

Real-Time Analysis of Student Comprehension: An Assessment of Electronic Student Response Technology in an Introductory Earth Science Course

Lisa Greer

Washington and Lee University, Geology Department, Lexington, VA 24450,
greerl@wlu.edu

Peter J. Heaney

Penn State University, Department of Geosciences, University Park, PA 16802,
heaney@geosc.psu.edu

ABSTRACT

Electronic student response technologies (SRT) are capable of assessing teaching and learning methods in real time, and they offer an exceptional means of introducing active learning protocols in classes with large enrollments. These wireless systems allow students to key in responses with remote control units to questions posed by an instructor in the classroom. Student responses then are displayed in real time, allowing both students and instructors to gauge student comprehension instantaneously. From Spring 2002 to Spring 2003, we utilized SRT in 4 sections of a high-enrollment introductory Earth Science course (Geosc 020: Planet Earth) at Penn State University. We conducted a multi-faceted assessment of the use of SRT in our course that included quantitative and qualitative perception data from students enrolled in the course and faculty/administrator visitors to our classroom. Our preliminary assessment of the pedagogical merits of SRT in our course suggests that this technology is an effective tool for introductory geoscience education.

INTRODUCTION

A number of studies have shown that traditional methods for teaching science to non-science majors are limited in their effectiveness (Pinet, 1995; Dufresne et al., 1996; Mazur, 1997; DeCaprariis, 1997; Gerace et al., 1999; McManus, D.A., 2002; McConnell et al., 2003). In the conventional approach, instructors present information in a lecture format and the students passively gather that information by listening and taking notes. Several newer teaching models stress active student participation, in which students process material presented in class via discussion with the instructor and peers, problem solving, and group activities interspersed with periods of listening and note-taking (Angelo and Cross, 1993; Bykerk-Kauffman, 1995; Mazur, 1997; Yuretich et al., 2001; Crouch and Mazur, 2001). However, even when more progressive teaching methods are employed, it often is difficult to gauge student involvement, interest, and level of comprehension.

Electronic student response systems present one method for overcoming these barriers to engagement and effective learning (Dufresne et al., 1996; Mestre et al., 1997; Wenk et al., 1997; Gerace et al., 1999; Judson and Sawada, 2002; Meltzer and Manivannan, 2002; McConnell et al., 2003). When an instructor can query and collect responses from every individual in his or her classroom, the instructor can gauge instantaneously what students understand, and more important, which concepts they are failing to grasp. This feedback allows the teacher to spend less time on material that already

has been processed in favor of focusing on 'problem areas'.

Inspired by our on-site observation of classroom response systems used in physics and biology courses at the University of Massachusetts at Amherst in 2001, we decided to test similar technologies in Geosc 020: Planet Earth, a general education course at Penn State with mean semester enrollments of ~145 students per section (Table 1). In Spring 2002 we initiated our experimentation with a commercially manufactured electronic response technology produced by eInstruction called the Classroom Performance System (CPS). While response systems have been successful instruments of active learning in university-level physics, chemistry, and biology courses for well over a decade (Littauer, 1972; Dufresne et al., 1996; Mestre et al., 1997; Gerace et al., 1999; Judson and Sawada, 2002; Meltzer and Manivannan, 2002), SRT use in the collegiate Earth Sciences is in the early stages of implementation (McConnell et al., 2003).

The primary pedagogical goal of our SRT integration project was the creation of an active-learning environment in a large introductory Geoscience course (Geosc 020), which previously had been taught in traditional lecture format. Specific objectives of the project were to encourage active student participation in Geosc 020, to enhance student communication and collaboration skills, to develop problem solving skills during class time, and to increase student attendance in class from the historic mean attendance of ~50% by mid semester.

As a necessary component of this effort, we wished to evaluate the perceived effectiveness of SRT technology in enhancing both student learning and instructor teaching. To address this requirement, we conducted a multi-faceted assessment of student opinions on the benefits and disadvantages of using this technology in our class. We compiled quantitative data via extensive student surveys and student attendance data. We collected qualitative data from oral student surveys and from interviews with faculty peers who observed our operation of SRT in our classes (Greer et al., 2002; Heaney and Greer, 2003).

METHODS

What is the Classroom Performance System?

