STEM Topic: Clickers, classroom response systems, peer instruction

Deslauriers, L., Schelew, E., Weiman, C. 2011. Improved learning in a large-enrollment physics class. Science. Vol. 332, 862-865.

> We compared the amounts of learning achieved using two different instructional approaches under controlled conditions. We measured the learning of a specific set of topics and objectives when taught by 3 hours of traditional lecture given by an experienced highly rated instructor and 3 hours of instruction given by a trained but inexperienced instructor using instruction based on research in cognitive psychology and physics education. The comparison was made between two large sections (N = 267 and N = 271) of an introductory undergraduate physics course. We found increased student attendance, higher engagement, and more than twice the learning in the section taught using research-based instruction.

Moss, K., Crowley, M. 2011. Effective learning in science: The use of personal response systems with wide range of audiences. Computers & Education. Vol. 56, 36-43.

> This paper describes the flexibility of Personal Response Systems (PRSs), (also known as 'clickers' or electronic voting systems (EVS)), as part of strategies to support students' learning in science. Whilst variants of this technology began to appear 12 years ago, there is now a steadily increasing adoption of these systems within higher education, including science programmes, and this use has grown significantly in the last six years. They have previously been shown to offer a measurable learning benefit. Typically, someone at an institution buys these systems for learning support and they never make it out of their cases. Far less work has been done with these systems at school level. In this practitioner based paper, the broad range of practical uses for these systems is described in a variety of formal and informal learning situations – from testing the understanding of science concepts (from primary aged school children up to physics undergraduates), to undertaking evaluation of events as well as public participation in data collection for research on attitudes to careers. In addition, the data collected on such handsets can be mapped to demographic factors such as gender and age yielding further layers of analysis. Overall this is a highly flexible and transferable approach to the use of interactive technology for engaging learners of all ages as well as carrying out research.

Smith, M.K., Wood, W.B., Krauter, K., Knight, J.K., 2011. Combining peer discussion with instructor explanation increases student learning from in-class concept questions. Life Science Education. Vol. 10, 55-63.

> Use of in-class concept questions with clickers can transform an instructor-centered "transmissionist" environment to a more learner-centered constructivist classroom. To compare the effectiveness of three different approaches using clickers, pairs of similar questions were used to monitor student understanding in majors' and nonmajors' genetics courses. After answering the first question individually, students participated in peer discussion only, listened to an instructor explanation only, or engaged in peer discussion followed by instructor explanation, before answering a second question individually. Our results show that the combination of peer discussion followed by instructor explanation improved average student performance substantially when compared with either alone. When gains in learning were analyzed for three ability groups of students (weak, medium, and strong, based on overall clicker performance), all groups benefited most from the combination approach, suggesting that

peer discussion and instructor explanation are synergistic in helping students. However, this analysis also revealed that, for the nonmajors, the gains of weak performers using the combination approach were only slightly better than their gains using instructor explanation alone. In contrast, the strong performers in both courses were not helped by the instructor-only approach, emphasizing the importance of peer discussion, even among top-performing students.

Smith, M.K., Trujillo, C., Su, T.T., 2011. The benefits of using clickers in small-enrollment seminar-style biology courses. Life Sciences Education. Vol. 10, 14-17.

Although the use of clickers and peer discussion is becoming common in large-lecture undergraduate biology courses, their use is limited in small-enrollment seminar-style courses. To investigate whether facilitating peer discussion with clickers would add value to a small-enrollment seminar-style course, we evaluated their usefulness in an 11-student Embryology course at the University of Colorado, Boulder. Student performance data, observations of peer discussion, and interviews with students revealed that adding clickers to a small-enrollment course 1) increases the chance students will do the required reading before class, 2) helps the instructor engage all students in the class, and 3) gives students a focused opportunity to share thinking and to learn from their peers.

Milner-Bolotin, M., Antimirova, T., Petrov, A. 2010. Clickers beyond the first-year science classroom. Journal of College Science Teaching. Vol. 40, 14-19.

This case study's primary objective is to describe the implementation of the electronic response system (clickers) in a small (N = 25) second-year physics course at a large public university and to draw attention of the science faculty who teach upper-level science courses to the potential benefits of this pedagogy. This pilot study discusses the impact of the clicker-enhanced pedagogy on students' cognitive and affective outcomes and their attitudes toward using clickers. We also outline challenges faced by the students and the instructors on the way of successful clicker implementation beyond the first year and suggest a few possible ways of addressing them.

Perez, K.E., Strauss, E.A., Downey, N., Galbraith, A., Jeanne, R., Cooper, S. 2010. Does displaying the class results affect student discussion during peer instruction? Life Sciences Education. Vol. 9, 133-140.

The use of personal response systems, or clickers, is increasingly common in college classrooms. Although clickers can increase student engagement and discussion, their benefits also can be overstated. A common practice is to ask the class a question, display the responses, allow the students to discuss the question, and then collect the responses a second time. In an introductory biology course, we asked whether showing students the class responses to a question biased their second response. Some sections of the course displayed a bar graph of the student responses and others served as a control group in which discussion occurred without seeing the most common answer chosen by the class. If students saw the bar graph, they were 30% more likely to switch from a less common to the most common response. This trend was more pronounced in true/false questions (38%) than multiple-choice questions (28%). These results suggest that observing the most common response can bias a student's second vote on a question and may be misinterpreted as an increase in performance due to student discussion alone.

