

Literature Review on Clickers

Prepared for: i>clicker (Bedford, Freedman, & Worth Publishing)

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Summary: This document surveys the literature on the educational use of “clickers” in various learning environments and across many disciplines. Additionally, relevant data from prior studies on the use and prevalence of clickers at the University of Colorado at Boulder has been included in this review.

Studies which specifically document the use and implementation of clickers are included, while other studies that simultaneously document numerous pedagogical techniques or document the success of interactive engagement, such as the often cited “Hake data,” are not included in this review. The majority of studies listed in this review report positive student learning outcomes, predominantly in large lecture courses, from the use of clickers with appropriate pedagogical techniques, such as Peer Instruction. Many authors offer suggestions to new instructors on the implementation of clickers and the design of concept tests. Note that due to the prevalence of clickers across many fields and the myriad of alternative names used in place of the term “clicker,” some studies may have been mistakenly overlooked when compiling this literature review.

Note on Clicker Terminology

Clickers have been used and studied in many different disciplines—as a result, there are a variety of terms used to describe “clickers.” The list below consists of other terminology used in place of clickers that appear in published works. Note that this list may not be complete, and some terms may be trademarked.

1. clickers
2. zappers
3. personal response system
4. personal electronic response system
5. peer response system
6. classroom response system
7. electronic response system
8. audience response system
9. group response system
10. interactive response system
11. interactive student response system
12. electronic student response technology
13. wireless response technology
14. voting machine
15. electronic voting machine
16. electronic voting system
17. electronic polling system
18. classroom polling tool
19. wireless keypad
20. classroom communication system
21. wireless classroom communication system
22. wireless course feedback system
23. classroom feedback system
24. classroom performance system
25. audience-paced feedback system
26. CATAALYST (Classroom Aggregation Technology for Activating and Assessing Learning and Your Students' Thinking)

Studies at the University of Colorado

Noah Finkelstein, Steven Pollock, Michael Dubson, Valerie Otero, Christopher Keller, and Chandra Turpen, “First Year Foundations of the Colorado PhysTEC Project, Physics Teacher Education Coalition.” PhysTEC Annual Report, University of Colorado at Boulder, 2005.

From Section 4.4, pages 46-48:

With support of the physics department and FTEP in Spring 2002, Michael Dubson, a lead investigator for the Colorado PhysTEC project, installed the first electronic personal response system at the University of Colorado. Since then, he has spearheaded the implementation of the HiTT-personal response system (<http://www.h-itt.com>) throughout various physics courses and various departments at the University of Colorado. Since its installation, the integration of concept tests with electronic personal response has become significantly more widespread in the physics department educational practice and across other disciplines. Figure 1 shows the growth in the use of clickers in the classroom at the University of Colorado since its installation.

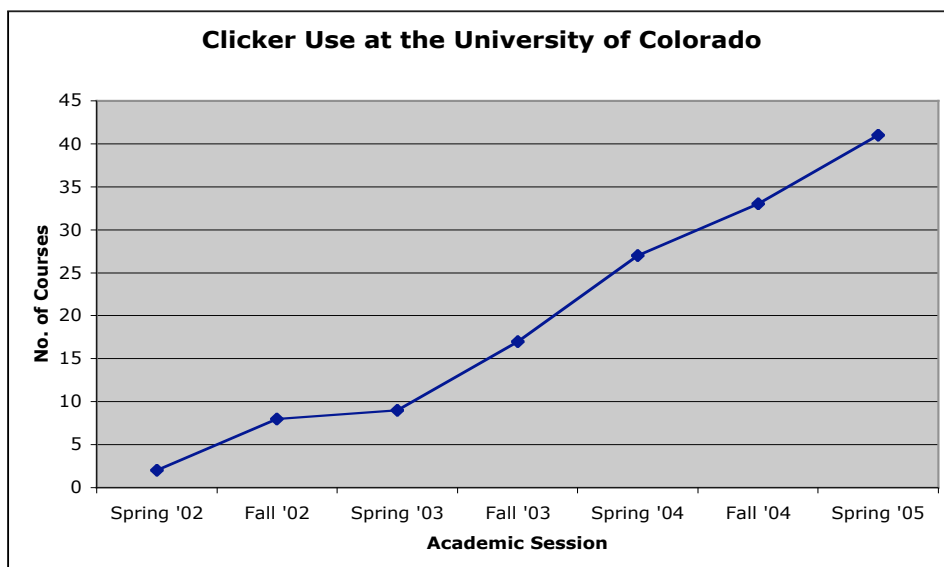


Figure 1. Growth in the use of clickers at the University of Colorado since its installation.

Michael Dubson and the Physics Department have lead the efforts in communicating the effectiveness of this new technology across departments. The large increase in other departmental involvement can be accredited to Michael Dubson’s efforts over his sabbatical in Fall 2003 in which he gave talks across the campus to a variety of departments. The growth in various departmental use of the personal response system is shown in Figure 2. The involvement of differ-

ent departments was crucial to the success of this technology in order to justify to students the need to purchase a clicker and to contribute to the installation and maintenance costs of the technology.

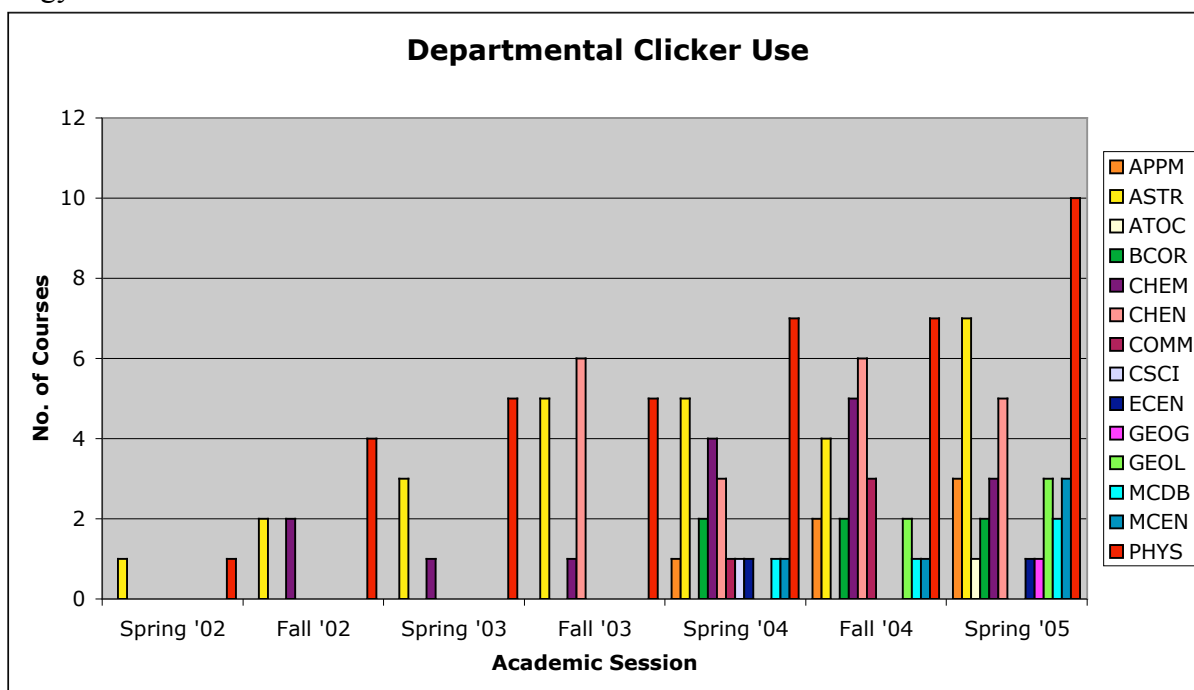


Figure 2. Departmental use of clickers at the University of Colorado.

In Fall 2004, ten physics faculty integrated concept tests and clicker response into their lectures as a step towards creating a more interactive and engaging classroom environment. Similarly, there were eleven physics faculty who used clickers in their classrooms in Spring 2005. Over the 2004-2005 academic year, 15 different professors were involved in implementing this classroom transformation. Table 1 shows the courses in which clickers have been utilized over the 2004-2005 academic year. The increase in faculty use of clicker technology can be partially accounted for by the creation and access to Concept Test question banks. Through the support of FTEP (Faculty Teaching Excellence Program) and the NSF-DTS (Distinguished Teaching Scholar), Carl Wieman, Paul Beale, Steve Pollock, Michael Dubson, and Noah Finkelstein have been actively involved in the creation of these Concept Test Banks. This has helped to reduce the time and effort needed from professors to implement this classroom transformation. This has resulted in faculty previously not involved in educational reforms to use this classroom transformation even in upper division courses such as Thermodynamics and Statistical Mechanics. Clicker questions for Thermodynamics and Statistical Mechanics were developed by Michael Dubson the previous year and were then made available to professors the following semesters. In the future, the hope is for PhysTEC PI's to gradually teach more upper division courses and develop more Concept Test question banks for broader faculty use.

Table 1. Summary of Physics Courses with Clicker Use for the 2004-2005 Academic Year	
Fall 2004	Phys 1010: Physics of Everyday Life 1 Phys 1110: General Physics 1 - Calculus-based Phys 1120: General Physics 2 - Calculus-based Phys 1140/1150: Experimental Physics 1&2 Phys 1230: Light and Color for Nonscientists Phys 2010: General Physics 1 - Algebra-based Phys 2020: General Physics 2 - Algebra-based
Spring 2005	Phys 1020: Physics of Everyday Life 2 Phys 1110: General Physics 1 - Calculus-based Phys 1120: General Physics 2 - Calculus-based Phys 1140/1150: Experimental Physics 1&2 Phys 1230: Light and Color for Nonscientists Phys 2010: General Physics 1 - Algebra-based Phys 2020: General Physics 2 - Algebra-based Phys 2130: General Physics 3 – Modern Physics for non-physics majors Phys 3070: Energy and the Environment Phys 4230: Thermodynamics and Statistical Mechanics

Michele H. Jackson and April R. Trees, “Clicker Implementation and Assessment.” Department of Communication, University of Colorado at Boulder, Submitted to Information and Technology Services and Faculty Teaching Excellence Program. December 19, 2003.