Student response technology has been in development for several years. The ClassTalk system (Dufresne et al., 1996; Webking, 1998; Mestre, pers. comm., 2001), pioneered primarily by the physics faculty at the University of Massachusetts at Amherst, is a hard-wired response system with software that allows an instructor to view a real-time 'map' of the classroom. Each student response is color-coded by seat and student name or identification number. Unfortunately, installation of

Term	Enrollment*	Instructor
Spring 2002	155	Heaney
Spring 2002	125	Greer
Fall 2002	210	Greer
Spring 2003	92	Heaney

Table 1. Enrollment data for the 4 semesters of SRT use in Geosc 020. *Note: Fluctuations in enrollment are historically determined by scheduled class times

hard-wired electronic response systems is prohibitively expensive for many universities.

Fortunately, recent advances in student response technology now offer sophisticated systems at dramatically reduced costs. After researching a variety of commercially produced applications, we selected eInstruction's Classroom Performance System. The latest version of CPS is relatively inexpensive to both the instructor and the student. Expenditures for the CPS package from the instructor's side include the purchase of the eInstruction application software, an infrared receiver (which is encapsulated in a plastic disk measuring 4 inches in diameter), and a central processor that sorts and relays the receiver output to a standard personal computer. In addition, each student is required to purchase a remote control unit and register it with eInstruction through the company's website (www.eInstruction.com). Several SRT manufacturers, including eInstruction, have developed agreements with academic publishing companies to package their systems with specific textbooks at markedly reduced costs to the instructor and to the student.

Because the CPS technology is wireless, it is highly portable, and it can accommodate responses from up to ~500 students (170 student responses per signal receiver). Thus, the operation of these units in the classroom is logistically straightforward. Before the lecture, the instructor enters the day's lecture questions into the CPS application database. At the appropriate point during the lecture, the instructor can call up the CPS program and present the desired question to the entire class using a standard LCD projector connected to the computer. Students may be asked individually to key in their answers with their remote control units before or after extensive discussion in peer groups. The student response data are then displayed in a histogram or other format using the LCD projector. Total collection times typically fall under one minute. This technology thus allows the instructor to gauge student perception and understanding of a given topic in real time and to alter lecture content accordingly. In addition, students can measure their level of understanding of course material and concepts relative to their peers.

The system software is upgraded frequently, and it is adaptable to a variety of instructional modes, including student examinations. Response data can be analyzed in a number of ways. Instructors can monitor individual or group response success from one lecture to the next, and they can cross-correlate performance on individual questions that are offered repeatedly over the history of the course. Thus far, we have explored only the in-class question-and-answer capabilities of the CPS application.

Assume that the fictional radioactive element *Joepaternium* decays with a half-life of 1 million years. If a rock has 32 trillion atoms of *Joepaternium* to start with, how many atoms remain after 4 million years?

A None

B 4 million

C 1 trillion

D 2 trillion

E 16 trillion

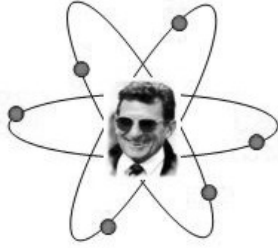


Figure 1. Example of a quantitative analysis question presented in class with SRT.

HOW DO WE USE SRT IN OUR CLASSROOMS?

To date, SRT has been employed in 4 of our class sections of Geosc 020 over 3 semesters. We introduced the technology simultaneously in two separate sections of Geosc 020 during Spring 2002. Subsequently, Greer continued its use in Fall 2002, and Heaney employed SRT in the Spring 2003 semester (Table 1).

The questions that we posed can be classified into categories that include Quantitative Problems, Popular Misconceptions of Science, Applied Reasoning, and Creative Thinking as outlined below:

Quantitative problems require students to perform mathematical calculations based on a formula or physical model presented in class, as exemplified by radioactive decay (Figure 1). Many of our non-science majors tend to 'freeze' when confronted with questions of this sort on exams. A major virtue of the SRT is that the instructor may better gauge the ability of *all* students to handle these exercises in a format where the correct response does not affect a student grade.

Popular misconceptions of science questions offer an excellent means of 'hooking' indifferent students into a new lecture topic. Paradoxical observations, such as the Earth-Sun distance in winter and summer, surprise students and force them to reconsider their assumptions about the natural world. The SRT reveals how widely distributed such misconceptions are.

