Personal Response Systems and Learning: It Is the Pedagogy That Matters, Not the Technology

By Kyle Gray and David N. Steer

Research has shown that asking conceptually based questions along with a personal response system (clickers) is an effective way of implementing the peer instruction pedagogy. Lecture tutorials are a paper-based method that also incorporates peer instruction. Past research has shown that both methods yield significant learning gains for students in introductory science courses. This study investigated whether using clickers in conjunction with lecture tutorials yields higher student learning gains than using only lecture tutorials. Students from an introductory Earth Science course participated in the study. Course data (exams, quizzes, attendance) and results from the Geoscience Concept Inventory indicated that high-performing students who used only lecture tutorials yielded similar learning gains to those of high-performing students who used both clickers for conceptually based questions and peer instruction lecture tutorials. The results suggest that the addition of clicker-based peer instruction pedagogy to lecture tutorials does not lead to additional learning gains.

Over the past two decades, undergraduate science education has experienced a pedagogical revolution as active-learning pedagogies have rapidly supplanted the traditional classroom lecture. This new teaching paradigm stems from a constructivist view of learning and holds that students create their own knowledge as they progress through courses rather than collect knowledge that is dispensed by the instructor (Bransford, 2000). Supporters such as Carl Wieman (Wieman et al., 2007) and Eric Mazur (2011) have developed and promoted active-learning strategies at all levels, especially in introductory undergraduate science courses. Examples of these research-based methodologies include just-in-time teaching (Novak, Gavrin, Christian, & Patterson, 1999) and peer instruction (Mazur, 1997).

Peer instruction (Mazur, 1997) is a widely adopted active-learning pedagogy through which personal response systems (also called clickers) are often used (Abrahamson, 2006). During peer instruction, the instructor lectures for 10 to 20 minutes before asking a conceptually based question called a ConcepTest (see Figure 1 for an example). Students then use their remote transmitters to anonymously answer the question. If fewer than 75% of the students correctly answer the question, the instructor encourages the students to discuss the question and answer a second time. On the basis of this feedback, the instructor can gauge whether additional lecture time should be devoted to explaining the target concept. Even though personal response systems are commonly used with peer instruction, they are not required (Lasry, 2008).

Research has shown that both faculty and students have accepted the use of personal response systems. Undergraduate faculty members use the technology because it efficiently provides a means to formatively assess student learning in all types of classes (Sevian & Robinson, 2011). Students tend to embrace the technology as well and credit it with helping them learn (Crossgrove & Curran, 2008). There is also some evidence that the technology may promote a more inclusive learning environment (Steer, McConnell, Gray, Kortz, & Liang, 2009). Studies of peer instruction and the use of personal response systems in physics courses show that this type of interactive setting yields significantly higher learning gains when compared with traditional didactic lecture (Crouch & Mazur, 2001; Fagen, Crouch, & Mazur, 2002; Lasry, Mazur, & Watkins, 2008). Similar findings are reported from other science disciplines including geoscience (McConnell et al., 2006), chemistry (Butcher, Brandt, Norgaard, Atterholt, & Salido, 2003), and biology (Suchman, Uchiyama, Smith, & Bender, 2006).

As the popularity of personal response systems continues to rise, several authors have reminded us that significant learning gains stem from improvements in pedagogy rather than from the technology. Lasry (2008) noted that learning gains from using a personal response system and peer instruction are primarily due to changes in teaching practice, not the technology itself. Mayer et al. (2009) reminded us that often new educational technologies are rapidly embraced and claims are made that student learning gains are due to the technology rather than changes in how the course is taught. Recently, Beatty and Gerace (2009) reviewed the literature on personal response systems and noted that many studies confounded the technology with the pedagogy. They argued that studies should focus on the most effective ways of using the technology (i.e., the pedagogy) rather than the technology itself. Mayer et al. (2009) presented a learning model showing that personal response systems (when used with peer instruction) result in higher learning gains because students are engaged in deeper cognitive processing than students attending a traditional lecture. The literature clearly shows that the peer instruction paradigm, along with personal response systems, produces significant learning gains.