From pages 25-28:

An increasing number of instructors in several departments are experimenting with the HIT student response system informally known as “clickers.” At this point, little systematic information exists regarding the socio-technical infrastructure needed to support clicker use across campus, or the effect of clickers on the learning environment. This report represents a first attempt to provide that information. If sufficient interest and funding are available, we are interested in expanding beyond this exploratory study, by conducting a follow up study and analysis in Spring-Summer 2004.

Our main finding is that while clicker technology is simple, its effects on the classroom are complex and can be challenging to manage. The effectiveness of a “clicker classroom” depends on a combination of technical, social, and pedagogical factors. This study is a first attempt to unpack the nature of this combination.

A central implication of this study is the importance for providing support and resources to instructors to learn how to use clickers in ways that can accomplish their learning goals. One approach is Concept Tests, but additional approaches need to be developed for instructors who either do not wish to use Concept Tests, or whose material is not well suited to that approach.

Our observations are based on two sources of data. First, we draw on the experiences of two instructors who piloted clickers Fall 2003, April Trees and John Jackson. Communication is the first department outside of the sciences to implement clickers. Our experiences are instructive to other non-science departments interested in adopting clickers, such as the social sciences, business, and humanities.

Faculty Survey Results:

	Paul Beale	Josh Colwell	Doug Duncan	John Jackson	Steve Pollock	Nick Schneider	April Trees
Course	PHYS 2010	ASTR 1110	ASTR 1120	COMM 1300	PHYS 1110	ASTR 1110	COMM 1210
Required Course?	No	Yes	No	Yes	Yes	No	Yes
Team taught?	No	No	No	No	No	No	No
Faculty rank of Instructor	Professor	Instructor/ Research Associate	Sr. Instructor	Instructor	Assoc. Prof	Assoc. Prof	Assist. Prof
Support person regularly available to help with clicker system?	Yes	Yes	Yes	No	Yes	Yes	No
Length of Class Period	50 mins	75 mins	50 mins	50 mins	50 mins	50 mins	50 mins
Number of lecture class period per week (i.e., non lab or non recitation)	3	2	2	1	3	3	2
% of class period used clickers	100%	100%	80%	70%	100%	100%	70%
Typical number of clicker questions asked in a single class period	7-9	4-6	1-3	1-3	4-6	1-3	1-3
How often experienced technical problems with clickers	20%	10%	20%	40%	10%	20%	80%

Faculty Interview Results:

1. Could you please describe briefly your typical use, perhaps by describing a typical clicker question, or how they were incorporated into class sessions?

Beale: Totally concept test-based. Students were expected to have read the material in advance. Almost all questions were designed for students to talk to each other in small groups (the peer instruction method).

Colwell: Typically 4 clicker questions scattered throughout the lecture, sometimes 2 in a row. Conceptual questions on material just covered in class. If the number of wrong answers is high we discuss it and repeat the question. Sometimes use clicker for non-instructional polling: how many students will go to review session, for example.

Duncan: The best, by far, are ones that provoke discussion. I ask a question, let student discuss in groups of three.

Jackson: I usually asked 3-4 questions, often on concepts we had just discussed or on video examples we had watched. I also used them to give them idea of how I would ask questions on the midterm/final.

Pollock: Clicker questions all available online, www.colorado.edu/physics/phys1110 [see the lecture notes and much more link, then concept tests. Conceptual physics questions (mixed in with lecture & demos). Modeled on Eric Mazur's Concept Tests, we use peer-instruction/discussion with them.

Schneider: Class always started with a reading comprehension question to reward preparing for class, attendance, and on-time arrival. Subsequent questions (2-3 more) were concept-based, with discussion encouraged and prof/instructor roaming & interacting

Trees: I used clickers in two different ways: 1) I would give students questions to test their understanding of concepts and then explain the correct answer. I used this for the exam review and then at various places throughout the semester as well as we were discussing the material. 2) I would use clicker questions to illustrate a particular concept or idea in class—there was not really a correct answer for these clicker questions. For example: I used them to demonstrate stereotypes about how men and women talk, to assess dialectical tensions in people's relationship problems, to see the ways in which interaction is typically patterned in account sequences. I also used them at the very beginning of the semester to allow students to choose a speech to watch in class.

2. Did you notice any particular differences in classroom dynamics compared to when you don't use clickers? If so, what were they?

Beale: Attendance as about 90% compared to 50-70% in the same course a few years ago taught using the standard lecture format.

Colwell: Better attendance, less sleeping in class, more background noise because they get in the habit of talking in class during clicker questions

Duncan: Greater attendance. Greater involvement when the questions were good.

Jackson: It was a much noisier classroom. It seemed to increase the amount of chatter. I don't know if they were talking about course material or just talking. Oftentimes students did seem really interested in seeing how the questions were answered by their classmates. They would react when they saw the graph.

Pollock: I switched from colored card voting to clickers and saw a slight increase in participation and discussion levels, slight increase in attendance (I've never given a "traditional" lecture in this large class) compared to observation of conventional lecture, it's a world of difference ñ more engagement, better feedback in both direction, makes large class feel much smaller

Schneider: I love what clickers have done for my classroom. The main benefits are (1) increased attendance; (2) active participation; (3) better preparation for class.

Trees: The clickers clearly impacted the classroom experience. I have used interaction activities in class before, so it is not just having students talking to each other once in a while. Some students were much more disruptive and talked throughout class ñ even when we weren't doing clicker questions or other interactive activities. I visited recitations to discuss this with my students and their take was that a) students who otherwise wouldn't come were coming and didn't want to be there so they were talking (some of the comments lead me to the conclusion that having seniors in an intro level class was contributing to this) and this was frustrating for students who did not have that attitude and also reflected a negative attitude on the part of students behaving that way, b) some students felt that I was patronizing ñ because of my response to this behavior, c) some students thought that I was teaching a large class like a small one and you can't do that and maintain control over what is going on in the class—the use of clicker questions encouraged students to talk all the time because they were asked to talk some times.

3. **What method do you use to motivate students to use the clickers? In other words, do you incorporate clicker use into a students grade and, if so, how and how much are they worth relative to the total course grade? (extra credit? Replacement for other points? Participation grade? Etc.) AND how satisfied are you with this method?**

Beale: 15% of the class grade was based on clicker responses. 2 pts for any answer, 3 for the correct answer. Questions designed to illuminate misconceptions were all scored correct.

Colwell: 10% of their grade. They get partial credit for incorrect answers. They get free drop days to allow for unavoidable absences. Next time I might make it 15% of the grade and reduce the homework grade.

Duncan: 10% of the grade. And they act like it's even more important than that!

Jackson: Because I wasn't sure about how this would work, I am only using them for extra-credit points and only for a tiny portion of the overall grade—maybe 2%. This owes in part to the small part that lecture plays in the class—most of the grades from the class are from activities in recitation.

Pollock: Extra credit: total clicker score can take away up to 10% of the weight of exams in the class (which are in, in turn, 60% of the grade). (See syllabus on web page for more details). Very satisfied, motivates, but low pressure

Schneider: Clickers account for 10% of their grade, with their lowest 20% of clicker days dropped. Students earn 50% clicker credit even if they give all wrong answers. Based on several semesters, I've learned that with no clickers, attendance drops to ~50% towards the end of semester, with 5% credit attendance dips no lower than ~75%, and with 10% credit attendance is 80-85%.

Trees: Participation points—2 per day regardless of the accuracy of the answer ñ there were more days than clicker points, but I don't think students understood this since it wasn't explicitly discussed the first day of class and laid out in the syllabus.

From the *Proceedings of the Physics Education Research Conference, Greensboro, North Carolina, 2007*:

Research-based Practices For Effective Clicker Use

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Abstract. Adoption of clickers by faculty has spread campus-wide at the University of Colorado at Boulder from one introductory physics course in 2001 to 19 departments, 80 courses, and over 10,000 students. We study common pedagogical practices among faculty and attitudes and beliefs among student clicker-users across campus. We report data from online surveys given to both faculty and students in the Spring 2007 semester. Additionally, we report on correlations between student perceptions of clicker use and the ways in which this educational tool is used by faculty. These data suggest practices for effective clicker use that can serve as a guide for faculty who integrate this educational tool into their courses.

Keywords: Clickers, Personal Response Systems, Classroom Response Systems
PACS: 01.40.gb, 01.50.-i, 01.50.H-, 01.40.Fk

INTRODUCTION

Since being introduced six years ago in one introductory physics course at the University of Colorado at Boulder, clicker¹ use has spread extensively, with nearly half the undergraduate population using clickers in one semester. Although their use is becoming more prevalent, it is not known how this tool is used by faculty at the campus level, nor do we understand student perceptions and attitudes towards this tool.

Research on clickers remains a popular topic within PER and other science and education communities. (For example, see [1, 2, 3]; for an extensive literature review, see [4].) The purposes of the present study are to identify common faculty pedagogical practices regarding clicker use across the variety of disciplines at one institution, study student perceptions towards this tool, and look for correlations between faculty practices and student perceptions. We seek to identify effective clicker uses across these varieties of disciplines and environments in which they are employed. An ultimate goal will be to correlate faculty practices with student learning—others have already demonstrated

correlations between student attitudes and beliefs and content learning gains in other contexts (e.g., see [5] and [6]). However, studying student learning gains is beyond the scope of the present work. In this piece, we present limited results from an extensive study of dozens of faculty and thousands of students.