Turpen, C., Finkelstein, N.D., 2010. The construction of different classroom norms during Peer Instruction: Students perceive differences. Physics Education Research 6. 020123.

This paper summarizes variations in instructors' implementation practices during Peer Instruction _PI_ and shows how these differences in practices shape different norms of classroom interaction. We describe variations in classroom norms along three dimensions of classroom culture that are integral to Peer Instruction, emphasis on: _1_ faculty-student collaboration, _2_ student-student collaboration, and _3_ sense-making vs answer-making. Based on interpretations by an observing researcher, we place three different PI classrooms along a continuum representing a set of possible norms. We then check these interpretations against students' perceptions of these environments from surveys collected at the end of the term. We find significant correspondence between the researchers' interpretations and students' perceptions of Peer Instruction in these environments. We find that variation in faculty practices can set up what students perceive as discernibly different norms. For interested instructors, concrete classroom practices are described that appear to encourage or discourage these norms.

Beckert, T.E., Fauth, E., Olsen, K. 2009. Clicker satisfaction for students in human development: Differences for class type, prior exposure, and student talkativity. North American Journal of Psychology. Vol. 11, 599-612.

Clicker technology is growing in popularity in psychology and human development classes. It allows all students to provide instant feedback to instructor inquiry by using radio-frequency remote voting. The goal of this study was to determine the degree to which exposure, class type, and self-reported level of verbal interaction related to user satisfaction. One hundred seventy human development students participating in classrooms with clicker technology completed a 36-question clicker satisfaction survey. Overall students were satisfied with the use of clickers. Specifically students using clickers in multiple classrooms and in upperdivision classes indicated higher levels of satisfaction. Additionally, students who self-reported to be less likely to comment verbally in class indicated higher levels of satisfaction with clicker use.

Brickman, P., Gormally, C., Armstrong, N., Hallar, B. 2009. Effects of inquiry-based learning on students' science literacy skills and confidence. International Journal for the Scholarship of Teaching and Learning. Vol. 3, 22.

Calls for reform in university education have prompted a movement from teacher- to student-centered course design, and included developments such as peer-teaching, problem and inquiry-based learning. In the sciences, inquiry-based learning has been widely promoted to increase literacy and skill development, but there has been little comparison to more traditional curricula. In this study, we demonstrated greater improvements in students' science literacy and research skills using inquiry lab instruction. We also found that inquiry students gained self-confidence in scientific abilities, but traditional students' gain was greater –likely indicating that the traditional curriculum promoted over-confidence. Inquiry lab students valued more authentic science exposure but acknowledged that experiencing the complexity and frustrations faced by practicing scientists was challenging, and may explain the widespread reported student resistance to inquiry curricula.

Ghosh, S., Renna, F. 2009.Using electronic response systems in economics classes. Journal of Economic Education. Fall. 354-367.

> College instructors and students participated in a pilot project at the University of Akron to enhance student learning through the use of a common teaching pedagogy, peer instruction. The teaching pedagogy was supported by the use of technology, an electronic personal response system, which recorded student responses. The authors report their experiences in using this technology-enhanced teaching pedagogy and provide another example of an active and collaborative learning tool that instructors can use to move beyond "chalk and talk." Preliminary survey results from students participating in this pilot project are also reported.

Knapp, F.A., Desrochers, M.N. 2009. An experimental evaluation of the instructional effectiveness of a student response system: A comparison with constructed overt responding. International Journal of Teaching and Learning in Higher Education. Vol. 21, 36-46.

> Student response systems (SRSs) are increasingly being used in the classroom. However, there have been few well-controlled experimental evaluations to determine whether students benefit academically from these instructional tools. Additionally, comparisons of SRS with other interactive methods have not often been conducted. We compared SRS, Constructed Overt Response (COR), passive, and control conditions to determine their effects on learning and affect. We found that students performed better in the interactive conditions—SRS and COR—than the other conditions. Participants' gain and retention of gain scores in the SRS condition were lower than those in the COR condition. Participants in the SRS condition perceived their condition as more enjoyable than those in the passive condition and more useful than those in the control condition. Additional research questions are raised about how these interactive methods may best improve student learning.

Lucas, A., 2009. Using peer instruction and I-clickers to enhance student participation in calculus. PRIMUS. Vol. 19, 219-231.

> In my Calculus classes I encourage my students to actively reflect on course material, to work collaboratively, and to generate diverse solutions to questions. To facilitate this I use peer instruction (PI), a structured questioning process, and i-clickers, a radio frequency classroom response system enabling students to vote anonymously. This article concludes that PI and i-clickers enhance student participation and comprehension. It is important, however, that students write down their reasoning during PI so as not to be led astray by dominant group members.