Lecture tutorials are a lesser known method for incorporating the peer instruction pedagogy to create an active-learning environment. Rather than using an electronic device to answer questions projected on a screen, students are given a piece of paper containing a small number of conceptually based questions that increase in difficulty. After a short lecture, students spend approximately 10 minutes working on the problems in small groups. The instructor circulates around the classroom and answers individual questions before continuing with the lecture. The papers can be collected and graded after class or the students may keep the papers for later study (see Figure 2 for an example). This process promotes peer interactions among the students

FIGURE 1

Two examples of exemplary plate tectonics ConcepTest questions used with clickers.

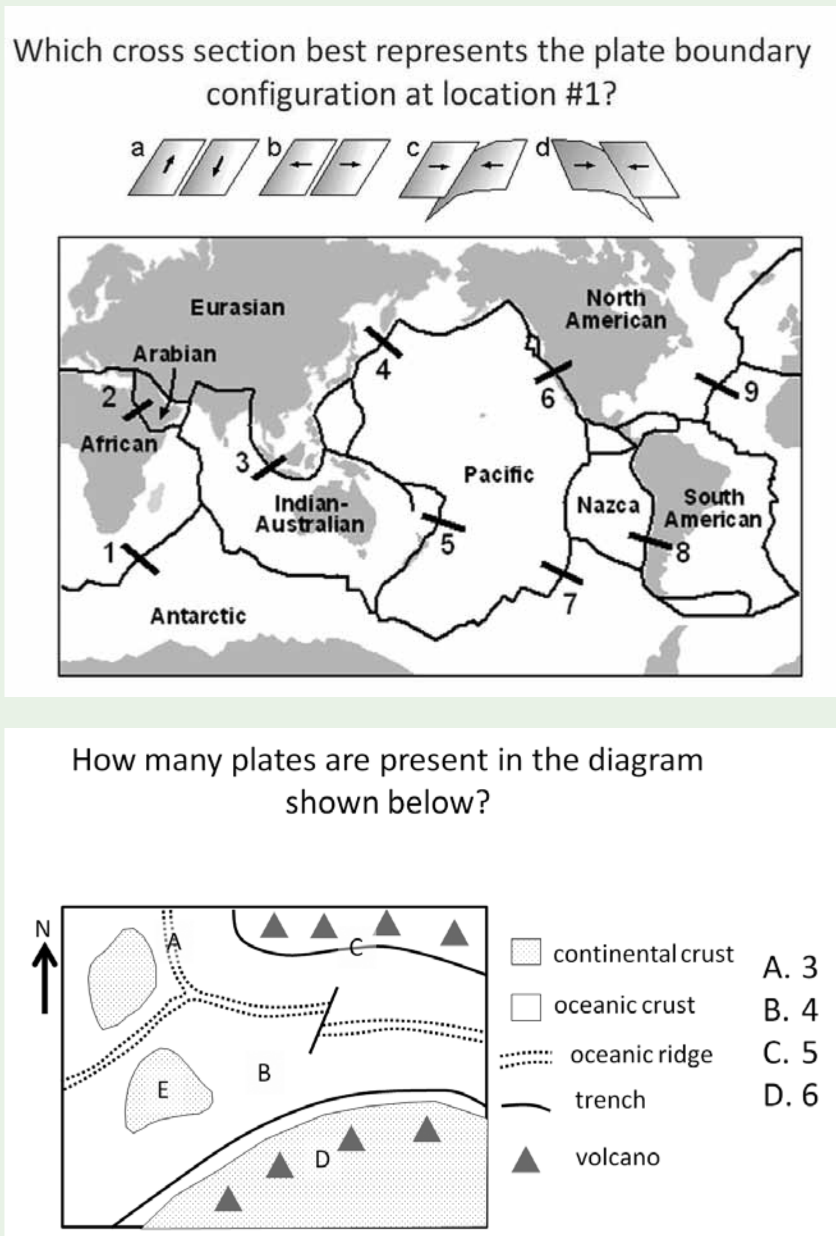
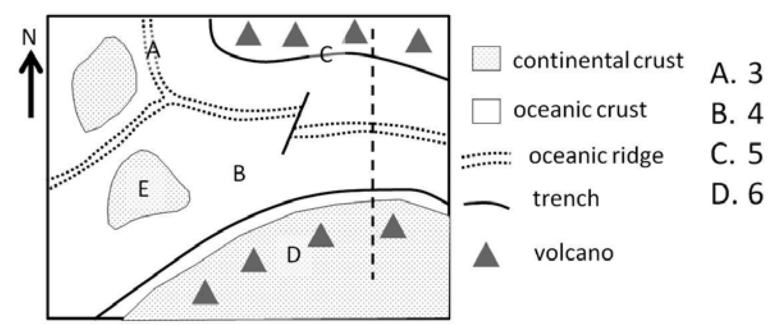