When correlating faculty practices with student attitudes, we find that the students' perception of the utility of clickers improves as faculty encourage peer-discussion and succeed in getting students to discuss with each other in lecture. Additionally, students find conceptual questions slightly more useful than factual recall or calculation-oriented questions.

INSTITUTIONAL USE OF CLICKERS

During the Spring 2007 semester at the University of Colorado at Boulder, clickers were used by 70 faculty in 94 lecture sections, with an average enrollment of 144 students in each lecture section. Although this breadth of use represents a tiny fraction of all faculty on campus (3%), it represents a significant fraction of the student body due to the high average enrollment of

¹ We opt for the term "clicker," whereas others use "personal response system," "voting machine," and a myriad of other terms (see Reference [4]).

courses using clickers. In this semester, clickers were used by 10,011 unique students, which include 9,941 undergraduates and 70 graduate students. Students using clickers made up 44% of all undergraduate students and 1.6% of graduate students. Despite the widespread use among the undergraduate student body, there is still opportunity for clicker use to expand. Only 28% of departments on campus are using clickers and only 24% of large lecture sections (where the enrollment is greater than 100) are using clickers. We see some departments that currently use clickers in all large lecture courses that they offer, such as Physics, Astrophysics, and Chemical Engineering. Other large departments, such as Psychology and Sociology, use clickers in 1 and 2 large courses (out of 16 and 7, respectively).

We find the majority of courses using clickers to be in STEM fields. The total number of courses that used clickers in STEM fields was 63, while there was 10 in Business, 6 in Social Sciences, and 1 in Humanities.

Of the 94 lecture sections² using clickers, 79 of these are using i>clicker³ and the remaining 15 are using H-ITT⁴. Of all unique students who used clickers, 70% used clickers in one course only, while 29% used clickers in 2 courses, and fewer than 1% used clickers in either 3 or 4 courses.

FACULTY PRACTICES

Faculty using clickers were given two different online surveys. The first survey was given at the start of term approximately 3 weeks after the beginning of classes, and 54 faculty responded to 16 multiple-choice and long answer questions. The second online survey was given at the end of term, and 69 responses were collected to 15 multiple-choice and long answer questions. To access both surveys, see [4]. Questions from both surveys probed how faculty used clickers in their own courses and on their experience and beliefs surrounding clickers. The results presented in this section were collected from both faculty surveys. Observational data of classroom practices demonstrate some similar trends as seen in faculty self-reported data presented here for a subset of physics courses using clickers. [7]

The majority of faculty using clickers has little or no experience using this tool—59% of the respondents are using clickers for the first time or have only one prior semester of clicker experience.

Some slight variation does exist in how frequently faculty use clickers, in terms of the average number of questions given per day and the overall percentage of class days when clickers are used throughout the semester (see Table 1 & 2). However, the majority of faculty asks 3 to 4 questions per day and use clickers 90 – 100% of class meetings over the semester.

TABLE 1. Average number of questions given per class meeting, reported by faculty

Number of Clicker Questions	% of Courses [standard error] [†] N=69
1 to 2	19 [5]
3 to 4	65 [6]
5 to 6	13 [4]
7 or more	3 [2]

[†]Bracketed numbers in tables are estimated standard error of the mean.

TABLE 2. Percent of all classes days when clickers are used, reported by faculty

% of class days	% of Courses, N=69
< 50%	7 [3]
50 - 75%	4 [3]
75 - 90%	20 [5]
90 - 100%	68 [6]

In addition to reports of frequency of use, we examine how clickers are used. Figure 1 reports the frequency of use of several broad categories of clicker questions.

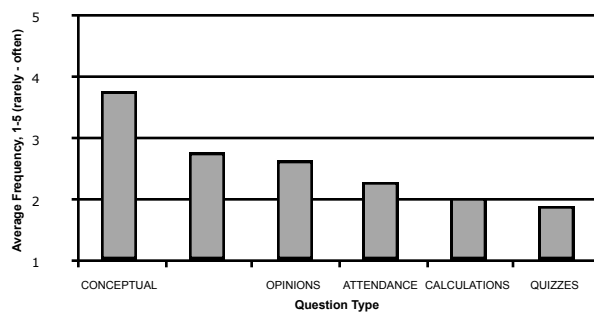


FIGURE 1. Types of clicker questions used, reported by faculty.

We see some variation in the extent to which faculty encourage discussion among their students, and the extent to which students do discuss with their peers in lecture (according to faculty). The majority of fac-

² Note that many courses have multiple lecture sections; hence the difference between 80 courses and 94 lecture sections.

³ <http://www.iclicker.com>

⁴ <http://www.h-itt.com>

ulty claim to encourage discussion and claim to succeed at getting a large fraction of students to discuss in lecture (see Table 3).

TABLE 3. Extent of peer-discussion, reported by faculty

Type of Discussion	% of Faculty
Do not allow discussion	3 [2]
Do not encourage discussion, & <i>small</i> fraction of students discuss	6 [3]
Do not encourage discussion, & <i>large</i> fraction of students discuss	6 [3]
Encourage discussion, & <i>small</i> fraction of students discuss	22 [5]
Encourage discussion, & <i>large</i> fraction of students discuss	63 [6]

STUDENT PERCEPTIONS & PRACTICES

Approximately one month prior to the end of term, an online survey was distributed to students in courses where clickers were currently being used. To access the student survey, see [4]. Of the 10,011 students using clickers, 3,697 responses were collected. The 11 multiple-choice questions on the survey probed students' attitudes and beliefs about clickers and asked them to respond to how clickers are currently being used in their courses. Of the 80 courses using clickers, data from students were collected in 51 courses. The data presented in this section are a summary of results from the student survey.

Overall, we find students' experience with clickers to be positive. 56.4% of students responding had a favorable attitude towards the *utility* of clickers in their respective courses (compared to 22.9% that were neutral and 20.7% that had unfavorable attitudes) and 55.3% of students had a favorable attitude towards the *enjoyment* of clickers (compared to 24.5% that were neutral and 20.2% that had unfavorable attitudes). These favorable results for clickers are noted elsewhere (for example, see [8]).

TABLE 4. Student discussion practices during clicker questions, reported by students

Student Practice	% of Students, N=3,697
Usually not allowed to talk with other students	2 [0.03]
Rarely use a clicker in this course	1 [0.01]
Guess the answer and do not check with other students	2 [0.03]
Actively think about the question independently and arrive at an answer without speaking or listening to other students	19 [0.3]
Listen to other students' answers and/or reasoning	18 [0.2]
Actively participate in discussions with other students around me	59 [0.4]

When asked what they normally do during the delivery of a clicker question, most students claim to be actively participating in discussions with their peers (see Table 4).

The utility of different types of clicker questions was rated. Students found conceptual questions the most useful (3.92 ± 0.02 , on a scale of 1–5, negative to positive), followed by factual recall (3.51 ± 0.02), and numerical calculations (3.32 ± 0.02).

CORRELATIONS BETWEEN FACULTY PRACTICES & STUDENT ATTITUDES

The final goal of the present work is to study what impact faculty practices regarding clickers have on student attitudes. We begin to determine these relations by correlating faculty use of this tool with student perception of clickers.

It is commonly argued that encouraging discussion among students is of greater benefit than passively using clickers in lecture [2]. We find there to be a strong relationship between the extent of peer-discussion in lecture and students' attitude towards the utility of clickers. Of course, students do not uniformly agree within a single course when asked to what extent their instructor encourages discussion. Taking the mode of student responses to be an accurate representation of how instructors encourage student discussion, the average fraction of students with a favorable attitude towards the utility of clickers is 66% in courses where instructors encourage discussion and get a large fraction of students to do so (see Table 5).

TABLE 5. Average percent of students who have favorable attitudes towards clicker use, listed by classes where plurality of students reported use of clickers in stated fashion.

Type of Discussion	% Favorable
Does not allow discussion	38 [5]
Does not encourage discussion, & <i>small</i> fraction of students discuss	37 [8]
Does not encourage discussion, & <i>large</i> fraction of students discuss	36 [22]
Encourages discussion, & <i>small</i> fraction of students discuss	55 [8]
Encourages discussion, & <i>large</i> fraction of students discuss	66 [3]

Similarly, we examine how the role of students during a question correlates with their perceived utility of the clickers. We see a trend toward students finding clickers more useful as they become more active in lecture, with 64% of the students who claim to be actively participating in discussion having a favorable attitude towards the utility of clickers (see Table 6).

We also see a strong correlation between the instructor's experience with clickers (i.e., the number of

prior semesters where an instructor has taught with clickers) and student perception of utility ($r=0.52$), suggesting that faculty become better over time at effectively using this tool and that novice faculty may need more assistance.

In addition to students finding conceptual questions more useful than other types of questions, the fraction of students in a course who claim to be actively participating is correlated with the average student rating of utility of conceptual clicker questions within a course ($r=0.43$), suggesting that conceptual questions are most useful when students discuss the questions with their peers.

TABLE 6. Percent of students from each student role who have favorable attitudes toward the utility of clickers.

Student Role	% Favorable
Does not apply--usually not allowed to talk with other students	28 [5]
Rarely use a clicker in this course	16 [6]
Guess the answer and do not check with other students	17 [4]
Actively think about the question independently and arrive at an answer without speaking or listening to other students	51 [2]
Listen to other students' answers and/or reasoning	45 [2]
Actively participate in discussions with other students around me	64 [1]

CONCLUSION

This study presents self-reported faculty pedagogical practices and student perceptions of clicker use at a large research university across many disciplines. In addition to shedding new light on how this tool is being used by faculty and its corresponding perception by students, we wish to use these data to study how faculty practices impact student behaviors and views.

