department, and it has a strong quantitative focus. Each student was assigned a transmitter. PRS questions were incorporated into Power Point presentations, and were used in 16 of a total of 30 lectures. The instructor posed 33 questions during the quarter, with one to four being posed on a given day. The data were collected during the second year that PRS was used in this class. Besides the common goals for both instructors given above, the physiology instructor had the additional goal of using the PRS questions to assist students with exam preparation by introducing questions similar to those that might appear on exams. The questions were typically conceptually-based and required some reflection on the material presented before. Students read the question and then individually responded to it. After responses were collected the instructor presented the histogram of responses and followed with some discussion, often getting students to explain their rationale for particular answers. In a relatively small number of cases, students answered individually, then engaged in peer discussion, and then answered again before there was any general discussion. In almost all cases, this led to a higher percentage of correct answers. Whatever discussion format was used, the instructor summarized what was right and wrong with each answer in an attempt to leave the correct message with the students, rather than any misconceptions that were revealed by the discussion.

2.3.2. Thermodynamics

A total of 53 students from the Thermodynamics course participated in the study. All students were assigned a transmitter at the beginning of the quarter. The instructor posed 60 PRS questions during the quarter. Besides the general goals for using PRS presented above, the instructor wished to create a community of learners among the students in the class. The PRS system was used in 19 of the 30 lectures. Peer discussion followed by a second presentation of the question was more frequently employed in the Thermodynamics course. As in the Physiology course, questions were typically concept-based and required some reflection on the material presented previously. Correct answers were also summarized before moving on.

2.4. Data Collection and Outcome Measures

Students' responses were automatically recorded during each class session and were compiled at the end of the quarter. Two measures associated with PRS use were created. A "Response" index was calculated as the percentage of questions answered. A second index, the "Correct Response" index was calculated by dividing the number of correct answers by the number of questions attempted. Learning outcomes were assessed using the score on each exam (two midterm exams and a final exam in each course) and the overall score for the class, which included all exams and homework.

At the end of the quarter, students also completed a survey on their perceptions of PRS use, which asked 20 questions that were answered on a 5 point Likert scale, ranging from strongly agree (5), through agree and neutral to disagree and strongly disagree (1). In the analysis below, the mean response is presented for each question. In addition, the number of students selecting agree plus strongly agree was computed, as was the number of students selecting disagree plus strongly disagree.

2.5. Statistical Analysis

Correlation analysis was used to evaluate the relationship between PRS use and learning outcomes. We evaluated correlations between the Correct Response index and grades and between the Response index and grades. In addition to correlation analysis, we conducted a regression analysis on overall grades using the two PRS response indices as predictors.

3. Results

3.1. PRS use and class performance

We evaluated correlations between PRS use and grades. Table 1 shows the results of the correlation analysis for both courses, including the significance level. For the Physiology course, significant correlations were found between the Correct Response Index and each exam grade and between the Response index and grades for the second midterm exam (exam 2) and the final exam. Both PRS use and the Correct Response index were also positively correlated with overall scores in the course. Results from the correlation analysis for the Thermodynamics course were slightly different than those in the Physiology course. In this case, the strongest correlations were found between the Response index (i.e. PRS use) and grades, but no significant correlations were found between the Correct Response index and grades.

Table 1. Correlations found in Physiology and Thermodynamics

			Exam1	Exam2	Final Exam	Overall Course Percentage
Physiology N=48	Correct Response %	Pearson Correlation	**.436(**)**	**.501(**)**	**.349(*)**	**.497(**)**
		Sig. (2-tailed)	.002	.000	.015	.000
	Response %	Pearson Correlation	**.131**	**.362(*)**	**.288(*)**	**.356(*)**
		Sig. (2-tailed)	.381	.013	.047	.013

Thermodynamics N=53	Correct Response %	Pearson Correlation	.028	**.299**(*)	.077	.188
		Sig. (2-tailed)	.844	.029	.582	.178
	Response %	Pearson Correlation	.183	.074	**.441**(**)	**.466**(**)
		Sig. (2-tailed)	.190	.598	.001	.000

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

We used scatter plots to further assess the relationships between PRS use and course grade. We present 2 graphs for each course. The first plot (Figure 1) presents overall grade vs Correct Response Index for Physiology, and the second (Figure 2) represents overall grade vs Response Index also for Physiology. Figures 3 and 4 are similar graphs for the Thermodynamics class. As also reflected in Table 1, the graphs indicate a stronger linear relationship between Correct Response index and course grade in the Physiology course (see Figure 1) than in the Thermodynamics course (see Figure 3). Moreover, in the Thermodynamics class there is a stronger relationship between Response index and grade (see figure 4) than between Correct Response index and grade (see Figure 3).