Applied reasoning questions are especially appropriate for visually based interpretations of geologic phenomena, such as the Laws of Superposition and Cross-Cutting Relationships (Figure 2). Additionally, these problems are useful when a framework for understanding a geological concept has been provided (e.g., definition of a mineral), and student understanding of that framework must be immediately gauged (e.g., Is a snowflake a mineral?).

Creative thinking issues, which may include multiple or subjective responses, may be less well suited for SRT-assisted instruction in small class environments. The free-wheeling thought process that attends a

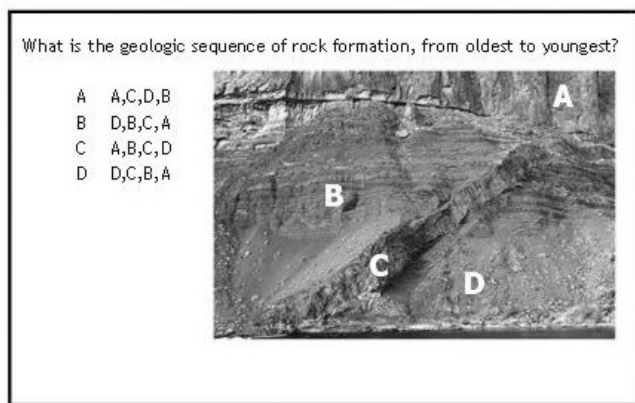


Figure 2. Example of an applied reasoning question presented in class with SRT. Modified from Figure 4.16, Press and Siever, 2001 [Permission of W.H. Freeman].

consideration of why gemstones are more valuable than water, for example, is tricky to encapsulate in the multiple-choice SRT format, but in large classes the SRT question helps to launch class-wide discussion.

The questions shown in Figures 1 and 2 demonstrate the ability of the SRT software to incorporate accessory illustrations by inputting files in common graphics formats (e.g., jpeg, tiff). Although we experimented with questions having multiple correct answers or no correct answer, students clearly indicated that they were frustrated unless only one of our proposed multiple-choice answers was correct. In addition, in the first stages of our SRT experimentation, we asked anywhere from 0 to 5 questions per 50 minute class period. In response to student feedback, we shortly settled on 2 to 3 as the optimal number per 50 minute class session for this particular course.

Even though we constructed our lectures independently, we shared the same course syllabus, lecture outline, course structure, and grading scheme throughout each semester. Therefore, we each developed our own database of questions, generally sharing questions and responses only after each class period. This approach allowed us to maintain our own classroom 'style' during the semester. Typically, we adopted both a simple question and response and a modified think-pair-share approach to SRT presentation (Mazur, 1997). We generally would present material, pose a problem, and then ask for an immediate response or allow students to discuss the SRT question, often after asking each student to write down an initial individual response. After students had responded electronically to the question at hand, the student response results were discussed in an instructor-facilitated group format to ensure that answers were interpreted correctly.

ASSESSMENT PROTOCOL

During each semester of SRT integration we attempted to assess the student perception of SRT effectiveness using a variety of feedback methods. These initial efforts at assessment of SRT effectiveness included: Attendance data; Quantitative student survey data; Qualitative visitor feedback; and Qualitative input from selected Geosc 020 students as outlined below.

Midterm Assessment of the Classroom Performance System

Please respond to the following statements using the rating system below:

- | | |
|---------------------|------------|
| 1 Strongly agree | 2 Agree |
| 3 Neutral | 4 Disagree |
| 5 Strongly disagree | |
- The CPS system helps me to gauge my level of understanding of course material.
 - The CPS system helps me prepare for the exams.
 - The CPS system reinforces important concepts presented in lecture.
 - The CPS system improves my problem solving skills.
 - The CPS system increases my desire to come to class.
 - The CPS system is fun to use.
 - I like the CPS system because it breaks up the lecture.
 - The CPS system increases my interaction with other students.
 - The CPS system is an effective teaching and learning tool.

Use the rating system below to answer the following questions.

- | | |
|------------------------|--------------------|
| 1 Completely satisfied | 2 Highly satisfied |
| 3 Moderately satisfied | 4 Poorly satisfied |
| 5 Not satisfied at all | |
- Describe your level of satisfaction with the course so far.
 - Rate your overall level of satisfaction with the CPS system.