Student attitude is strongly impacted by the extent to which faculty encourage and succeed in generating peer-discussion during the administration of clicker questions. Students have a much more positive attitude towards the utility of clickers if faculty encourage discussion and are able to get a large fraction of students discussing. Likewise, student attitude is also improved when students are actively participating in discussions with their peers, as opposed to being passive or working independently.

We wish to move beyond providing discipline-specific and/or anecdotal suggestions with regard to the use of clickers. Rather, we seek to provide research-based evidence of their effective use. At this point, we can make two suggestions to faculty that are supported

by this work: 1) encourage students to discuss with their peers during clicker questions and create environments that get students to discuss; and 2) ask conceptual questions appropriate for most students' level of knowledge.

Other research-based suggestions exist, but this is a topic for future work. For example, how do faculty practices differ between the highest and lowest rated courses, as measured by student perception of the utility of clickers? How useful to students are clickers compared to other course resources? How do varying methods of awarding credit for clicker use affect students' attitudes? Future work will seek to answer these questions to provide guidelines on the effective use of clickers to the expanding population of novice clicker-using instructors.

ACKNOWLEDGMENTS

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REFERENCES

1. Banks, David A. (ed.) *Audience response systems in higher education: applications and cases*. Information Science Publishing, 2006.
2. E. Mazur, *Peer Instruction*. Prentice Hall, New Jersey, 1997.
3. Caldwell, J. CBE—Life Sciences Education, Vol. 6, Spring 2007.
4. <http://www.colorado.edu/physics/EducationIssues/keller/clicker.html>
5. N.D. Finkelstein and S.J. Pollock, Phys. Rev. ST Phys. Educ. Res. 1, 010101 (2005).
6. K.K. Perkins, W.K. Adams, N.D. Finkelstein, S.J. Pollock, and C.E. Wieman. "Correlating student attitudes with student learning using the Colorado Learning Attitudes about Science Survey." PERC Proceedings, 2004.
7. Turpen, C., Finkelstein, N., and Keller, C., "Understanding Faculty Use of Peer Instruction," PERC Proceedings 2007 (this volume).
8. d'Inverno, R., Davis, H., and White, S., "Using a personal response system for promoting student interaction." Teach. Math. Appl. 22(4), 163-169.

References

Below are published works on the educational use of clickers, categorized by discipline.

General

Banks, David A. (ed.) “Audience response systems in higher education : applications and cases.” *Information Science Publishing*. Hershey, PA, 2006.

Taking advantage of user-friendly technology, audience response systems (ARS) facilitates greater interaction with participants engaged in a variety of group activities. Each participant has an input device that permits them to express a view in complete anonymity, and the composite view of the total group appears on a public screen. ARS can then be used to support summative and formative activities with groups ranging in size from as small as five through to large groups of several hundred. The data can be used to help the facilitator adjust the pace of teaching to match the requirements of the learners, gauge understanding, or trigger discussion and debate.

Audience Response Systems in Higher Education: Applications and Cases reveals some of the history behind these systems, explores current theory and practice, and indicates where technology may move in the future. Cases are used to present the work of educators in a wide range of subject areas and with differing levels of experience with these systems.

Beatty, I. D. “Transforming Student Learning with Classroom Communication Systems.” *EDUCAUSE Center for Applied Research*, November 6–9, 2002.

Classroom communication systems (CCSs) are technology products—combinations of hardware and software—designed to support communication and interactivity in classes. Through use of these products, large “lecture” classes can function more like small discussions. In an economic context where brick-and-mortar universities face increasing competition from distance education and self-paced learning programs, they must capitalize on the fact that they bring students and faculty together face-to-face. CCSs can help them do that.

This research bulletin will describe the nature and use of CCSs and will identify significant benefits they offer to higher education as well as challenges their use presents to instructors, administrators, support staff, and students. It will also share some advice drawn from the lessons learned through a decade of experience.

Broida, J. "Classroom Use of a Classroom Response System: What Clickers Can Do for Your Students." Addison Wesley / Benjamin Cummings, 2007.

(Abstract not available.)

Burnstein, R., Lederman, L. "The use and evolution of an audience response system." Audience Response Systems in Higher Education: Applications and Cases, David Banks, ed., *Information Science Publishing*, 2006.

This chapter reports the authors' use and refinement of a wireless audience response system (ARS) over a 10-year period. The motivation for this effort was to replace the traditional passive lecture with a more interactive classroom. Our classroom procedures and the evolution of these procedures are detailed. The authors also illustrate how ARS systems can be applied in a variety of ways, including the use of modified multiple-choice questions. ARS systems allow for both formative and summative assessment in real time, which is a unique and desirable property. The use of ARS systems similar to the ones described has increased rapidly in the past few years. A brief survey of current and proposed commercial wireless keypad systems is included.

Chu, Y. "Study and evaluation of the student response system in undergraduate instruction at Skidmore College." *Report prepared for the National Science Foundation*, Arlington, VA, 1972.

The Student Response System (SRS) is discussed and evaluated. This is an electronic system whereby an instructor receives instant feedback from students by asking questions each with up to five multiple choice answers. The report covers a description of the SRS, a review of the Skidmore College project on computer applications, and a review of the grant from the National Science Foundation, physical setup for the project, common uses of the SRS, uses of the SRS at Skidmore, combined uses of the SRS in class, uses of computer analysis, individualized uses of the response system, extent of usage, evaluation of the response system, a small statistical evaluation, and a summary of evaluation.

Cue, N. "A universal learning tool for the classroom?" *Proceedings of the First Quality in Teaching and Learning Conference*, 1998.

Questions and answers are used commonly in instructions to provide immediate feedback and reinforcement that are key elements of active learning. However, in a normal class, not all students can be asked to respond because of time limitations. Moreover, many would rather not be called upon so as to avoid the risk of being embarrassed by an incorrect or improper answer. If the class is large, some may not even pay attention. The situation could be improved significantly

with the use of an electronic student response system (SRS) which empowers all students to respond to a question in private, records all responses, and displays the statistical results immediately for feedback and reinforcement. At HKUST, a wireless SRS called the Personal Response System (PRS) has been developed and the prototypes tested in several classes in fall 1997. The wireless, pocket-sized, low-cost and ID-encoded features of the PRS transmitter handset make it feasible for students to own their unit and bring it along to use in any classroom. The receiver is equally portable and the Windows-based software is easy to use. This combination of features endows the PRS with the potential of being a universal learning tool for classrooms. In other words, the PRS can facilitate the practice of interactive engagement for active learning in the classroom and, thereby, make the practice accessible to all wanting to adopt the approach. Also, the ease of use would free the instructor to concentrate on pedagogy and content, and not be distracted by the tool. Described here are the details of PRS, the results of the field tests, and the implementation plan for a campus-wide system at HKUST.

Cutts, Q., et al. "Maximising dialogue in lectures using group response systems." *The 7th IA-STEM International Conference on Computers and Advanced Technology in Education, Hawaii, 2004.*

Laurillard sees dialogue as a crucial component of learning and she states that it is almost impossible to achieve in lectures. This paper identifies eight impediments to dialogue in lectures, and shows how they are or can be overcome by (a) adjusting the activities that take place within lectures, (b) using existing Group Response Systems (GRSs), and (c) using extensions to GRSs proposed in this paper. In addition to facilitating dialogue within lectures, this paper shows how a record of the lecture-based dialogue could be used to improve learning environments outside the lecture.

Cutts, Q., Carbone, A. van Haaster, K. "Using an Electronic Voting System to Promote Active Reflection on Coursework Feedback." *Proceedings of the International Conference on Computers in Education, Melbourne, Australia, November 30–December 3 2004.*

Many lecturers use coursework as the primary mechanism for providing students with feedback on their learning. However, against the models of Laurillard and Kolb which view learning as a cyclical process, they provide little or no scaffolding to support effective assimilation of the feedback by the students. This paper proposes a pedagogical script for using an electronic voting system (EVS) to promote the necessary assimilation, based on the generation of discussion found in Mazur's Peer Instruction method. The script's use in three case studies is described. Staff and students found the sessions beneficial over traditional remediation mechanisms. Over three-quarters of the final session was spent in students working on and discussing the misunderstandings apparent in their coursework.

Davis, S. M. "Observations in classrooms using a network of handheld devices." *Journal of Computer Assisted Learning*, 19, p. 298–307, 2003.

This paper illustrates the educational implications of the design features of public anonymity and private accountability in a classroom network of handheld devices. The author draws from four years of observations of classes using two early network prototypes. Themes discussed are anonymity of data submission to the group, the ability for students to see their data displayed in the group space, the ability for the teacher to instantly assess how all students are doing at any time during a lesson, and that the ability of the network to let all students answer all questions may have an impact upon student engagement in the classroom. The paper goes on to highlight research done in the field of communications using synchronous electronic submission systems and relates this to the use of similar networks in the classroom.

Draper, S. W. "Evaluating effective use of PRS: results of the evaluation of the use of PRS in Glasgow University," October 2001-June 2002.

The Personal Response System (PRS) has been used in 12 different classes in Glasgow University and also in several workshops and Open Days. The classes varied in subject, level and size: Computing Science, Medicine, Psychology; Levels 1-4 and GP's; approximately 15 to 300 students. The use of the system was evaluated using observations, informal interviews, and questions asked via the system and written student comments. From the evaluation it is possible to give some information which should ensure the effective use of PRS in the future. This paper also includes some examples of the types of questions used.

Draper, S. W., and Brown, M. I. "Use of the PRS (Personal Response System) handsets at Glasgow University," *Interim Evaluation Report*: March 2002.