Mayer, R.E., Stull, S., Deleeuw, K., Almeroth, K., Bimber, B., Chun, D., Bulger, M., Campbell, J., Knight, A., Zhang, H. 2009. Clickers in college classrooms: Fostering learning with questioning methods in large lecture classes. Contemporary Educational Psychology. Vol. 34, 51-57

> What can be done to promote student–instructor interaction in a large lecture class? One approach is to use a personal response system (or "clickers") in which students press a button on a hand-held remote control device corresponding to their answer to a multiple choice question projected on a screen, then see the class distribution of answers on a screen, and discuss the thinking that leads to the correct answer. Students scored significantly higher on the

course exams in a college-level educational psychology class when they used clickers to answer 2 to 4 questions per lecture (clicker group), as compared to an identical class with in-class questions presented without clickers (no-clicker group, d = 0.38) or with no in-class questions (control group, d = 0.40). The clicker treatment produced a gain of approximately 1/3 of a grade point over the no-clicker and control groups, which did not differ significantly from each other. Results are consistent with the generative theory of learning, which predicts students in the clicker group are more cognitively engaged during learning.

Mazur, E. 2009. Farewell, lecture? Science. Vol. 232, 50-51.

Discussions of education are generally predicated on the assumption that we know what education is. I hope to convince you otherwise by recounting some of my own experiences. When I started teaching introductory physics to undergraduates at Harvard University, I never asked myself how I would educate my students. I did what my teachers had done—I lectured. I thought that was how one learns. Look around anywhere in the world and you'll find lecture halls filled with students and, at the front, an instructor. This approach to education has not changed since before the Renaissance and the birth of scientific inquiry. Early in my career I received the first hints that something was wrong with teaching in this manner, but I had ignored it. Sometimes it's hard to face reality.

Salemi, M.K. 2009. Clickenomics: Using a classroom response system to increase student engagement in a large-enrollment principles of economics course. Journal of Economic Education. Fall 385-406.

One of the most important challenges facing college instructors of economics is helping students engage. Engagement is particularly important in a large-enrollment Principles of Economics course, where it can help students achieve a long-lived understanding of how economists use basic economic ideas to look at the world. The author reports how instructors can use Classroom Response Systems (clickers) to promote engagement in the Principles course. He draws heavily on his own experience in teaching a one semester Principles course at the University of North Carolina at Chapel Hill but also reports on how others have used clickers to promote engagement. He concludes with evidence that students find clickers very beneficial and with an assessment of the costs and benefits of adopting a clicker system.

Smith, M.K., Wood, W.B., Adams, W.K., Wieman, C., Knight, J.K., Guild, N., Su, T.T. 2009. Why peer discussion improves student performance on in-class concept questions. Science. Vol. 323, 122-125.

When students answer an in-class conceptual question individually using clickers, discuss it with their neighbors, and then revote on the same question, the percentage of correct answers typically increases. This outcome could result from gains in understanding during discussion, or simply from peer influence of knowledgeable students on their neighbors. To distinguish between these alternatives in an undergraduate genetics course, we followed the above exercise with a second, similar (isomorphic) question on the same concept that students answered individually. Our results indicate that peer discussion enhances understanding, even when none of the students in a discussion group originally knows the correct answer.

Turpen, C., Finkelstein, N.D. 2009. Not all interactive engagement is the same: Variations in physics professors' implementation of peer instruction. Physical Education Research. Vol. 5, 020101

While educational reforms in introductory physics are becoming more widespread, how these reforms are implemented is less well understood. This paper examines the variation in faculty practices surrounding the implementation of educational reform in introductory physics courses. Through observations of classroom practice, we find that professors' actual practices differ strikingly. We present a framework for describing and capturing instructional choices and resulting variations in enacted practices for faculty who are implementing *Peer Instruction*. Based on our observations, there are a variety of scientific practices that are supported and modeled in the use of Peer Instruction. In all of the classrooms studied, students were found trying out and applying new physical concepts and discussing physics with their peers. However, there were large discrepancies in students' opportunities to engage in formulating and asking questions, evaluating the correctness and completeness of problem solutions, interacting with physicists, identifying themselves as sources of solutions, explanations, or answers, and communicating scientific ideas in a public arena. Case studies of six professors demonstrate how these variations in classroom practices, in aggregate, create different classroom norms, such as the relative emphasis on student sense-making vs answer-making during *Peer Instruction*.

Willoughby, S.D., Gustafson, E. 2009. Technology talks: clickers and grading incentive in the large lecture hall. American Journal of Physics. Vol. 77, 180-184.

Two sections of an introductory astronomy class were given different grading incentives for clicker participation for two consecutive semesters. In the high stakes classroom points were awarded only for correct answers, in contrast to the low stakes classroom in which points were awarded simply for participating. Self-formed groups of four students each were recorded in both sections several times during the spring 2007 semester and their conversations were transcribed and categorized into nine topics to analyze the variations between the sections. Performance on clicker questions and tendency to block vote were correlated with class grades and gains for the pre- and post-test scores on the Astronomy Diagnostic Test.

Crossgrove, K., Curran, K. 2008. Using clickers in nonmajor- and major-level biology courses: Student opinion, learning, and long-term retention of course material. Life Sciences Education. Vol. 7, 146-154.