Use the yes/no rating system below to answer the following questions

- | | |
|-------|------|
| 1 Yes | 2 No |
|-------|------|
- Does the CPS system increase your willingness to ask questions in class?
 - Would you recommend the use of CPS technology in Geosc 20 next year?
 - Would you recommend the use of CPS technology in other courses?
 - Do you feel that CPS technology helps you learn?
 - Do you find the class more/less enjoyable than expected?
- | |
|--------------------------------|
| 1 Significantly more enjoyable |
| 2 More enjoyable |
| 3 About what I expected |
| 4 Less enjoyable |
| 5 Significantly less enjoyable |

Please provide a short answer to the following questions:

What do you like best about the CPS System?
 What do you like least about the CPS System?
 What suggestions do you have for increasing the effectiveness of CPS (what types of questions do you like/dislike, logistical concerns, etc.)?

Figure 3. Midterm student survey form used to assess perceived SRT effectiveness in Geosc 020. Questions not pertaining to SRT are excluded.

Attendance data - The CPS software records student attendance as it registers individual student responses. We have compared our attendance rates with the historical values for Geosc 020.

Quantitative student surveys - Student surveys that solicited the students' impressions of the effectiveness of SRT were conducted in Spring 2002 (Greer and Heaney), Fall 2002 (Greer), and Spring 2003 (Heaney). Students completed these surveys at mid semester on a voluntary and anonymous basis in class. The survey for both sections of Geosc 020 in Spring 2002 contained 30 questions. Nine of these questions dealt with technical aspects of the CPS system and were no longer pertinent following upgrades by eInstruction. Consequently, these questions were eliminated for the evaluations in the Fall 2002 and Spring 2003 semesters. The resulting 21-question survey is reproduced in Figure 3.

Qualitative data from Geosc 020 students - In addition to the quantitative student survey data, most students submitted qualitative commentary on perceived SRT effectiveness as part of the anonymous student surveys described above (Figure 3) and the university-mandated course assessment forms at Penn

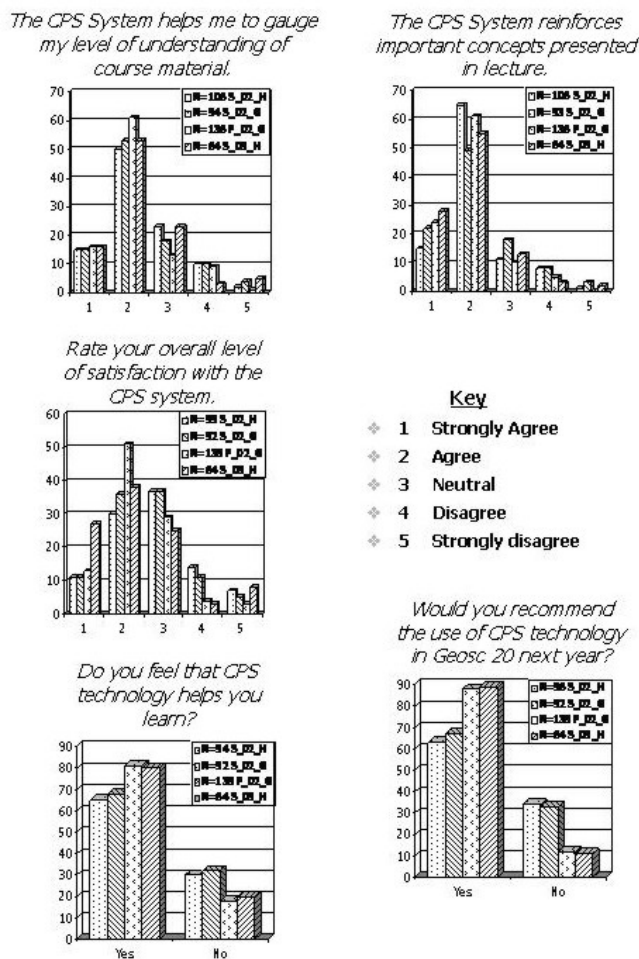


Figure 4. Results from selected student survey questions.

State known as the Student Ratings of Teaching Effectiveness (SRTEs).

Qualitative visitor feedback - During the first semester of SRT integration, Greer sent an open invitation to Penn State faculty and administrators to visit her classroom via the Center for Excellence and Learning (CELt) at Penn State. Approximately 30 faculty, administrators, and graduate students from across the University Park campus observed her class in Spring 2002. Visitors included representatives from a variety of departments (physics, biology, chemistry, economics, political science, English and others) as well as CELt, the Undergraduate Studies Program, and the Penn State Teaching and Learning Consortium. Visitors were encouraged to provide any feedback on an informal basis.