FIGURE 2

Sample plate tectonics lecture tutorial for written responses in nonclicker section (only "d" would appear on clicker section tutorial; all other parts would be ConcepTests).



a. How many plates are present on this diagram?

b. Where is a mountain range similar to the Andes Mountains (South America) most likely to be present?

c. What direction is B moving relative to D?

d. Sketch a cross-section of the plates along the dashed line shown above.

e. Which letter(s) is (are) likely to experience deep earthquakes?

and fosters conceptual understanding by providing time for the students to wrestle with questions that require higher-order thinking skills. Tutorials like these have been successfully implemented into astronomy courses (McDermott & Shaffer, 2002; Prather et al., 2005) and geology courses (Kortz, Smay, & Murray, 2008) and yield similar learning gains as personal response systems.

Though much has been written about the use of personal response systems within the peer instruction pedagogy, nearly all of these studies compared peer instruction with a traditional lecture. This study sought to investigate the hypothesis that combining two different methods of using the peer instruction pedagogy would lead to higher learning gains. That is, would students who complete a lecture tutorial and answer ConcepTest questions using a personal response system yield higher learning gains than students who only experienced the lecture tutorial methodology? Should clickers provide substantial learning improvements in this active setting, they may be worth the additional cost and time needed to implement the technology. Should they not result in significant gains, those resources could be reallocated.

Setting

This study used archived data from two sections of an introductory Earth Science course for nonmajors taught by the same instructor. Both sections were held in auditorium-style lecture halls with fixed stadium seating facing a wall-sized projection screen. There was no laboratory period or scheduled recitation time, and sections met for three 50-minute sessions each week. Course content included concepts related to the nature of science, basic astronomy, plate tectonics, rocks and minerals, geologic time, streams and groundwater, oceans, the atmosphere, weather, climate, and global change. The text (McConnell, Steer, Knight, Owens, & Park, 2008) was written for this type of course and includes explicit learning outcomes that require students to use higher-order thinking skills. For instance, in the chapter on plate tectonics, students are expected to show they understand how to identify plate boundaries by counting the number of plates on a previously unviewed map (Figure 1). They also analyze the various boundaries to predict distributions of the earthquakes, volcanoes, trenches, mountains, and plate motions. Finally, the students must apply the principles associated with plate interactions to draw cross sections across various boundaries and evaluate hazards associated with the boundaries. Similar outcomes used to scaffold learning are provided in the textbook and in class for all content areas. The instructor used an assessment-based approach to reinforce learning during every lesson. Peer instruction has been fully incorporated into this course for the past 10 years and is used to foster student understanding of the day's target concepts.

During the second week of classes, students were randomly assigned to permanent four-person learning teams with assigned seating. Students interacted within these teams when discussing ConcepTest questions and response histograms or working on lecture tutorials. Students were expected to read the relevant textbook material before coming to class. As the students entered the room, they picked up printed copies of key PowerPoint slides and a blank lecture tutorial that was used throughout the lesson. During a typical lesson, the instructor discussed 1 or 2 slides followed by time for students to complete a formative assessment. This continued throughout the class with each session having 6 to 12 key concept slides that required 20 to 25 minutes of total lecture time. The remainder of the 50-minute class period was parceled into the smaller increments during which students worked in their groups on ConcepTest questions or lecture tutorial materials. The instructor and one teaching assistant circulated through the classroom as students completed various activities related to the lecture tutorial, answered questions, and provided feedback to guide student work.