In the current academic year (Oct 2001- March 2002), interactive handsets have been trialled at the University of Glasgow by lecturers in Philosophy Psychology, Computing Science, IBLS, Medicine, Vet School and the Dental School (with GPs), with audience sizes from 20 to 300, and with students in level 1 to level 4. Handsets have been used in lectures and formative assessment sessions. They have been well received by students in all but one case, as judged by responses to our key evaluation question about whether, in each student's view, there was a net gain in benefits over disadvantages. The lecturers who used them have also been asked about their views, and again in all but one (different) case, felt the benefits outweighed the difficulties. Our evaluations, conducted by Margaret Brown, have also amassed a list of benefits and of disadvantages mainly from the student view, which we will be writing up soon.

Draper, S., Cargill, J., and Cutts, Q. "Electronically enhanced classroom interaction." *Aust. J. Educ. Technol.* 18(1), 13–23, 2002.

A design rationale for introducing electronic equipment for student interaction in lecture theatres is presented, linking the instructional design to theory. The effectiveness of the equipment for learning depends mostly on what pedagogic method is employed: various alternative types are introduced. Prospective studies are outlined for exploring its use over new ranges of application. Rival views of the concept of interactivity are one way to organise the evaluation of this learning technology.

Draper, S. W., Brown, M. "Increasing interactivity in lectures using an electronic voting system." *Journal of Computer Assisted Learning*, 20(2), 2004.

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.

Duncan, Douglas, "Clickers in the Classroom." *Pearson/Addison Wesley*, 2005.

Clickers (Classroom Response Systems) have quickly become one of the most popular and widely adopted new classroom teaching technologies in recent history. Whether you're a clicker novice or veteran, this is the book for learning how clickers can enhance your classroom lectures.

In this handbook, experienced clicker educator Doug Duncan provides everything you need to know to successfully teach using clicker technology: What are the benefits of using clickers? What is the clicker experience like at other schools? What research has been published on clicker usage? How will clickers change the dynamic of your classroom? What types of clicker questions work best in lectures? How should I prepare my students before introducing clickers?

Fagen, A., Crouch, C., Mazur, E. "Peer instruction: results from a range of classrooms." *The Physics Teacher*, 40, April 2002.

Peer Instruction (PI) is a widely used pedagogy in which lectures are interspersed with short conceptual questions (ConcepTests) designed to reveal common misunderstandings and to actively engage students in lecture courses. [1–3] Correspondence and informal discussions indicate a user base of hundreds of instructors around the world who teach with PI, yet to date there has been no systematic study of PI implementation and effectiveness in the variety of settings in which it is used. As a first step toward such a systematic study, we polled current and former PI users via a web-based survey to learn about their implementation of and experience with PI. [4] The survey collected data about how instructors learned about PI, courses in which PI was used, implementation details, course assessment, effectiveness, instructor evaluation, and the community of PI users.

Fies, C., Marshall, J. "Classroom Response Systems: A Review of the Literature," *Journal of Science Education and Technology*, 15(1), 2006.

As the frequency with which Classroom Response Systems (CRSs) are used is increasing, it becomes more and more important to define the affordances and limitations of these tools. Currently existing literature is largely either anecdotal or focuses on comparing CRS and non-CRS environments that are unequal in other aspects as well. In addition, the literature primarily describes situations in which the CRS is used to provide an individual as opposed to a group response. This article points to the need for a concerted research effort, one that rigorously explores conditions of use across diverse settings and pedagogies.

Freeman, M., Bell, A., Comerton-Forder, C., Pickering J., & Blayney, P. "Factors affecting educational innovation with in class electronic response systems." *Australasian Journal of Educational Technology*, 23(2), 149-170, 2007.

This paper reports the use of Rogers' diffusion of innovation perspective to understand the factors affecting educational innovation decisions, specifically in regard to in class electronic response systems. Despite decreasing costs and four decades of research showing strong student support, academic adoption is limited. Using data collected from academic users, non-adopters and other stakeholders reflecting on factors known to affect innovation diffusion, we find issues of cultural compatibility, complexity and relative advantage to be the most critical aspects affecting adoption decisions. These issues partially negate the benefits of increased in class interaction and student engagement. Suggestions for overcoming these issues are discussed.

Froehlich, H.P. "What about classroom communicators?" *Audio Visual Communication Review*, 11, p. 19-26, 1963.

(Abstract not available.)

Johnson, D., McLeod, S. "Get answers: using student response systems to see students' thinking." *Learn. Lead. Technol.* 32(4), 18-23, 2004.

Imagine if teachers could view their students' thinking, like peeking inside a pot of cooking stew to see if it is done. Wouldn't it be nice if they could know what their students were learning, while they were teaching them? Most teachers use a variety of classroom techniques to understand what their students know and can do. Tests, quizzes, papers, and projects are time-honored ways to assess student learning, but they often are time consuming to administer and grade, and there are inherent delays between submission, assessment, and feedback.

Judson, E., Sawada, D. "Learning from past and present: electronic response systems in college lecture halls." *Journal of Computers in Mathematics and Science Teaching*, 21(2), 2002.

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 an electronic response system.

Judson, E., Sawada, D. "Audience response systems: insipid contrivances or inspiring tools?" *Audience Response Systems in Higher Education: Applications and Cases*, David Banks, ed., *Information Science Publishing*, 2006.

Surprising to many is the knowledge that audience response systems have been in use since the 1960s. Reviewing the history of their use from the early hardwired systems to today's computer-

integrated systems provides the necessary scope to reflect on how they can best be used. Research shows that the systems have had consistent effects on motivation, and varying effects on student achievement over the years. The intent of this chapter is to consider lessons learned, consider the relation of technology and pedagogy, and to highlight elements of effective use. This chapter emphasizes the crucial role of pedagogy in determining whether audience response systems can lead to greater student achievement.

Kaletka, R., & Joosten, T. "Student response systems: A University of Wisconsin study of clickers." *EDUCAUSE Center for Applied Research, Research Bulletin*, Volume 2007, Issue 10, May 8, 2007.

(Abstract not available.)

Kalinowski, K., Jones, G. "Student Response Systems in Education: Past, Present and Future," *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications*, p. 2454-2459, 2005.

Student response systems—also referred to as audience response systems, personal response systems, interactive learning systems and classroom communication systems—have been used in higher education for decades. Their design blossomed out of a need to turn large lecture hall experiences into something beyond a one-way, passive "download" of information. Although the use of student response systems has had mixed support and results over the years, recent development of a new generation of systems based on active learning theories has erupted. Student response systems have quickly migrated into an array of classroom types and a variety of disciplines, often without research to support their new role.

Keller, C., Finkelstein, N., Perkins, K., Pollock, S., Turpen, C., Dubson, M. "Research-based Practices for Effective Clicker Use." *Proceedings for the Physics Education Research Conference, Greensboro, North Carolina, 2007.*

Adoption of clickers by faculty has spread campus-wide at the University of Colorado at Boulder from one introductory physics course in 2001 to 19 departments, 80 courses, and over 10,000 students. We study common pedagogical practices among faculty and attitudes and beliefs among student clicker-users across campus. We report data from online surveys given to both faculty and students in the Spring 2007 semester. Additionally, we report on correlations between student perceptions of clicker use and the ways in which this educational tool is used by faculty. These data suggest practices for effective clicker use that can serve as a guide for faculty who integrate this educational tool into their courses.

Littauer, R. "Instructional implications of a low-cost electronic student response system." *Educational Technology: Teacher and Technology Supplement*, 12(10), p. 69-71, 1972.

(Abstract not available.)

Liu, Tzu-Chien, et al. "The features and potential of interactive response systems." *The 2003 International Conference on Computers in Education*, Hong Kong, 2003.

Integrating Interactive Response System (IRS) with a classroom computer is an inexpensive and promising means to overcoming or alleviating obstacles of in-class teacher-student and peer interactions. Unfortunately, such potential applications are often neglected. Accordingly, this study identifies IRS's features, investigates the merits and limitations of applying existing IRSs to instruction and learning, and further interprets how IRS's existing features can be elaborated and generates more useful features for instructional application based on three finished research: 1. developing a more powerful IRS, called EduClick II, to support various types of classroom activities and interactions, 2. expanding IRS to a network-supported environment to facilitate teachers' developing and sharing of pre-authored IRS-based materials, students' review of the materials and their in-class response on the IRS after class, and parents' understanding of their child's performance in using IRS, and 3. expanding IRS to other advanced devices, which could possess IRS's existing features.

Lowery, R. "Teaching and learning with interactive student response systems: a comparison of commercial products." *The Southwestern Social Science Association Annual Meeting, New Orleans, Louisiana*, 2005.

This paper is addressed to the college or university faculty member contemplating adoption of an evolving form of classroom technology – the interactive student response system (SRS). Marketed under a variety of brand names, this student-polling technology is designed to maximize student participation, especially in large-enrollment lectures. We will look at the components and operation of the two most common types of student response systems, wireless keypad and web-based input devices. Also provided is a brief survey of four decades of published research assessing the generally positive impact of student response systems on teaching and learning.

Penuel, W., Roschelle, J., Crawford, V., Shechtman, N., Abrahamson, L. "CATAALYST workshop report: advancing research on the transformative potential of interactive pedagogies and classroom networks." *SRI International*, Menlo Park, CA, 2004.

Within-classroom networks of handheld devices—powerfully combining a more agile, interactive pedagogy with content-rich materials and low costs—are drawing widespread interest among K-12 teachers, university lecturers, and commercial vendors. This combination, which we term CATAALYST, has attracted over \$11 million of NSF funds. The funds have been used to develop and study applications of CATAALYST for improving STEM education and have resulted in a large body of preliminary, descriptive research and production of high quality materials and pedagogical strategies for many subjects and grade levels. The descriptive research highlights consistent benefits of CATAALYST but has not yet produced the rigorous experimental or implementation research needed to guide educational policy.

Penuel, W. R., Boscardin, C. K., Masyn, K., & Crawford, V. M. “Teaching with student response systems in elementary and secondary education settings: A survey study.” *Educational Technology, Research and Development*, 55(4), 2007.