RESULTS OF SRT ASSESSMENT

Attendance - Over the past 10 years, attendance in Geosc 020 had fallen well below an estimated 50% by the midpoint of each semester, despite the use of daily or weekly quizzes (in part as attendance monitors) which have counted for as much as 10-15% of the course grade. By the final month of classes, student representation generally ranged between 30% and 40%, as measured by

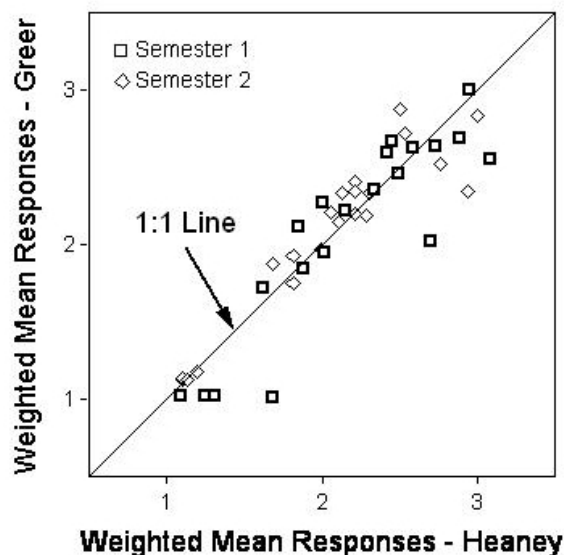


Figure 5. Weighted response correlation for each assessment question for each instructor.

the return of the university-mandated student evaluations.

Our use of the CPS system enabled us to measure attendance on a day-to-day basis. We encouraged student attendance by counting SRT responses (regardless of correct/incorrect answers) as 15% of the final grade. This practice was not exceptionally different from the weekly or daily quizzes that had been used to encourage attendance in previous years. We observed that daily lecture attendance rates were as high as 90% in the middle of the semester and mean attendance for Geosc 020 ranged from 81% to 84% over the four semesters assessed. These numbers were confirmed by head counts in order to allow for the possibility that absent students had handed their remote control units to friends who entered responses on their behalf. Typically the discrepancies between the attendance numbers calculated by CPS and the direct headcounts were on the order of $\pm 2\%$. Often headcounts revealed a higher number of students than remotes, as students sometimes forgot to bring their remotes to class.

Quantitative Student Surveys - Based on our late-term assessment questionnaires, a majority of students believed that the integration of SRT into the class lecture increased the quality of course content and facilitated higher-order learning during class time. Results for five key survey questions are highlighted in Figure 4.

The majority of students surveyed in each section (65-77%) felt that the SRT helped them gauge their level of understanding of course material. An even higher percentage of students (71-85%) agreed that SRT use reinforced important concepts presented in lecture. A slightly lower number of students believed SRT to be an effective teaching and learning tool in Spring 2002 (54-57% with 13-16% in disagreement and the rest remaining neutral). However, the positive response to this question increased dramatically in Fall 2002 and identically in Spring 2003 to 75% in agreement and only 8% in disagreement. This improvement might have been attributable to a refinement of our pedagogical approach and to upgrades in the CPS hardware. Overall, between

65% and 81% of students believed that SRT helped them learn.

The percentage of student respondents who would recommend SRT use in Geosc 020 (63-67%) as well as in other courses at Penn State (67-71%) was remarkably high in Spring 2002, especially in light of the numerous technical difficulties encountered during the first semester of SRT adoption (as this was the first use of the CPS system in a university-level course; the company has since addressed these early software and hardware problems). These numbers increased significantly in Fall 2002 and Spring 2003, with 88% and 89%, respectively, recommending SRT use in future sections of Geosc 020. Similarly, 86% in both of these sections desired the SRT in their other courses at Penn State.

We are attempting to determine the degree to which our assessment responses reflect the merits of the SRT rather than the idiosyncrasies of the instructors. A rigorous statistical analysis of these data is in process and will be treated in a separate paper. Nevertheless, a graphical presentation (Figure 5) demonstrates that the SRT system elicited similar responses from the students despite differences in teaching style. To construct Figure 5, we calculated a weighted response for each assessment question for each instructor for each semester. For example, if a given assessment question yielded the following results: 10% Strongly Agree (1); 30% Agree (2); 30% Neutral (3); 20% Disagree (4); and 10% Strongly Disagree (5), then the weighted mean response calculated for that question is 2.9. The closeness of the response set for the two instructors is a strong indication that the student reaction to the SRT was independent of the instructional style.