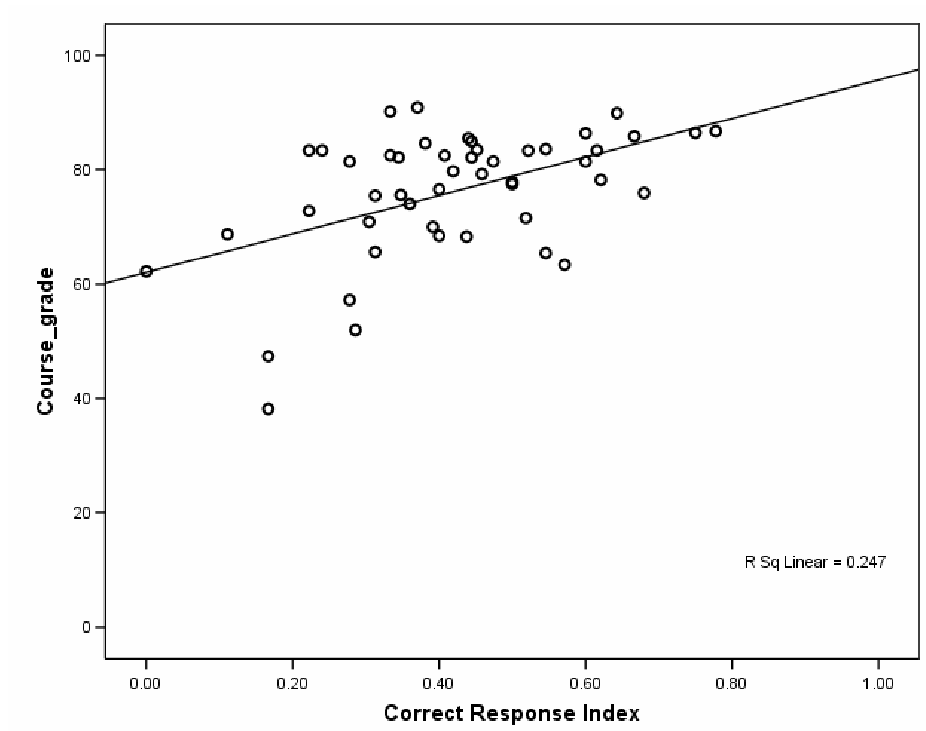

Figure 1. Physiology: Course grade vs Correct Response Index

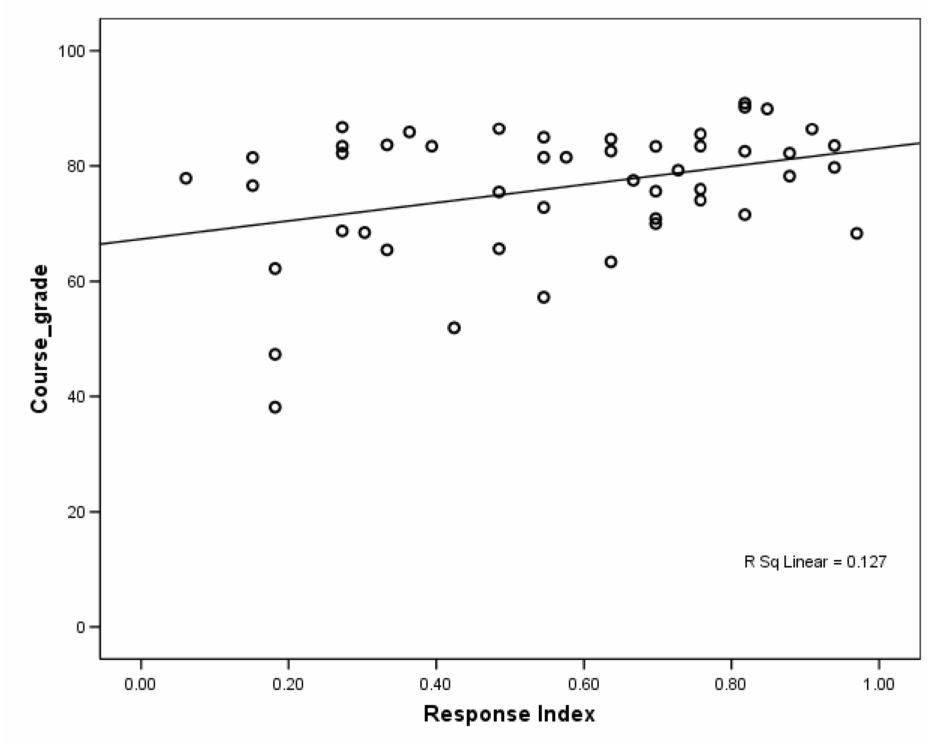

Figure 2. Physiology: Course grade vs Response Index

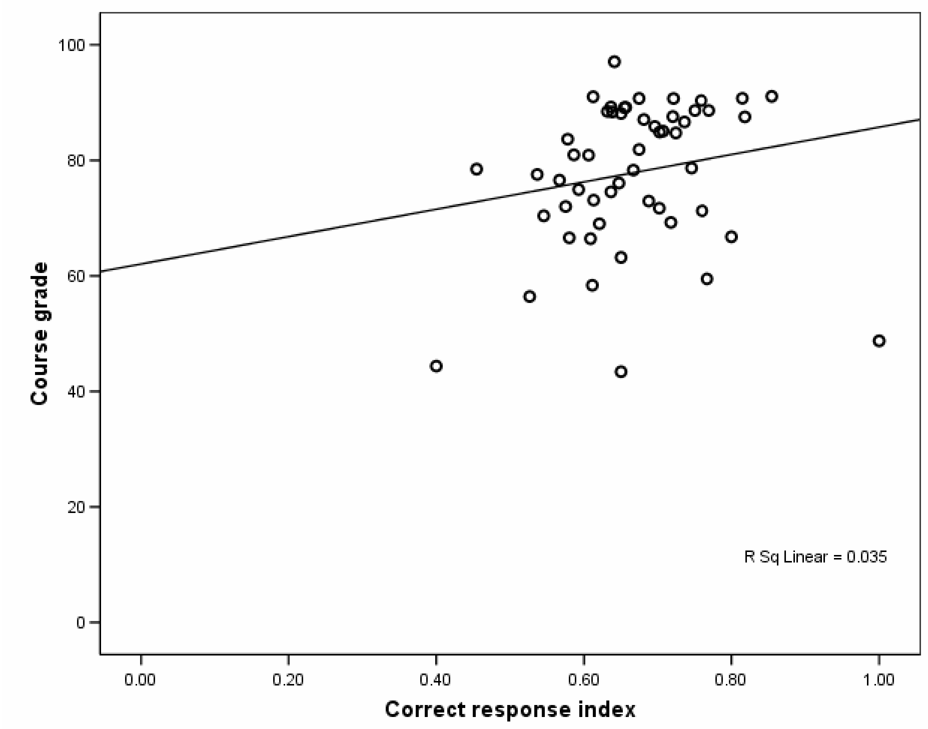

Figure 3. Thermodynamics: Course grade vs Correct Response Index

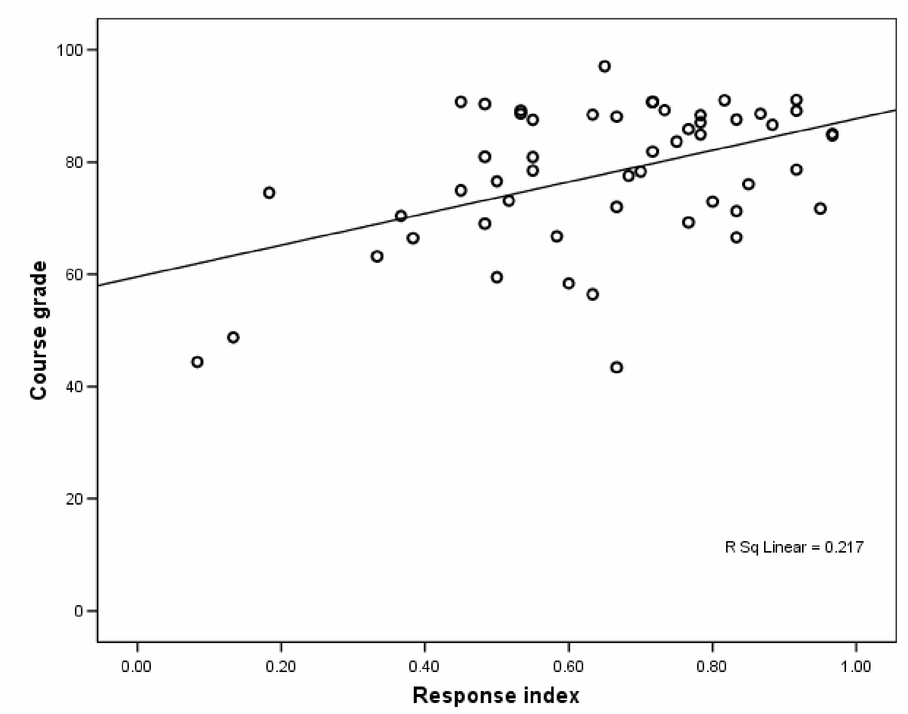

Figure 4. Thermodynamics: Course grade vs Response Index

The two measures of PRS use were combined into a regression model to evaluate their relative and combined effects. The response variable used was course grade. For the Physiology course, the model based on percentage attempted and percentage correct explained 32% of the variance in overall grade (R^2=0.32). The regression model was significant (p=0.0001). Results from the regression analysis in the Thermodynamics course resulted in R^2=0.23, that is, the model explained 23 % of the variance in grade. The model was also significant (p=0.002). However, one main difference between the two courses was that in the Thermodynamics course, only the percentage of questions attempted was a significant predictor of the final grade in the course. On the other hand, in the Physiology course, both percent correct and percent attempted were significant predictors of final grade. As a result, in Physiology we found a positive relationship between Correct Response Index and course grade and between Response Index and course grade. In the Thermodynamics class, the relationship was only significant between Response Index and course grade.

3.2. Distribution of Correct Responses

To help us evaluate the different results of the correlation analysis, we compared the distribution of correct responses in both courses. Figure 5 represents the histograms of percentage of correct PRS answers for both courses, with the Physiology class at the top and the Thermodynamics class at the bottom. The abscissa represents the percentage of correct answers whereas the ordinate represents the number of students achieving each percentage in each course. Figure 5 also incorporates data on mean and standard deviation of the Correct Response index. The mean percentage of correct answers in Physiology was shifted to the left compared to the mean in

Thermodynamics. Possible reasons for the lower correct response rate in the Physiology course are that 1) the questions posed were at a higher level of difficulty, and/or 2) slightly more than one third of the responses in the Thermodynamics course occurred after discussion with a peer, and one would therefore expect a greater rate of correct responses.