This study examined how 498 elementary and secondary educators use student response systems in their instruction. The teachers all completed an online questionnaire designed to learn about their goals for using response systems, the instructional strategies they employ when using the system, and the perceived effects of response systems. Participants in the study tended to use similar instructional strategies when using the technology as have been reported in higher education. These include posing questions to check for student understanding and diagnose student difficulties, sharing a display of student responses for all to see, asking students to discuss or re-think answers, and using feedback from responses to adjust instruction. A latent class analysis of the data yielded four profiles of teacher use based on frequency of use and breadth of instructional strategies employed. Teachers who used the technology most frequently and who employed broadest array of strategies were more likely to have received professional development in instructional strategies and to perceive the technology as more effective with students.

Roschelle, J., Penuel, W., Abrahamson, L. “Classroom response and communication systems: research review and theory.” *The 2004 Meeting of the American Educational Research Association, San Diego, CA, 2004.*

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.

Roschelle, J., Penuel, W. R., Abrahamson, L. "The networked classroom." *Educ. Leadership*, 61(5), 50–54, 2004.

In the typical mathematics or science class, a few students routinely answer most of the questions and share their work on a problem. Teachers rarely hear from the shy and less confident students. The networked classroom—handheld devices connecting to the teacher's laptop computer and integrated with a shared screen—can change all that. The authors describe recent research on how classroom networks can enhance communication in the classroom and improve student achievement. They also describe one such system in action.

Shapiro, J.A. "Student response found feasible in large science lecture hall." *Journal of College Science Teaching*, 26(6), p. 408-412, 1997.

This article describes the author's experience in designing and implementing a student response system for a large lecture hall on a small budget. Outcomes and plans for the future are also discussed.

Simpson, V., Oliver, M. "Electronic voting systems for lectures then and now: A comparison of research and practice." *Australasian Journal of Educational Technology*, 23(2), 187-208, 2007.

Research and practice in the use of electronic voting systems has developed over the last five years. Electronic voting systems, also known as personal response systems, audience response systems or classroom communication systems, use handsets to elicit responses from students as part of structured teaching sessions, typically lectures. The use of this information has implications for pedagogy; they are associated with the introduction of interactive, discursive and more segmented approaches to teaching. The pedagogic and organisational implications of adopting such systems are summarised, along with the perceptions that staff and students hold. Comparisons are drawn between practice up to 2002 and between 2002 and 2006; these reveal how both practice and research on this topic has matured, highlighting (for example) the development of models that seek to abstract and share practice. The paper concludes by outlining the ways in which such tools can be used to improve lecturing, and identifies an agenda for future work in this area.

Turpen, C., Finkelstein, N. "Understanding How Physics Faculty Use Peer Instruction." *Proceedings for the Physics Education Research Conference, Greensboro, North Carolina*, 2007.

We investigate how the use of physics education research tools is spreading throughout faculty practice and examine efforts to sustain the use of these practices. We specifically focus on analyzing the local use of the innovation Peer Instruction. We present data based on observations of teaching practices of six physics faculty in large enrollment introductory physics courses at our institution. From these observations, we identify three dimensions that describe variations in faculty practices: the purpose of questions, participation with students, and norms of discussion.

Woods, H. A., Chiu, C. “Wireless Response Technology in College Classrooms.” *The Technology Source*, September/October 2003.

Recent advances in wireless technology provide interesting and effective solutions to two perennial problems in large-classroom teaching. The first problem is to entice students into participating actively. In lecture classes, a variety of diversions can conspire to distract students from the lecture podium. Some of these problems can be alleviated by alternatives to straight lectures—for example, interactive learning techniques such as group discussion or student presentations. However, many instructors are uncomfortable with using these techniques in their classes. The second problem is monitoring student comprehension. As instructors, we probably feel in general that our lectures are good, and that the students are learning quite a bit. Nonetheless, in large classes, we usually have no simple way of assessing how well students understand the material, other than by reviewing their mid-term and final test scores. From day-to-day interactions in the classroom, it is extraordinarily difficult to gauge understanding. Conversing with one's class can help, but discussion with a small (often the same) subset of students is likely to be seriously misleading about class-wide comprehension.

Biological Sciences

Allen, D., and Tanner, K. “Infusing active learning into the large-enrollment biology class: seven strategies, from the simple to complex.” *Cell Biol. Educ.* 4, 262–268, 2005.

(Abstract not available.)

Barber, M., Njus, D., “Clicker Evolution: Seeking Intelligent Design.” *CBE-Life Science Education*, 6(1), 1-8, 2007.

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.

Bessler, W.C. "The effectiveness of an electronic student response system in teaching biology to the non-major utilizing nine group-paced, linear programs." *Doctoral dissertation*, Ball State University, Muncie, IN, 1969.

This paper presents the procedures, results, and conclusions of a study designed to determine the effectiveness of an electronic student response system in teaching biology to the non-major. Nine group-paced linear programs were used. Subjects were 664 college students divided into treatment and control groups. The effectiveness of the response system in presenting the programs was measured by achievement of the students on the examinations given during the course. The results of the study indicated that there was no significant difference between the achievement of students taught in control discussion sections and the achievement of students taught in treatment discussion sections. In addition, no significant interactions were found among student characteristics, instruction characteristics and achievement in control and treatment sections. The author concluded that the study provided statistical evidence that the electronic student response system when used with group-paced, linear programs was an effective educational medium.

Bessler, W.C., Nisbet, J.J. "The use of an electronic response system in teaching biology." *Science Education*, 3, p. 275-284, 1971.

An electronic student response system was used in teaching college biology to non-science students. Achievement of this treatment group was compared with that of the control group (not utilizing the response system). The only statistical significant difference found in an analysis of covariance was an interaction between treatment group and time of day. Mornings favored treatment sections; afternoons, control sections.

Brewer, C. "Near real-time assessment of student learning and understanding in biology courses." *BioScience*, 54(11), 1034–1039, 2004.

Computer technologies have transformed biology research, but the application of instructional technology tools to better connect teaching with learning has proceeded at a far slower pace. Especially in large-enrollment classes where many undergraduates are first introduced to biology,

faculty can use computer-assisted instructional technologies to help gauge student understanding (and misunderstanding) of core science concepts and to better evaluate their own teaching practices. In this article, I report on two instructional technology tools, which prompt students to reflect on their learning and allow faculty to gauge student understanding of material almost simultaneously: (1) off-the-shelf personal response systems, modified for in-class assessment in introductory biology classes, and (2) a custom-designed Web-based assessment for use between lectures (Bio-Bytes). On the whole, both faculty and students reported that these technologies helped to improve students' overall understanding of biological principles and concepts.

Caldwell, J.E. "Clickers in the large classroom: Current research and best-practice tips." *Life Sciences Education*, 6(1), 9-20, 2007.

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 ARS 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.

El-Rady, J. "To Click or not to click: That's the question." *Innovate Journal of Online Education*, 2(4), 2006.

Classes of 100 students or more are not uncommon in higher education. With such large enrollments, it can be difficult for instructors to integrate active learning components to the traditional lecture format typically adopted in such large classes. To help address this problem, Johnny El-Rady discusses his use of an electronic classroom voting system to administer quizzes and pose class participation questions in a high-enrollment biology course for non-majors. Via a pocket-sized "clicker," students were able to answer questions posed by their instructor and to receive instantaneous feedback on their answers. El-Rady illustrates how instructors can use such questions to provide breaks in lengthy lectures, utilize the scores and distributions of answers to clear up potential misunderstandings, and provide follow-up discussion to quizzes and questions. Attendance rates and exam scores in El-Rady's course increased, suggesting that CPS may indeed make the class more engaging and increase student retention of concepts.

Hatch, J., Jensen, M., Moore, R. "Manna from heaven or 'clickers' from hell: experiences with an electronic response system." *Journal of College Science Teaching*, 34(7), 2005.

Instructors used an electronic response system to enhance student-centered learning in large and small college biology classes. The system worked well to engage students in learning the subject matter and to assess their prior knowledge and misconceptions. It provided useful feedback to students as well as instructors. Problems encountered resulted mainly from not having permanent installation of the hardware components in the large class.

Preszler, R.W., Dawe, A., Shuster, C.B., & Shuster, M. "Assessment of the effects of student response systems on student learning and attitudes over a broad range of biology courses." *CBE-Life Sciences Education*, 6(1), 29-41, 2007.

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.

Ribbens, R. "Why I like clicker personal response systems." *Journal of College Science Teaching*, 37(2), 60-63, 2007.

For those of you unfamiliar with clicker personal response systems, a clicker is a handheld remote that students use to enter their responses to multiple choice questions. The question is displayed on the classroom overhead screen, usually within a Power Point presentation, and a receiver connected to a computer at the front of the room collects all responses, grades and stores each response, and (when requested) highlights the correct answer and displays a bar graph showing how many students chose each option. Here the author shares his personal experience using clickers during large introductory biology courses.

Smith, A. C., Stewart, R., Shields, P., Hayes-Klosteridis, J., Robinson, P., Yuan, R. “Introductory biology courses: a framework to support active learning in large enrollment introductory science courses.” *Cell Biol. Educ.* 4(2), 143–156, 2005.

Active learning and research-oriented activities have been increasingly used in smaller, specialized science courses. Application of this type of scientific teaching to large enrollment introductory courses has been, however, a major challenge. The general microbiology lecture/laboratory course described has been designed to incorporate published active-learning methods. Three major case studies are used as platforms for active learning. Themes from case studies are integrated into lectures and laboratory experiments, and in class and online discussions and assignments. Students are stimulated to apply facts to problem-solving and to learn research skills such as data analysis, writing, and working in teams. This course is feasible only because of its organizational framework that makes use of teaching teams (made up of faculty, graduate assistants, and undergraduate assistants) and Web-based technology. Technology is a mode of communication, but also a system of course management. The relevance of this model to other biology courses led to assessment and evaluation, including an analysis of student responses to the new course, class performance, a university course evaluation, and retention of course learning. The results are indicative of an increase in student engagement in research-oriented activities and an appreciation of real-world context by students.