QUALITATIVE OBSERVATION

Students - Some of the more enlightening insights into the advantages and disadvantages of the SRT came from anonymous written student comments. Many of these were effusively positive. Almost all negative comments were related to the expense of the remotes and to the use of SRT as a monitor of attendance, since SRT participation was counted as 15% of their final grade. Below we have included a sampling of the comments received. Of the completed surveys, over 75% of students expressed qualitative opinions. We judge the following comments as representative of the comments received.

What do you like best about the CPS system?

'I liked the CPS system because it gave shy kids the chance to participate. It also helped in tracking one's own progress. It helped everyone to get involved in such a large class.'

'I liked the CPS questions, I felt they gave you an incentive to a) go to class and b) pay some attention throughout the course instead of just studying for the exams.'

'The CPS questions were fun! They encouraged involvement with the lecture and made me problem solve.'

'Although at first I thought the CPS was a little odd (i.e. more suited for jr/sr high school) I learned to appreciate the way it brought the class together and made us think.'

'I'm anti-modern technology so I thought that I would hate it at first. However, it has really increased my level of participation and I don't feel put on the spot when doing so.'

'I like that it lets me see if I am understanding the lecture or not and it truly does give a nice break from straight lecturing. Also, since it [my answer] doesn't count as a grade, I don't have to stress about it - instead, I can relax, listen, and try my best to answer correctly.'

'Dude, it's like playing video games. It has made me stop bringing my Game Boy to class.'

'It makes solving problems more fun.'

What do you like least about the CPS system?

'I think the CPS System is an extremely expensive way to take attendance. This class is one of the most expensive classes I have ever taken at PSU.'

'It forces me to come to class.'

'It takes up class time when she should be lecturing.'

'I thought the CPS is overrated and expensive.'

'It takes attendance and that determines if you were in class and sometimes I forgot my remote and was still in class but didn't get credit for being there.'

'Man, it's expensive. It cut into my beer budget the first week of class. Bummer.'

'I do not so much dislike the system as I dislike the way the teacher uses the system' [i.e., as an attendance monitor].

'Probably the fact that it's not used in more classes.'

Faculty - Overall visitor feedback was extraordinarily positive although several visitors shared insightful observations concerning SRT logistics and presentation style. Observations focused on how students appeared to respond to the system, how much of the class time might successfully be devoted to SRT question periods, which groups of students seemed to be responding more or less willingly to the process, etc. These encounters led to discussions of such issues as the appropriate time for collection and display of SRT results and methods for encouraging active group discussions of SRT questions.

DISCUSSION

Impacts on Learning - Whether the SRT system actually improves student understanding and retention of the material presented in lecture is not resolved by the assessment results of this study. Neither of us taught Geosc 020 prior to Spring 2002. Thus we cannot compare student performance with the SRT to that without this technology. On the other hand, our assessment results

demonstrate unequivocally that our students perceived the SRT as a significant enhancement to the learning process (Figure 4). The strongly positive reaction to the electronic response technology is especially striking in light of the out-of-pocket expenses associated with SRT use. On average, 33% responded that the purchase and registration of the remotes fell outside their school budgets. That nearly 90% of our respondents in Fall 2002 and Spring 2003 nevertheless favored the continued usage of the SRT in Geosc 020 is a convincing argument for student belief in the effectiveness of this tool. We believe the increase in classroom attendance from previous years can be attributed to SRT use. This phenomenon has been noted by other users of SRT technology as well (Littauer, 1972; Judson and Sawada, 2002).

This study also cannot resolve the degree to which an interactive classroom setting, peer instruction, and think-pair-share techniques may have enhanced our course independent of the SRT system itself. The literature certainly supports the merits of these and other teaching techniques for use without interactive technology (Mazur, 1997; Cummings et al., 1999; Meltzer and Manivannan, 2002). However, the quantitative and qualitative data presented indicate that students *believe* that SRT is a useful teaching tool.