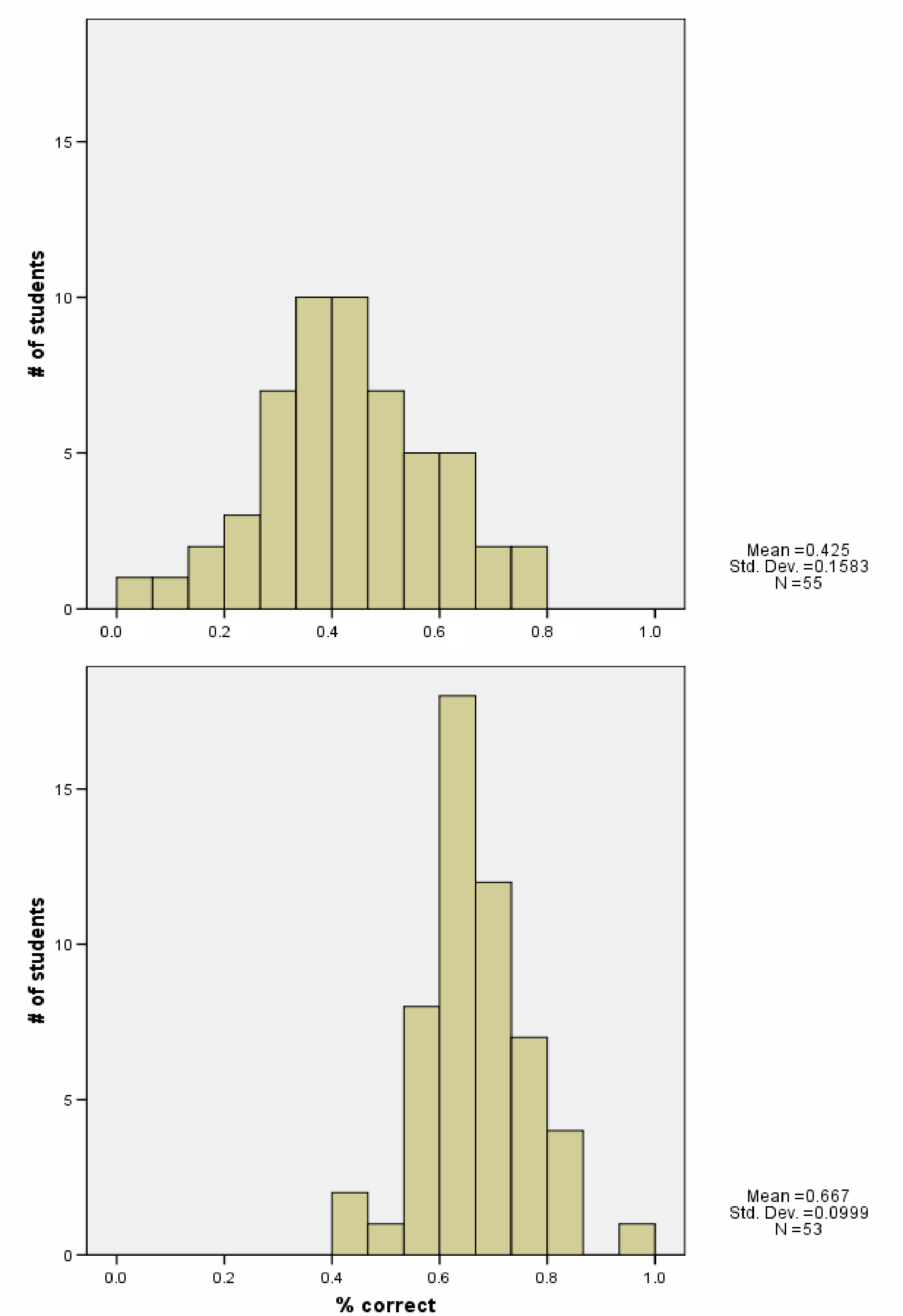

Figure 5. Histograms of the number of students giving different percentages of correct answers by course. The Physiology course is shown in the top graph and the Thermodynamics course is shown in the bottom graph.

3.3. Survey of Student Perceptions

Students' perceptions relative to PRS use in the course were measured using a questionnaire. The questionnaire consisted of twenty items assessing different aspects of the students' experience with PRS: conceptual understanding, interaction and discussion, enjoyment and learning [8]. Results from the questionnaire are shown in Table 2, which indicates the percentage of disagreement, percentage of agreement and overall mean for each question. The data indicate that students generally found the PRS system to be useful in both of these courses. In particular, participants strongly agreed that using PRS helps them to be aware of misunderstandings, to understand the material, and to see the relevance of the material to the outside world. It also makes them think more during class, and helps them learn by hearing each other's explanations. Students also strongly agreed that PRS helps the instructor to see the level of understanding of the students. These results are similar to survey results obtained from students in these two classes in the previous academic year.[8]