Student response systems (clickers) are viewed positively by students and instructors in numerous studies. Evidence that clickers enhance student learning is more variable. After becoming comfortable with the technology during fall 2005–spring 2006, we compared student opinion and student achievement in two different courses taught with clickers in fall 2006. One course was an introductory biology class for nonmajors, and the other course was a 200 level genetics class for biology majors. Students in both courses had positive opinions of the clickers, although we observed some interesting differences between the two groups of students. Student performance was significantly higher on exam questions covering material taught with clickers, although the differences were more dramatic for the nonmajors biology course than the genetics course. We also compared retention of information 4 mo after the course ended, and we saw increased retention of material taught with clickers for the nonmajors course, but not for the genetics course. We discuss the implications of our results in light of differences in how the two courses were taught and differences between science majors and nonmajors.

Gunersel, A.B., Simpson, N.J., Aufderheide, K.J., Wang, L. 2008. Effectiveness of calibrated peer review for improving writing and critical thinking skills in biology undergraduate students. J of the scholarship of Teaching and Learning, Vol. 8, 25-37.

This study focuses on student development with Calibrated Peer Review (CPR) TM, a web-based tool created to promote writing and critical thinking skills. Research questions focus on whether or not students showed improvement in writing and reviewing competency with repeated use of CPR in a senior-level biology course and whether the difference between higher performing and lower performing students decreased over time. Four repeated measures analyses were conducted with different sets of students. Repeated measures analyses indicate that students showed improvement in writing skills and reviewer competency with repeated use of CPR. The difference between higher and lower performing students decreased over time in both writing skills and reviewer competency.

King, D.B., Joshi, S. 2008. Gender differences in the use and effectiveness of personal response devices. Journal of Science Educational Technology. Vol. 17, 544-552.

The use of personal response devices (or ''clickers'') in the classroom has increased in recent years. While few quantitative studies on the effectiveness of clickers have been published, it is generally reported that clickers have been well-received by the students who use them. Two separate populations (Winter 2006 and Spring 2006) of engineering students were given clickers to use during a general chemistry class. Clicker use was compared to student grades for each course. During both terms, a higher percentage of female students than male students ''actively participated'' in the lectures, where active participation as defined as answering more than 75% of the clicker questions over the course of the term. Active male students earned final grades about 10 points higher than non-active male students. Active female students, however, scored only about 5 points higher than non-active female students. Student learning was assessed by comparing performance on exam questions and clicker questions with similar content. Students who answered clicker questions correctly were 11–13% more likely to answer the corresponding exam questions correctly than were students who did not answer the clicker question. In this paper, we demonstrate the effectiveness of clicker use in the classroom and examine gender differences associated with this use.

Lasry, N. 2008. Clickers or flashcards: Is there really a difference? The Physics Teacher. Vol. 26, 242-245.

A growing number of physics teachers are currently turning to instructional technologies such as wireless handheld response systems —colloquially called clickers. Two possible rationales may explain the growing interest in these devices. The first is the presumption that clickers are more effective instructional instruments. The second rationale is somewhat reminiscent of Martin Davis' declaration when purchasing the Oakland Athletics: "As men get older, the toys get more expensive." Although personally motivated by both of these rationales, the effectiveness of clickers over inexpensive low-tech flashcards remains questionable. Thus, the first half of this paper presents findings of a classroom study comparing the differences in student learning between a Peer Instruction group using clickers and a Peer Instruction group using flashcards. Having assessed student learning differences, the second half of the paper describes differences in teaching effectiveness between clickers and flashcards.

Lasry, N., Mazur, E., Watkins, J. 2008. Peer instruction: From Harvard to the two-year college. American Journal of Physics. Vol. 76, 1066-1070.

We compare the effectiveness of a first implementation of peer instruction _PI_ in a two-year college with the first PI implementation at a top-tier four-year research institution. We show

how effective PI is for students with less background knowledge and what the impact of PI methodology is on student attrition in the course. Results concerning the effectiveness of PI in the college setting replicate earlier findings: PI-taught students demonstrate better conceptual learning and similar problem-solving abilities than traditionally taught students. However, not previously reported are the following two findings: First, although students with more background knowledge benefit most from either type of instruction, PI students with less background knowledge gain as much as students with more background knowledge in traditional instruction. Second, PI methodology is found to decrease student attrition in introductory physics courses at both four-year and two-year institutions.

MacArthur, J.R., Jones, L.L. 2008. A review of literature reports of clickers applicable to college chemistry classrooms. Chemistry Education Research and Practice. Vol. 9, 187-195.

The use of clickers (also referred to as Audience Paced Feedback, Classroom Communication Systems, Personal Response Systems, Electronic Voting Systems, Student Response Systems, Audience Response Systems, voting-machines, and zappers) has grown in college chemistry classrooms within the last decade. This review summarizes the pedagogic applications of research on clickers as well as insights from their practical use. Fifty-six publications reporting on the use of clickers in college-level science classrooms are categorized as practical application or research studies, and reviewed. Publications on the practical use of clickers suggest that students have a positive attitude towards the technology and that many benefits and few drawbacks are associated with its use. Research studies show that the use of clickers results in measurable increases in student learning in some cases and inconclusive results in other cases. In every published report of student improvement with the use of clickers, the course included student collaboration of some form.