We suggest that students are attracted to the SRT system because it promotes active learning in a large-class environment. When used in concert with peer-instruction techniques, students became involved in the teaching process. They were eager to argue over possible answers with each other as well as with the instructor. In addition, student comments suggest that the SRT offers students a unique sense of ownership of course content. After a student 'vote', students appeared emotionally invested in the results. They often cheered when they learned that they picked the correct answer or groaned when they discovered that they were incorrect. This technology significantly increased the level of student-instructor interaction, making the course a more enjoyable experience for us as well as for our students.

Impacts on Teaching - The incorporation of SRT requires some front-end labor on the part of the faculty member. Setting up the hardware before class is fairly simple and can be accomplished within 10 minutes, though we always employed undergraduate interns to assist with this process. Learning how to manipulate the CPS software also is straightforward, and loading 2-3 questions typically took only 5 minutes once those questions had been developed. Perhaps the greatest challenge for each of us involved the creation of questions that are challenging, geared to the appropriate level, and intellectually valuable. Since our assessments revealed that students enjoy SRT in part because the questions provide timely breaks from the routine of lecture, we tried to separate our question and response exercises by 15- or 20-minute intervals. Consequently, the construction of our lectures had to be tightly integrated to the development of our question sets. In addition, we attempted to engage the students in problems that could be solved deductively in group-learning situations, and thus the SRT process influenced the material that we chose to teach and the way in which we presented it. Rather than introducing a topic with a detailed description of the currently accepted model for a given geologic process, the electronic response system inspired us to construct our

lectures using an inductive and often historical perspective. This approach laid the foundation for the students to infer the important conclusions on their own. Lastly, we believe SRT is best used when instructors are willing to remain flexible in the classroom. We were often surprised by the student response results and had to adjust our lecture presentation accordingly. A similar phenomenon has been documented by other SRT users (Meltzer and Manivannan, 2002).

Impacts on Course Enrollment - Undergraduate students rarely enroll in introductory Earth Science courses with the intention of becoming professional geoscientists or even of majoring in the subject. Too often, courses in the Earth Sciences are viewed as the path of least resistance towards satisfying a university's general education requirement. Thus, students in Geosc 020 perceive themselves as unlikely scientists, either by ability or by desire. Many have vague (and often misguided) notions of what 'science' is. Courses such as ours often provide the only chance to expose these students to scientific philosophy at the university level. We hope that one of the successful outcomes of incorporating SRT in our courses will be an increase in enrollment, and we hope that the popularity of this technique drives an increase in geoscience majors.

CONCLUSIONS

Our experiences with electronic student response systems at Penn State University have convinced us that the SRT is capable of creating a rapport between the professor and the student in large classroom environments. Both our quantitative and our qualitative assessments strongly support this conclusion. Further testing is required to gauge whether SRT is superior to the traditional lecture approach as a means of improving class comprehension. Nevertheless, keeping general education students in physical and intellectual attendance is the largest challenge for introductory level courses, and the fact that students perceive the system as engaging and effective has persuaded us that this technology justifies the initial expense in time and labor. We are eager to see this technology in widespread use so that a large pool of Earth science instructors can share their insights to maximize the impact of electronic response systems.

FUTURE WORK

While preliminary assessment results indicate that the integration of SRT in the Geosc 020 curriculum has been successful in its initial phase of development, we believe that the full extent to which SRT can be an effective active-learning tool has not yet been adequately assessed. We hope to extend the development of SRT use to other science instructors at Penn State and are currently integrating SRT in a Historical Geology course at Washington and Lee University. We hypothesize that SRT technology can be a highly effective learning tool in the different learning environments that characterize state-funded research-1 universities and small private liberal arts colleges. However, it is less clear whether the system can be used in both settings in an identical fashion, or how the usage must be tailored to the audience in order to maximize its effectiveness. We are cautiously predicting that the benefits of electronic

response technology will translate across a broad array of university-level Earth Science curricula.

ACKNOWLEDGEMENTS

This project was funded in part by the Penn State Center for Excellence in Learning and Teaching, the Penn State College of Earth and Mineral Sciences, and the Penn State Department of Geosciences. We wish to thank J. Mestre, R. Phillis, and R. Yuretich at the University of Massachusetts at Amherst for sharing their experiences and observations of electronic student technology. We are sincerely grateful to Dustin Houseman, Dan Fay, and Meredith Hill for help with data compilation and development and operation of SRT in our classrooms. We thank Stephen Piazza, Diane Enerson, Rudy Slingerland, and Tanya Furman for helpful discussions. We are most grateful to S. Linneman, D. Meltzer, and C. Cervato, whose detailed reviews significantly improved this manuscript.