Table 2. Questionnaire results*

	Physiology			**Thermodynamics**		
Question	% disagree	% agree	Mean	% disagree	% agree	Mean
In this course, I am more aware of my misunderstandings than in more traditional courses.	4	69	3.8	12	68	3.8
The change in awareness of my misunderstandings in this course is attributable mainly to the use of the PRS.	14	67	3.5	17.	60	3.5
Using the PRS helps me to understand the concepts behind problems.	14	76	3.8	19	64	3.6
The PRS questions asked help me to understand what is expected from me in this course.	16	65	3.8	12	79	3.7
This course provides some insight about the relevance of what is studied in the course to the outside world.	12	69	3.8	7	84	4.1
In this course, I got to know fewer students than I usually do in a traditional course.	27	16	2.9	68	0	2.2
I think that anonymous participation is a good idea.	8	80	4.1	5	84	4.2
I am more actively involved during this course than during traditional courses.	18	51	3.4	9	68	3.8
I am more actively involved in this course primarily due to the use of the PRS.	12	66	3.6	6	69	3.8
I have to think more in class sessions that use PRS than in those that do not.	10	71	3.9	9	70	3.8
I study less outside of class for courses that use PRS than for courses that do not use the PRS.	51	10	2.5	28	23	2.9
I remember less after class sessions that use the PRS than after class sessions that do not.	59	10	2.4	61	12	2.4
Discussing PRS questions with other students in the class helps me to better understand the subject matter.	10	73	3.8	14	2	3.7
Seeing the class responses to a concept question (histogram) helps increase my confidence.	10	57	3.7	10	79	3.8

I enjoy this course more than I enjoy traditional lecture courses.	16	53	3.5	10	62	3.7
The PRS should be used for other subjects.	12	69	3.8	5	83	3.6
Using the PRS helps the teacher to become more aware of student difficulties with the subject matter	8	82	4.1	2.4	88	3.9
Hearing other students explain problems in their own words when working in our small groups helps me to learn	10	76	2.8	12	79	3.9
I am more likely to attend class because of using the PRS	35	24	2.9	29	37	3.1
PRS responses to in-class questions should be counted for grade	90	2	1.4	88	5	1.6

[*] The table does not include the percentage of students who responded "neither agree nor disagree" to the questions. The agree columns include students selecting "agree" or "strongly agree," and the disagree column includes those students responding "disagree" or "strongly disagree" to the questions. Percentages do not add to 100% because the neutral responses are eliminated from the agree and disagree columns. However, all responses are included in the averages.

Conclusions and Discussion

We found a positive and significant relationship between PRS Response index and course performance for both courses.. There are many factors involved in course performance, but the variation in PRS use accounted for 13% of the variance in course performance in physiology and about 20% in thermodynamics. This result supports the work of Roselli & Brophy [9], who recently reported similar results for the use of PRS in a biomechanics class, and the work of Slain et al. [10], who were able to rigorously compare entire classes in pharmacy education with and without PRS use. The work of Slain et al.[10] is especially important, because they used the same final assessments in two courses that were similar except for PRS use, so they were able to conclude not only that PRS use is correlated with performance, but *causes* better performance. Thus, the value of PRS use for enhancing student performance now has strong experimental support.