During a typical class session that used clickers, the instructor would lecture for a few minutes and then use a ConcepTest question as a quick formative assessment of learning. The question was projected on the screen and students were allotted up to one minute to respond to the question using their electronic transmitters. The results of the student poll were displayed on the screen as a histogram. If fewer than 75% of the students answered the question correctly, students discussed the question within their teams and answered the question again. The new results were displayed and then briefly discussed by a randomly chosen student or sometimes the instructor. The question was immediately discussed if more than 75% of the students correctly answered on the first attempt.

For both sections, students also worked through exercises printed on the lecture tutorial as a routine part of each lesson. The lecture tutorials served as an additional formative assessment of learning that they could later use as a study aid. These exercises that targeted applying and analyzing cognitive domains typically required 2 to 5 minutes of class time (e.g., learning team problem solving, image analysis and interpretation, concept map or Venn diagram completion). Occasionally, as much as 20 minutes of class time was allocated for more involved exercises during which students had to synthesize multiple concepts as they evaluated scenarios or for class activities that involved student manipulation of physical models (see Gray, Steer, McConnell, & Owens, 2010, for an example of such an in-class activity).

Assessments included exams, quizzes, and participation in the various in-class activities (ConcepTest questions, lecture tutorials, etc.). Students from both sections completed four identical multiple-choice exams and an optional comprehensive final. All exams were administered in a proctored, computer-based testing center. Each week, students completed an online, open-book quiz as part of their homework. Participation grades (a proxy for attendance) were awarded based on answering ConcepTests (simple participation) or completing the lecture tutorials if a personal response system was not used. All other aspects of the course (e.g., content, learning outcomes, grading) were the same between the two sections.

Methods

This study investigated whether using both a personal response system and lecture tutorials in the same class would increase student learning over using lecture tutorials alone. During the spring 2009 semester, the second author of this paper taught two sections of this Earth Science course using two different approaches to the peer instruction pedagogy. Section A met from 8:50 a.m. to 9:40 a.m. and used lecture tutorials alone. Section B met from 11:00 a.m. to 11:50 a.m. on the same days and used both lecture tutorials and ConcepTests answered using a personal response system. Because clicker-based peer instruction takes up time during class, several open-ended questions were inserted into the Section A lecture tutorials. Students wrote out their answers to those open-ended questions during the time that was used in Section B for answering and discussing the ConcepTests. On average, students in the nonclicker section answered two open-ended questions per class session compared with four ConcepTests in the section with remotes.

Student learning was measured using multiple measures. Internally, we used grades from the course quizzes and exams to measure student learning throughout the semester. We did not include data from the final exam because it was optional. We also used the Geoscience Concept Inventory (GCI; Libarkin & Anderson, 2005) as an independent assessment of pre- and postcourse knowledge. The GCI is a valid and reliable instrument consisting of 15 multiple-choice questions on topics related to geology. Individual questions were written on the basis of common misconceptions obtained through open-ended surveys and interviews administered to undergraduate students. Research using the GCI in contexts ranging from a national sampling (Libarkin & Anderson, 2005) to preservice elementary education students (Petcovic & Ruhf, 2008) has shown that undergraduate students taking an introductory Earth Science course score an average of 39%–43% on a course pretest and 45%–48% on the subsequent posttest. The GCI was administered during the second and next to last lessons of the semester for both sections.

Besides these measures of student learning, we analyzed data from student course evaluations given at the end of each semester. Students manually submitted data using the IDEA evaluation system (Hoyt & Cashin, 1977), which uses a 5-point Likert scale to assess student attitudes on how well the instructor met the course objectives. Individual items and overall ratings from the global IDEA items "Excellent Teacher" and "Excellent Course" were compared between the two sections. The global items were considered more important as they have been shown to account for most of the variance in such evaluations (Cashin & Downey, 1992). The relevant Essential and Important course objectives (as determined by the instructor) that contributed to those scores included the following: for Essential—working as a team and learning fundamental principles; for Important—applying course material and learning factual knowledge. Attendance and participation were closely monitored in both classes. Lecture tutorials were collected from Section A (nonclicker), checked for completeness, and tallied as a measure of attendance. Incomplete sheets resulted in partial credit, and the instructor monitored student groups to ensure worksheets were not submitted for absent students. Overall average attendance in Section B was tallied by dividing the number of responses received for a particular student by the total number of questions asked during a lesson. Lessons were then averaged over the entire course. Participation scores were adjusted to account for students who forgot their remotes or experienced mechanical failure. Overall course grades included online, open-book weekly quizzes (35% of final grade); class participation (15%); and exams (50%). Students with missing pre- and/or postcourse GCI scores were excluded from the quantitative comparisons of the active-learning methodology.