Morse, D., Jutras, F. 2008. Implementing concept-based learning in a large undergraduate classroom. Life Sciences Education. Vol 7, 243-253.

An experiment explicitly introducing learning strategies to a large, first-year undergraduate cell biology course was undertaken to see whether awareness and use of strategies had a measurable impact on student performance. The construction of concept maps was selected as the strategy to be introduced because of an inherent coherence with a course structured by concepts. Data were collected over three different semesters of an introductory cell biology course, all teaching similar course material with the same professor and all evaluated using similar examinations. The first group, used as a control, did not construct concept maps, the second group constructed individual concept maps, and the third group first constructed individual maps then validated their maps in small teams to provide peer feedback about the individual maps. Assessment of the experiment involved student performance on the final exam, anonymous polls of student perceptions, failure rate, and retention of information at the start of the following year. The main conclusion drawn is that concept maps without feedback have no significant effect on student performance, whereas concept maps with feedback produced a measurable increase in student problem-solving performance and a decrease in failure rates

Radosevich, D.J., Salomon, R., Radosevich, D.M., Kahn, P. 2008. Using student response systems to increase motivation, learning, and knowledge retention. http://elearn.uaa.alaska.edu/ Shared%20Documents/classroom%20Clickers/Articles%20on%20Clickers/UsingSRSMontclairStU.pdf

Student response system (SRS) technology is one of the many tools available to help instructors create a rich and productive learning environment even within the framework of a traditional lecture-based lesson. The SRS presents questions to the class, prompts students to enter responses using a pocket-sized keypad transmitter (Figure 1), and provides aggregated feedback regarding student responses to the instructor. An SRS can be used to assess students' comprehension of complex material, affording both the instructor and the students immediate feedback so that instruction can be tailored to student needs. Furthermore, the question-and-feedback process has the potential to promote greater student engagement in class discussions, and group activities in which students solve problems together and submit answers using the SRS can promote active learning. The primary goal of this study is to examine the extent to which SRS can impact student motivation and foster active learning.

Woelk, K. 2008. Optimizing the use of personal response devices (clickers) in large-enrollment introductory courses. Journal of Chemical Education. Vol. 85, 1400-1406.

While many studies are still in progress, especially those seeking to quantify learning outcomes, clicker systems have already been permanently installed in numerous college and university classrooms, particularly for use in large-enrollment first- and second-year science courses. Evidently, instructors are encouraged by their own or their colleagues' evaluation of the technology so that they are willing to try or stick with this new way of interacting with students in the classroom. As the devices, hardware, and software have become less expensive, high school instructors are also experimenting with clickers.3 Teaching research studies *(2, 3)* and personal anecdotes, many of which are presented on Web pages, praise the successful con-tribution of clickers for enhancing the students' engagement in large-enrollment courses *(4)* and the positive impact clickers may have on final course grades *(5)*. A closer look at these studies indicates that the use of clickers particularly helps students with low grades to maintain or regain their interest in the subject matter. A recent literature review article is available *(6)* focusing on reports of clickers in educational settings.

Zhu, E. 2008. Teaching with clickers. Center for Research on Learning and Teaching. No. 22. 1-8.

Since the 1980s, the use of clickers has proliferated on college campuses. Faculty from various disciplines such as biology, chemistry, history, mathematics, political science, law and psychology have introduced clicker systems into their classrooms. Faculty use clickers for various purposes depending on their course goals and learning objectives. The most common uses of clickers include the following:

Barber, M., Njus, D. 2007. Clicker evolution: Seeking intelligent design. Life Sciences Education. Vol. 6, 1-8.

Two years after the first low-cost radio-frequency audience response system using clickers was introduced for college classrooms, at least six different systems are on the market. Their features and user-friendliness are evolving rapidly, driven by competition and improving technology. The proliferation of different systems is putting pressure on universities to standardize or otherwise limit the number of different clickers a student is expected to acquire. To facilitate that choice, the strengths and weaknesses of six systems (eInstruction Classroom Performance System, Qwizdom, TurningPoint, Interwrite PRS, iClicker, and H-ITT) are compared, and the factors that should be considered in making a selection are discussed. In our opinion,

the selection of a clicker system should be driven by the faculty, although students and the relevant teaching and technology support units of the university must also participate in the dialogue. Given the pace of development, it is also wise to reconsider the choice of a clicker system at regular intervals.

Caldwell, J.E. 2007. Clickers in the large classroom: Current research and best-practice tips. Live Science Education. Vol. 6, 9-21.

Audience response systems (ARS) or clickers, as they are commonly called, offer a management tool for engaging students in the large classroom. Basic elements of the technology are discussed. These systems have been used in a variety of fields and at all levels of education. Typical goals of RS questions are discussed, as well as methods of compensating for the reduction in lecture time that typically results from their use. Examples of ARS use occur throughout the literature and often detail positive attitudes from both students and instructors, although exceptions do exist. When used in classes, ARS clickers typically have either a benign or positive effect on student performance on exams, depending on the method and extent of their use, and create a more positive and active atmosphere in the large classroom. These systems are especially valuable as a means of introducing and monitoring peer learning methods in the large lecture classroom. So that the reader may use clickers effectively in his or her own classroom, a set of guidelines for writing good questions and a list of best-practice tips have been culled from the literature and experienced users.