The answer to the second question, regarding whether *performance* on PRS questions (the Correct Response index) is correlated with performance on summative measures, has been investigated less often. If a student selects the correct response more often, it suggests that he or she is more on top of the material when it is presented. The better students (e.g. the ones who have prepared in advance, are paying attention, can digest material faster) might be expected to do better on both formative and summative assessments, and this is why we expected a correlation. However, we only found a positive relationship between Correct Response index and summative measures for the Physiology course. Slain et al [10] also reported at best a weak relationship between PRS performance and course performance, with the strongest R^2 being 0.2 in the three classes they investigated. Upon further reflection, one recognizes that better performance on the PRS questions need not translate to better performance on summative assessments. One goal of using the PRS is to alert the students who get fewer PRS questions correct that they are not yet ready for a summative assessment, and need to learn more. Therefore, failure to find a relationship between the two kinds of performance, PRS and summative, does not reflect negatively on the use of PRS at all. However, we are left with the question of why a significant correlation between PRS performance and summative performance was found in Physiology but not Thermodynamics. One possible explanation is that the instructor in the Thermodynamics course more regularly combines PRS use with peer discussion, offering the opportunity for those students who responded incorrectly to engage in a personal discussion and perhaps increase their understanding to a level near that of their peers who responded correctly to the question. Since peer discussion around the PRS questions was used more frequently in the Thermodynamics course than in the Physiology course, that could explain the lack of a significant relationship between PRS Correct Response Index and grades in Thermodynamics. If true, this suggests that peer discussion enhances the learning gains of more students in the classroom and therefore is an important component to couple with PRS use. We are performing further studies to evaluate the characteristics of peer discussions and why they may help.

As an alternative to the explanation just offered, the instructors also evaluated whether differences in the types of exam questions in both courses might have caused the difference in the correlation of PRS performance and course performance. This seems less likely. The instructors believe on the basis of comparing exams from the two courses that exams from both courses required similar levels of conceptual understanding and cognitive processing. Typically, students were given scenarios and then were asked questions about them that attempted to assess their level of conceptual understanding of certain key concepts.

Previous research suggests that not just the use of personal response systems, but more specifically, the pedagogy associated with the use of these systems [3,4] is important. Some studies suggest that better learning outcomes are really the result of changes in pedagogical focus, from passive to active learning, and not the specific technology or technique used. However, PRS facilitates the transition by providing a platform that enhances student participation during the lectures. The technology's significant advantage originates from planning and aligning lecture format, pedagogical goals and learning assessment. One key aspect to enhance success and participation is the implementation of the technology, which should be meaningful and interesting to the student. The two approaches described in this paper were similar and both elicited positive responses and interest from the students. One difference is that peer discussion was used more frequently in the Thermodynamics course, and the results from the statistical analyses suggest that coupling peer discussion with PRS use can enhance students' ability to actively construct knowledge in class.

References

1. National Research Council. (1996). *National science education standards.* .Washington, DC: National Academy Press.
2. Wulf, W. A., & Fisher, G M. C (2002). A makeover for engineering education. *Issues in Science and Technology*. Online, http://www.nap.edu/issues/18.3/p_wulf.html.
3 . Ebert-May, D., Brewer, C., Allred, S. (1997). Innovation in Large Lectures: Teaching for Active Learning**.** *BioScience*, 47(9), pp. 601-607.
4. Kennedy, G. E.; Cutts, Q. I.(2005). The association between students' use of an electronic voting system and their learning outcomes. *Journal of Computer Assisted Learning, 21*(4), pp. 260-268(9).
5. Mazur, E. (1997), *Peer Instruction: A User's Manual*, New Jersey: Prentice Hall.

6. Dufresne, R.J., Gerace, W.J., Leonard, W.J., Mestre, J.P. and Wenk, L. (1996),‘Classtalk: A classroom communication system for active learning’, *Journal of Computing in Higher Education, 7*, 3-47.
7. Bransford, JD, Brown, AL & Cocking, RR, eds. (1999) *How People Learn: Brain, Mind, Experience and School.* Washington, DC: National Academy Press, 1999.
8. Linsenmeier, RA, Olds, SA, and Kolikant, Y B-D (2006) Instructor and course changes resulting from an HPL-inspired use of Personal Response Systems. *Proceedings, 36th ASEE/IEEE Frontiers in Education Conference, October, 2006*, San Diego, CA, 6 pp.
9. Roselli RJ & Brophy, SP (2006) Experiences with formative assessment in engineering classrooms. *Journal of Engineering. Education, 95*, 325-333.
10. Slain, D, Abate, M, Hodges, BM, Stamatakis, MK, & Wolak, S. (2004) An interactive response system to promote active learning in the doctor of pharmacy curriculum. Am. J. Pharmaceutical Education. 68(5), pp. 1 – 9.

Acknowledgements

This work was supported primarily by the Engineering Research Centers program of the National Science Foundation under grant EEC-9876363.