Quantitative data analyses of all student learning data were used to determine whether students who experienced both lecture tutorials and ConcepTest questions outperformed students who only used lecture tutorials. Independent-samples *t*-tests using section as the dependent variable were used to explore the relationships between mean student quiz scores, scores on each exam, overall exam scores, course grades, and GCI pre- and posttest scores. Significant differences in GCI posttest scores and exam or quiz scores but not in pretest GCI scores would indicate that using both lecture tutorials and ConcepTest questions with a personal response system leads to increased student learning. In addition, we analyzed data from student evaluations submitted at the end of the course to see if those responses correlated with the student-learning data. For all tests, significance was set at $\alpha = .05$.

Results

A total of 239 students from the two sections allowed the researchers to use their scores by signing an approved Institutional Review Board consent form; however, only 126 students were present for both the precourse and postcourse GCI assessments. Students from Section A were 59% male and 41% female; 68% were freshman; 20% were sophomores; and 12% were juniors, seniors, or fifth-year undergraduates. Students from Section B were 47% male and 53% female; 68% were freshman, 24% were sophomores, and 8% were juniors or seniors. Demographics of the students in both sections closely matched that of the institution, with 72% identifying as Caucasian, 15% African American, 10% nonreporting, and 3% other.

The GCI was used to assess student learning twice during the course (pre-/posttest) with summative quiz and exams administered weekly and monthly, respectively. Normalized gain scores for the GCI (using the method of Hake, 1998) showed that students using both lecture tutorials and personal response systems improved their scores by 12.3% (Table 1), whereas students who only used lecture tutorials improved by 9.6%, yet an independent-samples *t*-test indicated that these differences were not significant ($t_{(124)} = -1.02$, $p = .31$). Analysis of the raw gain scores (post/pre) produced similar results. The overall exam scores were nearly identical, with students using both lecture tutorials and a personal response system scoring 0.5% higher. A similar trend was observed for scores on individual exams. Nearly identical average quiz scores (based on 14 weekly quizzes) and average exams scores for both sections indicated this similarity existed throughout the semester. Because course grades were a combination of the previously mentioned data, final course grades were also indistinguishable. Attendance for Section A was slightly higher than for Section B but was not significantly different.

To test whether the high number of students who failed to provide both sets of GCI scores resulted in a biased sample, we analyzed the data for all students who signed consent forms (Table 2). Independent-samples *t*-tests for the GCI and other course assessments were not significantly different. Student attendance, however, was significantly different between the two sections ($t_{(157)}$ = –2.11, p = .04) with a small effect size (d = 0.30). Students from both sections who did not complete the pre- and postcourse GCI attended fewer classes (Section A = 63.0%, Section B = 77.2%) than students who did complete both assessments (Section A = 94.6%, Section B = 91.7%). We observed that 89 out of the 126 students who completed both GCI instruments had attendance rates at or above 90%, whereas only 28 out of the 113 students who did not provide both measures attended at least 90% of the time. In fact, only one student who completed both GCI instruments attended less than 60% of the time. When we restricted the analysis to all students who attended at least 60% of the time, the differences in attendance rates became nonsignificant (Section A = 91.2%, Section B = 90.1%, $t_{(194)}$ = 0.309, p = .76), along with all other measures of student learning.