REFERENCES

- Angelo, T.A. and Cross, K.P., 1993, Classroom assessment techniques: A handbook for college teachers, 2nd Edition. Jossey-Bass.
- Bykerk-Kauffman, A., 1995, Using cooperative learning in college geology classes, *The Journal of Geoscience Education*, v. 43, p. 309-316.
- Crouch, C.H. and Mazur, E., 2001, Peer-instruction: Ten years of experience and results, *American Journal of Physics*, v. 69, p. 970-977.
- Cummings, K., Marx, J., Thornton, R., and Kuhl, D., 1999, Evaluating innovations in studio physics. *Physics Education Research*, *American Journal of Physics Supplement*, v. 67, p. S38-S44.
- DeCaprariis, P.P., 1997, Impediments to providing scientific literacy to students in introductory survey courses, *The Journal of Geoscience Education*, v. 45, p. 207-210.
- 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*, v. 7, p. 3-47.
- Gerace, W.J., Dufresne, R.J., and Leonard, W.J., 1999, Using technology to implement active learning in large classes, *University of Massachusetts Physics Education Research Group Technical Report PERG-1999#11-Nov#2*, 22 p.
- Greer, L., Heaney, P.J., and Houseman, D., 2002, Integration and assessment of electronic student response technology in the geoscience classroom, *Geological Society of America Program with Abstracts*, v. 34, p. 296.
- Heaney, P.J. and Greer, L., 2003, Using electronic response technology to teach mineralogy in large class settings, *Clay Minerals Society Annual Meeting, Program and Abstracts*, p. 73.
- Judson, E. and Sawada, D., 2002, Learning from past and present: Electronic response systems in college lecture halls, *Journal of Computers in Mathematics and Science Teaching*, v. 21, p. 167-181.
- Littauer, R., 1972, Instructional implications of a low-cost electronic student response system, *Educational Technology*, p. 69.
- Mazur, E., 1997, *Peer Instruction: A User's Manual*, Prentice Hall, 253 p.
- McConnell, D., Steer, D., and Owens, K., 2003, Assessment and active learning strategies for introductory geology courses, *Journal of Geoscience Education*, v. 51, p. 205-216.
- McManus, D.A., 2002, The two paradigms of education and peer review of teaching, *Journal of Geoscience Education*, v. 49, p. 423-434.
- Meltzer, D.E. and Manivannan, K., 2002, Transforming the lecture-hall environment: The fully interactive physics lecture, *American Journal of Physics*, v. 70, p. 639-654.
- Mestre, J.P., Gerace, W.J., Dufresne, R.J., and Leonard, W.J., 1997, Promoting active learning in large classes using a classroom communication system, In: *The changing role of physics departments in modern universities: Proceedings of International Conference on Undergraduates Education* (Redish and Rigden, eds.), American Institute of Physics Conference Proceedings, 399, p. 1019-1021.
- Pinet, P.R., 1995, Rediscovering geological principles by collaborative learning, *Journal of Geoscience Education*, v. 43, p. 371-376.
- Press, F. and Siever, R., 2001, *Understanding Earth*, 3rd Edition, W.H. Freeman and Company, New York, 573 p.
- Webking, R.H., 1998, Classtalk in Two Distinctly Different Settings. From: 'Classtalk at University of Texas El Paso', CDROM authored at the Dept. of Political Science, Univ. of Texas - El Paso, September 1998.
- Wenk, L., Dufresne, R., Gerace, W., Leonard, W., and Mestre, J., 1997, Technology-assisted active learning in large lectures. In: *Student-active science: Models of innovation in college teaching*, A.P. McNeal and C. D'Avanzo (eds.), Fort Worth, TX, Saunders College Publishing, p. 431-451.
- Yuretich, R.F., 2002, Assessing higher-order thinking in large introductory science Classes, *Journal of College Science Teaching*.
- Yuretich, R.F., Khan, S.A., Leckie, R.M., and Clement, J.J., 2001, Active-learning methods to improve student performance and scientific interest in a large introductory oceanography course, *Journal of Geoscience Education*, v. 49, p. 11-19.