Preszler, R.W., Dawe, A., Shuster, C.B., Shuster, M. 2007. Assessment of the effects of student response systems on student learning and attitudes over a broad range of biology courses. Life Science Education. Vol. 6, 29-41.

With the advent of wireless technology, new tools are available that are intended to enhance students' learning and attitudes. To assess the effectiveness of wireless student response systems in the biology curriculum at New Mexico State University, a combined study of student attitudes and performance was undertaken. A survey of students in six biology courses showed that strong majorities of students had favorable overall impressions of the use of student response systems and also thought that the technology improved their interest in the course, attendance, and understanding of course content. Students in lower-division courses had more strongly positive overall impressions than did students in upper-division courses. To assess the effects of the response systems on student learning, the number of in-class questions was varied within each course throughout the semester. Students' performance was compared on exam questions derived from lectures with low, medium, or high numbers of in-class questions. Increased use of the response systems in lecture had a positive influence on students' performance on exam questions across all six biology courses. Students not only have favorable opinions about the use of student response systems, increased use of these systems increases student learning.

Poirier, C.R., Feldman., R.S. 2007. Promoting active learning using individual response technology in large introductory psychology classes. Teaching of Psychology. Vol. 34, 194-199.

Individual response technology (IRT), in which students use wireless handsets to communicate real-time responses, permits the recording and display of aggregated student responses during class. In comparison to a traditional class that did not employ IRT, students using IRT performed

better on exams and held positive attitudes toward the technology. IRT appears to be a promising technology for increasing active learning in the classroom and enhancing students' mastery of course content.

Rath, K.A., Peterfreund, A.R., Xenos, S.P., Bayliss, F., Carnal, N. 2007. Supplemental instruction in introductory biology I: Enhancing the performance and retention of underrepresented minority students. Life Sciences Education. Vol. 6, 203-216.

Supplemental instruction classes have been shown in many studies to enhance performance in the supported courses and even to improve graduation rates. Generally, there has been little evidence of a differential impact on students from different ethnic/racial backgrounds. At San Francisco State University, however, supplemental instruction in the Introductory Biology I class is associated with even more dramatic gains among students from underrepresented minority populations than the gains found among their peers. These gains do not seem to be the product of better students availing themselves of supplemental instruction or other outside factors. The Introductory Biology I class consists of a team-taught lecture component, taught in a large lecture classroom, and a laboratory component where students participate in smaller lab sections. Students are expected to master an understanding of basic concepts, content, and vocabulary in biology as well as gain laboratory investigation skills and experience applying scientific methodology. In this context, supplemental instruction classes are cooperative learning environments where students participate in learning activities that complement the course material, focusing on student misconceptions and difficulties, construction of a scaffolded knowledge base, applications involving problem solving, and articulation of constructs with peers.

Stowell, J.R. Nelson, J.M. 2007. Benefits of electronic audience response systems on student participation, learning, and emotion. Teaching of Psychology. Vol. 34, 253-250.

We compared an electronic audience response system (clickers) to standard lecture, hand-raising, and response card methods of student feedback in simulated introductory psychology classes. After hearing the same 30-min psychology lecture, participants in the clicker group had the highest classroom participation, followed by the response card group, both of which were significantly higher than the hand-raising group. Participants in the clicker group also reported greater positive emotion during the lecture and were more likely to respond honestly to in-class review questions.

Bunce, D.M., VandenPlas, J.R., Havanki, K.L. 2006.Comparing the effectiveness on student achievement of a student reponse system versus online WebCT quizzes. Journal of Chemical Education. Vol. 83, 488-494.

The use of computers to gather student responses is not new to science education. Use of electronic response systems, especially in large lectures, dates back to the 1960s *(3).* Research on the effectiveness of this approach has been limited to its influence on increased rates of passing the course *(4).* More work is needed to test the effectiveness of computers and ConcepTests on student achievement. It is this question that led to the incorporation of the Student Response System (SRS) into a second-semester nursing course. SRS is a Webbased questioning system *(5)* designed to assist instructors in receiving and analyzing student responses to questions posed in lecture or recitation. In this study, the electronic student

response system, SRS, was used primarily as a means of delivering electronic ConcepTests for students working in pairs.

Beatty, I.D., Gerace, W.J., Leonard, W.J., Dufresne, R.J. 2006. Designing effective questions for classroom response system teaching. American Journal of Physics. Vol. 74, 31-40.

Classroom response systems can be powerful tools for teaching physics. Their efficacy depends strongly on the quality of the questions. Creating effective questions is difficult and differs from creating exam and homework problems. Each classroom response system question should have an explicit pedagogic purpose consisting of a content goal, a process goal, and a metacognitive goal. Questions can be designed to fulfill their purpose through four complementary mechanisms: directing students' attention, stimulating specific cognitive processes, communicating information to the instructor and students via classroom response system-tabulated answer counts, and facilitating the articulation and confrontation of ideas. We identify several tactics that are useful for designing potent questions and present four "makeovers" to show how these tactics can be used to convert traditional physics questions into more powerful questions for a classroom response system.