Student attitudes toward the course were examined using IDEA course evaluations (Hoyt & Cashin, 1997). Like the measures of student learning, students from both sections provided similar ratings. Students gave ratings of 4.1 (Section A) and 4.0 (Section B) when responding to questions related to how well the course met course objectives (no standard deviation provided in IDEA output). Overall teacher and course excellence scores were also similar to one another (Section A: 4.3 and 3.9; Section B: 4.4 and 3.9, respectively). When compared with similar courses in the larger IDEA database, students who just used lecture tutorials (Section A) scored higher than average, whereas students who used both lecture tutorials and personal response systems (Section B) scored average. Another question asked students to rate whether the classroom activities prepared them for the exam. Students gave ratings of 4.1 ± 1.2 (Section A) and 3.8 ± 1.5 (Section B) when rating that attribute of the course. More detailed statistical analyses could not be performed because data for individual students were not available.

Discussion

These data suggest that incorporating both personal response systems and lecture tutorials does not result in improved student learning gains. The similar GCI precourse scores imply that students came into these

TABLE 1

Results from the Geoscience Concept Inventory (GCI) and other course-related measures of student learning for students who completed both the pre- and post-GCI assessments.

	Lecture tutorials Section A (n = 48)		**Lecture tutorials + clickers Section B** (n = 78)		**Results from *t*-tests**	
	Mean (%)	**SD**	**Mean** (%)	**SD**	***t***	***p***
Pre-GCI	30.3	15.8	30.4	17.2	0.5	.96
Post-GCI	39.9	2.4	42.7	2.8	0.9	.38
Normalized gain[a]	11.9	22.1	16.3	24.2	1.0	.31
Attendance	94.6	8.4	91.7	12.3	1.4	.16
All exams	70.9	11.4	71.5	11.6	0.3	.79
Quizzes	80.0	16.2	80.8	12.8	0.3	.77
Course grade	83.6	10.2	83.3	9.2	0.2	.86

[a][(Post-GCI) – (Pre-GCI)]/100 – (Pre-GCI)

TABLE 2

Results from the Geoscience Concept Inventory (GCI) and other course-related measures of student learning for all students included in this study.

	Lecture tutorials Section A			**Lecture tutorials + clickers Section B**			**Results from *t*-tests**	
	n	**Mean** (%)	**SD**	***n***	**Mean** (%)	**SD**	***t***	***p***
Pre-GCI	71	29.3	15.5	130	28.8	16.6	0.2	.83
Post-GCI	62	38.6	15.3	81	41.6	19.0	1.0	.30
Normalized gain[a]	48	11.9	22.1	78	16.3	24.2	1.0	.31
Attendance	97	78.6	28.1	132	85.5	18.9	2.2	.04
All exams	90	67.3	12.4	137	66.9	13.6	0.2	.81
Quizzes	97	68.6	26.9	142	73.0	23.5	1.3	.18
Course grade	97	71.6	25.1	142	73.9	21.9	0.8	.45

[a][(post-GCI) – (Pre-GCI)]/100 – (Pre-GCI)

classes with similar background knowledge in the geosciences (Table 1). Likewise, similar postcourse GCI scores illustrated that there was no appreciable difference in the increase in geosciences knowledge by the end of the semester. The lack of any significant differences in course grade and postcourse GCI scores indicates that students in each section achieved similar learning gains. If using a personal response system along with lecture tutorials had positively affected student comprehension, students from Section B would have scored higher on both instruments. The similar quiz and exam scores suggest that student performance remained similar between both sections throughout the course.

The overall course averages and GCI gains from this study concur with previous findings conducted in a similar course. McConnell et al. (2006) found that incorporating ConcepTest questions and a personal response system into Earth Science courses raised the average course grade from 60% to 70%. The gains in GCI score observed in this study (Section A = 9.6%, Section B = 12.3%) are similar to gains in the GCI reported by McConnell et al. In that study, a section of the same course taught at the same university as this study yielded a 12.6% gain when using peer instruction and a personal response system, but a similar control section using traditional lecture produced a gain of 3.3%. These results suggest that both lecture tutorials and ConcepTest questions (when used with a personal response system) are equally effective methods of using the peer instruction pedagogy to foster student comprehension.

Comparable student perceptions of the course also suggest that the two approaches were equally effective. Students from both sections stated that the course had met the objectives of teaching students to work within teams and to use course content to solve problems posed by the instructor. Such data suggest that the students were equally comfortable with both methods of implementing peer instruction, yet the lack of any significance testing means that the conclusions are only tentative. Additional work comparing student attitudes between the two formats (lecture tutorial versus personal response systems) should verify this finding.