Wood, W. B. “Clickers: a teaching gimmick that works.” *Dev. Cell.* 7(6), 796–798, 2004.

(Abstract not available.)

Business

Beekes, W. “The 'Millionaire' method for encouraging participation.” *Active Learning in Higher Education*, 7(1), 2000.

Encouraging students to participate during class time is important to facilitate the learning process and encourage deep learning to take place. However, students with certain cultural and education backgrounds are often reluctant to participate in class discussion. This article provides some initial insight into the use of the Personal Response System (PRS) to encourage class participation at the postgraduate level. I found that students' participation levels were increased when using the PRS, and further class discussion and debate was stimulated as a result.

Carnaghan, C., Webb, A. "Investigating the effects of group response systems on student satisfaction, learning, and engagement in accounting education." *Issues in Accounting Education*, 22(3), 391-409, 2007.

Our study examines the educational use of group response systems (GRS), also known as "clickers". We use theories of learning and prior research on GRS to provide a possible rationale for GRS vendors' claims that the technology improves student engagement and feedback, and thus indirectly improves learning. We then employ an experimental approach, with survey data as well as more objective measures, to test our resulting hypotheses.

In the context of an introductory management accounting course, we find support for student satisfaction with GRS, but limited evidence that this results in improvements in course satisfaction. We also find that GRS learning effects are conditional on the type of exam question, but not by students' learning ability. Contrary to our prediction, we find a moderately significant decline in engagement, as proxied by the average number of questions asked per student, when GRS were used. We discuss possible reasons for these findings, and suggest some issues for future research.

Freeman, M., Blayney, P., & Ginns, P. "Anonymity and in class learning: The case for electronic response systems." *Australasian Journal of Educational Technology*, 22(4), p. 568-580, 2006.

This research presents the results of a study of alternative response methods for in class formative questioning. Students' anonymity from their peers and instructor was studied through a research design that maintained a constant interactive teaching strategy in a large lecture hall, in all respects except for the method used by students to respond to the in class questions. A handheld electronic response keypad was the only approach affording complete anonymity. Student perceptions of the benefits of anonymity were obtained from a survey conducted at the end of the course. The results suggest that anonymity is a critical factor affecting student willingness to participate with in class exercises. Furthermore, the results indicate that students' propensity to engage with in class questions increases with the degree of anonymity provided to the student in revealing their response. The benefit of anonymity, combined with the increased availability and affordability of electronic response systems, will be of interest to academics keen to design engaging learning environments.

Guthrie, R., Carlin, A. "Waking the dead: using interactive technology to engage passive listeners in the classroom." *The 10th Americas Conference on Information Systems*, New York, NY, 2004.

This research attempts to learn students perceptions about the value that Audience Response Systems add to the classroom. The technology that is the subject of this research consists of eight-

button “response pads” that transmit student responses to a receiver connected to the computer in the classroom. The system allows the instructor to ask a variety of different question types and record and graphically-display the students’ responses in real time. Our research reveals that while initially leery of the technology and the modest cost it adds to the course, students are generally positive about its use, and prefer courses that use the technology over those that do not. Analysis reveals that student participation approaches 100% in class sessions where PRS are used due in part to anonymity, ease of use, and the ability to see how many others answered in the same way.

Williams, J. “Learning by remote control: exploring the use of an audience response system as a vehicle for content delivery.” *The 20th Conference of the Australasian Society for Computers in Learning in Tertiary Education*, Adelaide, Australia, 2003.

Audience response systems (also referred to as group response systems or personal response systems) have long been a feature of game-shows, televised pre-election debates, and corporate training workshops and conferences. More recently, these systems have found their way into the classrooms of tertiary educational institutions, primarily in the United States and in the United Kingdom. While their relative novelty precludes any detailed longitudinal study into their pedagogical effectiveness just yet, several studies have been published that endorse the more extensive adoption of this technology by universities and colleges. The conclusions of this exploratory study into the use of an audience response system at a graduate business school in Australia lend broad support to the findings of the existing body of research. Specifically, evidence is presented suggesting that, in a given context, the technology may be used in such a way that lectures (as they have been traditionally defined) may be discarded in favour of class meetings that are more interactive, and where students are motivated to engage more energetically with the course content. Importantly, the results of this study imply that, with enhanced opportunity for quality group discussion, there is a greater prospect of critical thought and deeper learning.

Chemistry

Bunce, D. M., Van den Plas, J. R., and Havanki, K. L. “Comparing the effectiveness on student achievement of a student response system versus online WebCT quizzes.” *J. Chem. Educ.* 83(3), 488–493, 2006.

This paper compares the effectiveness of an electronic student response system (SRS) to deliver ConcepTests with the use of WebCT quizzes for nursing students enrolled in general chemistry, organic chemistry, and biochemistry courses. SRS is a Web-based system designed to assist instructors in delivering and analyzing student responses to questions used in lecture and recitation. Student responses are captured and summarized graphically, providing students and instructors with immediate feedback. WebCT quizzes provide students with another opportunity for practice

of the concepts presented in class. Student achievement after experience with either or both SRS and WebCT quizzes on teacher-written hour-long exams and an American Chemical Society final exam was investigated. Results show that small differences in teacher implementation of both of these innovations can have large effects on student achievement. As currently implemented, SRS did not provide opportunities for reflection and review, while WebCT did. Using SRS demonstrated no effect on student achievement measured by teacher-written exams; a minimal effect of using SRS on student achievement measured by the ACS exam was shown. WebCT quizzes resulted in statistically higher achievement on teacher-written hour-long tests, but not on the ACS exam. This was probably a result of the WebCT quizzes not being reviewed by students because of time constraints. Student survey answers were used to corroborate this interpretation.

Casanova, J. "An instructional experiment in organic chemistry, the use of a student response system." *Journal of Chemical Education*, 48(7), p. 453-455, 1971.

(Abstract not available.)

Cuthbert, A., Kubinec, M., Douskey, M., Jeong, F. "Using Rich Media Technology to Support Peer Interaction in Large Lecture Courses." *Proceeding of Computers and Advanced Technology in Education*, 2004.

A critical challenge faced by education technology specialists and policy makers is how to develop effective strategies for using new technology. One way to address this challenge is to create a tighter connection between educational research, technology design, and teaching practices [1]. Towards this end, we present research findings from a large-scale undergraduate general chemistry course at UC Berkeley which used a peer interaction model to actively engage students by having them discuss instructional topics at strategic points throughout a lecture. During the lecture, students were presented with concept test questions (ChemQuizzes) that required them to synthesize the lecture content, cast individual votes using handheld devices, discuss their choices with their peers, and cast a second vote following the discussion. This form of peer interaction called "concept testing" was investigated in one section (N=311) of an undergraduate general chemistry course at UC Berkeley. A central goal of this investigation was to improve the technology that supports interactions around ChemQuiz concepts both during and after the class. We provide an overview of the learning environment, a summary of research findings, and an example of the next generation of web-based peer interaction tools informed by this research.

Hall, R., et al. "A Student Response System for Increasing Engagement, Motivation, and Learning in High Enrollment Chemistry Lectures." *Proceedings of the Eleventh Americas Conference on Information Systems, Omaha, NE*, August 11-14, 2005.

Student response systems (SRS) are devices that allow students to provide categorical and numerical responses to questions embedded within a lecture, and the responses can be tallied and scored in various ways to provide immediate feedback to the students and/or professors. In the fall of 2004 at the University of Missouri–Rolla, questions were systematically integrated into large general chemistry lecture sections, and students used the response system to answer. In order to evaluate the system, students' test scores were compared with previous years, and a survey was administered with the aim of evaluating the system at the end of the course when SRS was used. Test scores indicated substantial improvement from previous years. In addition, survey results indicated that a significant majority of the students found that the SRS made the course more engaging, motivational, and increased learning. Qualitative analyses of students' open-ended responses provided support and additional insights for the quantitative analyses.

Johnstone, A. H., and Su, W. Y. "Lectures—a learning experience?" *Educ. Chem.* 31(1), 75–79, 1994.

(Abstract not available.)

Communications

Fitch, J. "Student Feedback in the College Classroom: A Technology Solution," *Education Technology Research and Development*, 52(1), 2004.

Technology in the university classroom has made great strides in the area of presentation of materials. Ceiling-mounted projectors and media carts with projection capabilities have made the multimedia classroom presentation a routine event for much of the world of higher education. Now there is technology that permits the instructor to solicit student responses during class via wireless keypads. This allows all students to respond simultaneously and the instructor to know the results immediately. This article reports the results of a pilot study on student reaction to a specific system (LearnStar). Students were uniformly positive in their appraisal of this technology as a teaching tool.

Rice, R., Bunz, U. "Evaluating a wireless course feedback system: the role of demographics, expertise, fluency, competency, and usage." *The 89th National Communication Association Convention, Miami, FL*, 2003.

Current pedagogical theory emphasizes the use of new computer-based instructional technologies for convergence, collaborative and participative learning, and in-class feedback. However, it is necessary to evaluate these technologies, especially to identify any student factors that might

foster digital divides or differential outcomes. This study analyzes the influences on the student evaluation of a wireless course feedback system in two Master's classes, using a baseline influence survey, two later evaluation surveys, system data about answering review questions, and ratings and open-ended comments on the final course evaluation. Influences studied include demographics, variety of computer usage, web expertise, computer-email-web fluency, computer-mediated competency, levels of exposure to the system, and use of the system for in-class reviews and discussions. Fluency involved three dimensions, competency involved eight dimensions, and evaluation of the system included four dimensions. Different evaluation dimensions (training, easy to use, validity, fun, overall) were predicted (from 25% to 51%) by different combinations of prior web use, computer classes, exposure to the system, and different dimensions of computer-mediated competency (such as medium factors, interaction management, efficacy and overall CMC competency).