El-Rady, J. 2006. To click or not to click: That is the question. Innovate, Journal of Online Education. Vol. 2, 18.

It is not unusual in higher education these days to have classes with large enrollment. Indeed at the University of South Florida (USF) (enrollment 41,000), large classes are the norm. In the eight years during which I have been an instructor in the Biology Department at USF, my mid-level and lower-level classes have had enrollments ranging from 100-300 students. This large class size generates a few problems, especially in terms of engaging students in active learning. While a well-designed traditional lecture can be very effective, students can engage more directly with the material when they actively take part in their learning instead of simply passively receiving information. Another problem in large enrollment courses is low attendance, especially by students taking a non-major course.

McConnell, D.A., Steer, D.N., Owens, K.D., Knott, J.R., Van Horn, S., Borowski, W., Dick, J., Foos, A., Malone, M., McGrew, H., Greer, L., Heaney, P.J. 2006. Using conceptests to assess and improve student conceptual understanding in introductory geoscience courses. Journal of Geoscience Education. Vol. 54, 61-68.

Conceptests are higher-order multiple-choice questions that focus on one key concept of an instructor's major learning goals for a lesson. When coupled with student interaction through peer instruction, conceptests represent a rapid method of formative assessment of student understanding, require minimal changes to the instructional environment and introduce many of the recognized principles of effective teaching that enhance student learning. In this study, instructors from several different institutions developed over 300 conceptests for the geosciences. These instructors then used this suite of concept questions in a wide range of classroom settings, including large introductory general education Earth Science courses for non-majors at open enrollment institutions, smaller physical geology classes suitable for majors at private colleges, and in introductory geology laboratory settings. Results of pre- and post-class Geoscience Concept Inventory (GCI) testing and qualitative feedback from students and instructors showed that conceptests increased attendance, improved student satisfaction, and

enhanced student achievement. Participating instructors found implementation of conceptests into their classes straightforward and required less than 30 minutes of preparation per class. The conceptest question database is available on-line for geoscience instructors.

Carlson, P.A., Berry, F.C., Voltmer, D. 2005. Incorporating student peer-review into an introduction to engineering design course. 35th ASEE/IEEE Frontiers in Education Conference, October, Indianapolis, IN.

We report on a project to improve the teaching of engineering design at the junior level. Peer review of student work is an integral part of collaborative learning and reform-driven engineering education. Yet successfully implementing this pedagogical technique requires significant amounts of instructor and class time. Furthermore, if adequate formative assessment does not emerge from peer review, the experience may devolve into "busy work" in the eyes of the student. Here, we give early results from an NSF-funded study using Calibrated Peer Review (a web-delivered, collaborative learning environment) to enhance learning in engineering design.

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. Vol. 21, 260-268.

This paper reports on the use of an electronic voting system (EVS) in a first-year computing science subject. Previous investigations suggest that students' use of an EVS would be positively associated with their learning outcomes. However, no research has established this relationship empirically. This study sought to establish whether there was an association between students' use of an EVS over one semester and their performance in the subject's assessment tasks. The results from two stages of analysis are broadly consistent in showing a positive association between EVS usage and learning outcomes for students who are, relative to their class, more correct in their EVS responses. Potential explanations for this finding are discussed as well as modifications and future directions of this program of research.

McConnell, D.A., Steer, D.N., Owens, K.D., Knight, C.C. 2005. How students think: Implications for learning in introductory geoscience courses. Journal of Geoscience Education. Vol. 53, 462-470.

Non-major students in introductory geoscience classes exhibit a wide range of intellectual development. Approximately half of these students do not have the skills to understand the abstract scientific concepts traditionally discussed in introductory classes. Many geological concepts will remain unlearned without appropriate activities that build on a foundation of concrete examples. The good news is that these same students can improve their logical thinking skills when they participate in challenging in-class collaborative learning exercises with their more intellectually sophisticated peers. While the exercises themselves are important in promoting the development of higher-order thinking skills, the group interaction also appears to be a significant contributor to the improvement of reasoning.

Draper, S.W., Brown, M.I. 2004. Increasing interactivity in lectures using an electronic voting system. Journal of Computer Assisted Learning. Vol. 20, 81-94.

An overview of the experience of the opening two years of an institution-wide project in introducing electronic voting equipment for lectures is presented. Eight different departments

and a wide range of group size (up to 300) saw some use. An important aspect of this is the organizational one of addressing the whole institution, rather than a narrower disciplinary base. The mobility of the equipment, the generality of the educational analysis, and the technical support provided contributed to this. Evaluations of each use identified (formatively) the weakest spots and the most common benefits, and also (summatively) showed that learners almost always saw this as providing a net benefit to them. Various empirical indications support the theoretical view that learning benefits depend upon putting the pedagogy (not the technology) at the focus of attention in each use. Perceived benefits tended to increase as lecturers became more experienced in exploiting the approach. The most promising pedagogical approaches appear to be Interactive Engagement (launching peer discussions), and Contingent Teaching – designing sessions not as fixed scripts but to zero in on using diagnostic questions on the points that the particular audience most needs on this occasion.