The significant difference in student attendance suggests that differences may exist between those who completed both GCI instruments and those who did not. The very high attendance rates for the 126 students used in our analysis (>90%) are not particularly representative of the 75% attendance rates in most college courses (Friedman, Rodrigues, & McComb, 2001). The data suggest that students who completed both the pre- and postcourse GCI primarily were high-performing students. It is not known whether this bias affected the final outcome. When data from all 239 students were included, all measures of student learning produced nonsignificant differences. Without paired pre/post GCI scores, it is possible that the gains reported in this study are inflated by oversampling high-performing students who attended most of the classes. Yet the data suggest that sample bias may not adversely affect the study's conclusions. Comparisons of course grades, quiz grades, and exam scores that included all participants who signed consent forms did not produce a significant difference in scores between the two course sections. Active learning pedagogies are only effective when students are present to experience them. Students with low attendance rates may not attend class a sufficient number of times to greatly benefit from activities associated with peer instruction. Additional research is needed to determine the relationship between student attendance, student participation, and active learning pedagogies such as peer instruction. As such, the conclusion that there was no significant learning impact when comparing students who used electronic systems with those who did not must include a qualifier that these were "high-performing" students. Because higher-performing students are known to be more effective self-regulators (Sternberg, 1998), open-ended questions asked as part of the normal class activities may have provided the feedback they needed to effectively assess their learning.

Summary

The findings from this study suggest that adding ConcepTests answered using an electronic remote to a class that already uses lecture tutorials does not significantly improve student performance. Students who only used lecture tutorials performed equal to students who used lecture tutorials and answered ConcepTest questions using a personal response system. Our findings are counter to those of Mayer et al. (2009), who found that students using a personal response system correctly answered 3% more exam questions than students who answered similar questions on a piece of paper. Yet, we note that Mayer et al. used a form of peer instruction for the group using a personal response system but waited until the end of the lecture for them to answer the questions on paper. Mayer et al. suggested that the act of writing out the answers may have disrupted the class and inhibited student learning. It is also possible that our results differ from Mayer et al. because lecture tutorials incorporate the written questions within the peer instruction pedagogy. We also note that the majority of the literature in physics, chemistry, biology, and geology clearly espouses the benefits of ConcepTests using peer instruction compared with pure lecture. Our study suggests this approach does not improve learning above that which can already be expected when using a student-centered lecture tutorial approach. This implies instructors can choose lecture tutorials with or without ConcepTest questions using electronic remotes as they deem most appropriate for their students, course, and budget. ■

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References

Abrahamson, L. A. (2006). A brief history of networked classrooms: Effects, cases, pedagogy, and implications. In D. A. Banks DA (Ed.), *Audience response systems in higher education: applications and cases*. Hershey, PA: Idea Group.

Beatty, I. D., & Gerace, W. J. (2009). Technology-enhanced formative assessment: A research-based pedagogy for teaching science with classroom response technology. *Journal of Science Education and Technology, 18*, 146–162.

Bransford, J. (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academies Press.

Butcher D. J., Brandt, P. F., Norgaard, N. J., Atterholt, C. A., & Salido, A. L. (2003). Sparky IntroChem: A student-oriented introductory chemistry course. *Journal of Chemical Education, 80*, 137–139.

Cashin, W. E., & Downey, R. G. (1992). Using global student rating items for summative assessment. *Journal of Educational Psychology, 84,* 563–572.

Crossgrove, K., & Curran, K. L. (2008). Using clickers in nonmajors- and majors-level biology courses: Student opinion, learning, and long-term retention of course material. *CBE Life Science Education, 7,* 146–154.

Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69,* 970–977.

Fagen, A. P., Crouch, C. H., & Mazur, E. (2002). Peer instruction: Results from a range of classrooms. *The Physics Teacher, 40,* 206–209.

Friedman, P., Rodrigues, F., & McComb, J. (2001). Why students do and do not attend classes: Myths and realities. *Journal of College Teaching, 49*(4), 124–133.

Gray, K. R., Steer, D., McConnell, D., & Owens, K. (2010). Using a student-manipulated model to enhance student learning in a large, lecture class: Addressing common misconceptions pertaining to the causes for the seasons. *Journal of College Science Teaching, 40*(1), 86–95.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66,* 64–74.

Hoyt, D. P., & Cashin, W. E. (1997). *Development of the IDEA system* (IDEA Technical Report No. 1). Manhattan, KS: Center for Faculty Evaluation and Development in Higher Education, Kansas State University.

Kortz, K., Smay, J., & Murray, D. (2008). Increasing learning in introductory geoscience courses using lecture tutorials. *Journal of Geoscience Education, 56,* 280–290.

Lasry, N. (2008). Clickers or flashcards: Is there really a difference? *The Physics Teacher*, *46,* 242–244.

Lasry, N., Mazur, E., & Watkins, J. (2008). Peer instruction: From Harvard to the two-year college. *American Journal of Physics, 76,* 1066–1069.

Libarkin, J. C., & Anderson, S. W. (2005). Assessment of learning in entry-level geoscience courses: Results from the Geoscience Concept Inventory. *Journal of Geoscience Education, 53,* 394–401.

Mayer, R. E., Stull, A., DeLeeuw, K., Almeroth, K., Bimber, B., Chun, D., . . . Zhang, H. (2009). Clickers in college classrooms: Fostering learning with questioning methods in large lecture classes. *Contemporary Educational Psychology, 34,* 51–57.

Mazur, E. (2011, May). *Confessions of a converted lecturer.* Paper presented at the Centre for Leadership in Learning Lecture at McMaster University, in Hamilton, Ontario, Canada. Available at http://mazur-www.harvard.edu/search-talks.php

Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall.

McConnell, D. A., Steer, D. N., Knight, C., Owens, K. D., & Park, L. (2008). *The good earth: Introduction to earth science*. New York, NY: McGraw-Hill.

McConnell, D. A., Steer, D. N., Owens, K. D., Knott, J. R., Van Horn, S., Borowski, W., . . . Heaney, P. J. (2006). Using ConcepTests to assess and improve student conceptual understanding in introductory geoscience courses. *Journal of Geoscience Education, 54,* 61–68.

McDermott, L. C., & Shaffer, P. S. (2002). *Tutorials in introductory physics* (lst ed.). Upper Saddle River, NJ: Prentice Hall.

Novak, G. M., Gavrin, A., Christian, W., & Patterson, E. T. (1999). *Just-in-time teaching: Blending active learning with web technology*. Upper Saddle River, NJ: Prentice Hall.

Petcovic, H. L., & Ruhf, R. J. (2008). Geoscience conceptual knowledge of preservice elementary teachers: Results from the geoscience concept inventory. *Journal of Geoscience Education,* 56, 251–260.

Prather, E. E., Slater, T. F., Adams, J. P., Bailey, J. M., Jones, L.V., & Dostal, J. A. (2005). Research on a lecture-tutorial approach to teaching introductory astronomy for non-science majors. *Astronomy Education Review, 3,* 122–136.

Sevian, H., & Robinson, W. (2011). Clickers promote learning in all kinds of classes—small and large, graduate and undergraduate, lecture and lab. *Journal of College Science Teaching, 40*(3), 14–18.

Steer, D. N., McConnell, D., Gray, K., Kortz, K. M., & Liang, X. (2009). Analysis of student responses to peer-instruction conceptual questions answered using an electronic response system: Trends by gender and ethnicity. *Science Educator, 18*(2): 30–38.

Sternberg, R. J. (1998). Metacognition, abilities, and developing expertise: What makes an expert student? *Instructional Science, 26,* 127–140.

Suchman, E., Uchiyama, K., Smith, R., & Bender, K. (2006). Evaluating the impact of a classroom response system in a microbiology course. *Microbiology Education,* 7, 3–11.

Wieman, C., Perkins, K., Gilbert, S., Benay, F., Kennedy, S., Semsar, K., . . . Simon, B. (2007). *Clicker resource guide: An instructor's guide to the effective use of personal response systems (clickers) in teaching.* Available at http://www.cwsei.ubc.ca/

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