Roschelle, J., Penuel, W.R., Abrahamson, L. 2004. Proceedings from the Annual Meeting of the American Educational Research Association 04: Classroom response and communication systems: Research review and theory. San Diego, CA.

In How People Learn, Bransford and colleagues (National Research Council, 1999) cite classroom response system technology and the related pedagogy as one of the most promising innovations for transforming classrooms to be more learner-, knowledge-, assessment-, and community-centered. As a step towards guiding practice and advancing research, we present our review of the research on this and more advanced, but related technologies, particularly with regard to the popular use of these systems to enhance questioning and feedback. We also formulate tentative theoretical connections to a broader scientific literature that could explain how pedagogy and technology together realize multiple desirable outcomes

Wit, E. 2003. Who wants to be…The use of a personal response system in statistics teaching. MSOR Connections. Vol. 3, 14-21.

Service courses of statistics can be among the most recalcitrant. Undergraduate students do not always see immediately the relevance of the course to their own field so that interaction with them tends to be difficult. Add on top of that the large class size, and interactive teaching may seem impossible. The development of handsets as used in Who wants to be a millionaire? has proven to be a possible tool to enhance interaction and stimulate learning. In this article we describe this personal response system (PRS) and its implementation within a statistics service course to first year psychology students.

Hall, S.R., Waitz, I., Brodeur, D.R., Soderholm, D.H., Nsr, R. 2002. Adoption of active learning in a lecture-based engineering class. 32nd ASEE/IEEE Frontiers in Education Conference. November, Boston MA.

Three years ago, the Department of Aeronautics and Astronautics at MIT expanded its repertoire of active learning strategies and assessment tools with the introduction of muddiest-point-in-the-lecture cards, electronic response systems, concept tests, peer coaching, course web pages, and web-based course evaluations. This paper focuses on the change process of integrating these active learning strategies into a traditional lecture-based multidisciplinary course, called Unified Engineering. The description of the evolution of active learning in Unified Engineering is intended to underscore the motivation and incentives required for bringing about

the change, and the support needed for sustaining and disseminating active learning approaches among the instructors.

Judson, E., Swada, D. 2002. Learning from past and present: Electronic response systems I college lecture halls. Journal of Computers in Mathematics and Science Teaching. Vol. 21, 167-181.

This article reviews literature from the past 33 years particular to the use of electronic response systems in college lecture halls. Electronic response systems, primarily used in science courses have allowed students to provide immediate feedback to multiple-choice questions, and inform the instructor of student understanding. Research from the 1960s and 1970s indicates there is no significant correlation between student academic achievement and a stimulus-response method of using such systems. Recent studies have indicated there is significant student increase of conceptual gains in physics when electronic response systems are used to facilitate feedback in a constructivist-oriented classroom. Students have always favored the use of electronic response systems and attribute such factors as attentiveness and personal understanding to using electronic response systems. Ultimately, this review of literature points to the pedagogical practices of the instructor, not the incorporation of the technology as being key to student comprehension. Electronic response systems are viewed as a tool that holds a promise of facilitating earnest discussion. Recommendations are made that professional development focus on pedagogical practice for instructors considering the use of electronic response system.

Crouch, C.H., Mazur, E. 2001. Peer instruction: Ten years of experience and results. Americal Journal of Physics. Vol. 69, 970-978.

We report data from ten years of teaching with Peer Instruction ~PI! in the calculus- and algebra-based introductory physics courses for nonmajors; our results indicate increased student mastery of both conceptual reasoning and quantitative problem solving upon implementing PI. We also discuss ways we have improved our implementation of PI since introducing it in 1991. Most notably, we have replaced in-class reading quizzes with pre-class written responses to the reading, introduced a research-based mechanics textbook for portions of the course, and incorporated cooperative learning into the discussion sections as well as the lectures. These improvements are intended to help students learn more from pre-class reading and to increase student engagement in the discussion sections, and are accompanied by further increases in student understanding.

Robertson, L.J. 2000. Twelve tips for using a computerized interactive audience response system. Medical Teacher. Vol. 22, 237-240.

The role of the lecture in medical education has recently been called into question. Adults learn more effectively through active learning therefore where is the place for the traditional lecture? This paper describes the use of a computerized audience response system to transform large group teaching sessions into active learning experiences, thereby securing a future for the lecture format. We pass on our tips, gleaned from our varied experiences using the system, for the successful design and running of such interactive sessions.

Groccia, J.E., Miller, J.E. 1996. Collegiality in the classroom: the use of peer learning assistants in cooperative learning in introductory biology. Innovative Higher Education. Vol. 21, 87-100.

Experienced undergraduate students served as Peer Learning Assistants (PLAs) to facilitate group process and dynamics in cooperative learning groups. The use of this model in large classes (150 students) resulted in statistically significant improvements in group performance and satisfaction with the group experience. PLAs defused conflict in groups which were, by their cognitively diverse nature, conflict-prone. Student attitudes about their PLAs and PLA attitudes about the experience were positive. Faculty productivity was substantially enhanced because group dynamics problems rarely landed in the faculty office.