Trees, A. R., Jackson, M. H. "The learning environment in clicker classrooms: Student processes of learning and involvement in large university-level courses using student response systems." *Learning, Media, and Technology*, 32, 21-40, 2007.

To explore what social and educational infrastructure is needed to support classroom use of student response systems (Roschelle et al., 2004), this study investigated the ways in which student characteristics and course design choices were related to students' assessments of the contribution of clicker use to their learning and involvement in the classroom. Survey responses of over 1500 undergraduates enrolled in seven large enrollment "clicker courses" offered by three university departments are analyzed. A number of factors contribute to students' positive perception of clickers: a desire to be involved and engaged, a view that traditional lecture styles are not best, valuing of feedback, class standing, previous experience with lecture courses, anticipated course performance, and amount of clicker use in the classroom. These results underscore the importance of considering social and communication elements of the classroom when adopting student response technology. Survey instrument is appended. (Contains 3 tables.)

Computer Science

Cutts, Q., Kennedy, G. "Connecting learning environments using electronic voting systems." *The 2005 Australasian Computing Education Conference, Newcastle, Australia, 2005.*

Many educational theories depend on learning as a process of dialogue between teacher and learner. Traditional university methods such as lectures and tutorials do not facilitate dialogue since students are unable or unwilling to speak out. The use of an electronic voting system in lectures, where all students can respond to questions set by the lecturer with the aggregated results displayed to the class, aims to alleviate barriers to dialogue in lectures and so improve learning. A recent study, by the authors, of a three-year use of a voting system in introductory

programming lectures has shown that response rates by students are lower than expected. This paper outlines the educational purpose of using the system in this lecture course and postulates reasons for the low response rates. Based on these reasons, the paper presents an educational framework whereby students' votes not only enrich the lecture environment but are also used to facilitate learning in small group teaching sessions and the students' self-study environments.

Garg, D.P. "Experiments with a computerized response system: A favorable experience." *Conference on Computers in the Undergraduate Curricula, Fort Worth, TX, 1975.*

In order to obtain student feedback in computer programming courses at Duke University, a computer-based anonymous audience response system was used. This system consisted of a minicomputer, voting consoles, and a large electronic display. Students set their voting consoles in response to the question and the minicomputer interrogated the consoles. The cumulative responses in each category were flashed on an electronic display board to provide immediate feedback. The objective of the project was to acquaint the students with a unique application of the computers. The system was well-received by the students and proved to be very effective as a feedback device in promoting free and open dialog.

Kennedy, G. E., Cutts, Q. I. "The association between students' use of an electronic voting system and their learning outcomes." *Journal of Computer Assisted Learning*, 21, 260-268, 2005.

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.

Lopez-Herrejon, R., Schulman, M. "Using interactive technology in a short Java course: an experience report." *The 9th SIGCSE Conference on Innovation and Technology in Computer Science Education, Leeds, UK, 2004.*

Keeping students alert and responsive during lectures is a challenge even for experienced teachers in small group settings. Research has shown the importance of student participation and involvement in the learning process. Many ideas and strategies have been proposed to promote

these two vital education elements [5]. Among them is the use of interactive technology where the instructor asks a question to the class and each student answers individually. These answers are tallied and the professor can get immediate, quantitative, and real-time feedback information that can be used to detect and address comprehension problems and to adapt the lecture plan accordingly. In this paper we report our experiences using a wireless interactive system named the Classroom Performance System (CPS) [9] in a fast-paced, short but comprehensive Java programming course. We present the challenges we faced and the lessons we learned in designing and delivering lectures using this type of technology.

Martyn, M. "Clickers in the classroom: An active learning approach." *EDUCAUSE Quarterly*, 30(2), 71-74, 2007.

(Abstract not available.)

Purchase, H., Mitchell, C., Ounis, I. "Gauging students' understanding through interactive lectures." *Lecture Notes in Computer Science*, 3112, January 2004.

The Personal Response System (PRS) enables audience responses to multiple choice questions to be collected quickly, and for a summary of all the answers to be displayed to the whole group immediately, making it a useful tool for promoting classroom discussion. This paper describes its use as a means for assessing students' understanding of previously learned material, in the context of two consecutive database modules. The PRS was used in the areas of Entity-Relationship diagrams, Relational Algebra, and SQL, and proved to be useful in assessing students' current level of understanding.

Earth Sciences

Greer, L., Heaney, P. "Real-time analysis of student comprehension: an assessment of electronic student response technology in an introductory earth science course." *Journal of Geoscience Education*, 52 (4), 2004.

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 Uni-

versity. 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.

Zimmerman, A.R., & Smith, M.C. "Engaging today's students in earth science 101." *EOS*, 87(34), 339-344, 2006.

It is a sad fact, or perhaps a happy one, that many geoscientists in academia will find themselves in front of a classroom of 100–300 undergraduate nonscience majors, lecturing to them for three hours per week. Whether it is 'Rocks for Jocks' or 'Waves for Babes,' students often are under the impression that geoscience classes will be the least painful way to fulfill their science credit requirements. The sense of personal anonymity that can accompany large-enrollment classes often results in a different level of student engagement compared with smaller classes. Thus, if students are physically present at all, instructors often have only their much-divided attention. How can professors keep 300 students, even the ones in the back of the classroom who are barely visible, awake and engaged?

Economics

Elliott, C. "Using a personal response system in economics teaching." *International Review of Economics Education*, 1(1), 2003.

This paper offers a brief introduction to a Personal Response System that can be used in group-teaching scenarios, reporting the results of a trial using the technology in a second-year undergraduate Microeconomics Principles course. Advantages and disadvantages of the technology are discussed, and the possibilities for using this technology more widely are explored.

Freeman, M., Blayney, P. "Promoting interactive in-class learning environments: A comparison of an electronic response system with a traditional alternative." *Innovation for Student Engagement in Economics: Proceedings of the Eleventh Australasian Teaching Economics Conference*, 2005.

Interaction and peer learning with in-class questions is a common pedagogical solution to the large class problem. Hake (1998) shows students in interactive courses significantly improved achievement over those in traditional classes. Electronic response systems can be used to capture and aggregate student responses to in-class questions and allow for immediate feedback to stu-

dents. Draper and Brown (2004) and Judson and Sawada (2002) concludes that pedagogical design is the key to student learning and not the technology. However, previous research has not compared alternative response systems when classes are already interactive. If classes are interactive the introduction of an electronic response system may be an expensive and unnecessary alternative. The objective of this paper is to explore the effects of using alternative response methods while holding constant a constructivist pedagogical design. In this study interactive in-class questions and peer learning are used each class. The response method alone is changed, alternating between a handheld audience electronic response system and a traditional show of hands. A significant preference for using the electronic response system exists. It appears that this technology provides an additional incentive to engage, interact and understand. Anonymity is explored as a plausible explanation for these findings.

Hinde, K., Hunt, A. "Using the personal response system to enhance student learning: some evidence from teaching economics." Audience Response Systems in Higher Education: Applications and Cases, David Banks, ed., *Information Science Publishing*, 2006.

Recent increases in class size in higher education have focused more attention on the nature of the face-to-face learning experience. This chapter examines how a keypad technology facilitates active learning in the lecture hall using a number of pedagogically proven approaches. We survey 219 first-year business studies students tackling introductory economics, and find that the technology enhances learning in lectures because, among other things, it improves concentration, provides instantaneous and more effective student feedback, and allows students to make comparisons on how well they fare relative to their peers. Interestingly, we find less statistical support for the benefits of using the technology to allow students to respond anonymously, and explore some reasons for this results. Finally, we demonstrate our use of the tool to engage in teaching the Prisoner's Dilemma game. This forms part of the emerging knowledge on how to teach classroom experiments using keypad technology.

Engineering

Boyle, J., Nicol, D., Hamilton, B., Dempster, B. "The Use of Classroom Feedback Systems to Enable Active Learning in Large Engineering Mechanics Classes." *International Conference on Engineering Education*, Oslo, Norway, August 6–10, 2001.

Many recent studies have demonstrated that concept tests followed by immediate feedback and peer discussion improves students' understanding of difficult concepts in science and engineering. These effects have been shown both in conventional classrooms and in wired classrooms where students respond to concept tests using a 'classroom communication system.' These systems enable interactive learning even with large numbers of students. Little is known, however, about how students experience this method of teaching and learning or about what contributes to

their enhanced understanding. To explore this, and its implications for engineering teaching and learning, data is being collected from mechanical engineering students taking an introductory mechanics course using semi-structured interviews, minute papers, critical incident analysis, and questionnaires etc. Data on improvements in conceptual understanding are also being collected. The study examines differences in students' responses to, and experiences of three different peer discussion sequences and the contribution of different feedback methods (i.e. computer-generated, peer-generated and tutor-provided) to learning.

Boyle, J., Nicol, D., Hamilton, B., Dempster, B. "Experience with classroom feedback systems to enable socratic dialogue in large engineering classes." *Engineering Education 2002: Professional Engineering Scenarios*, Vol. 1, Jan. 2002.

Many studies have demonstrated that concept tests followed by immediate feedback and peer discussion improve students' understanding of difficult concepts in science and engineering. These effects have been shown both in conventional classrooms and in wired classrooms where students respond to concept tests using a 'classroom communication system'. These systems enable interactive learning even with large numbers of students. Little is known, however, about how students experience this method of teaching and learning or about what contributes to their enhanced understanding. To explore this, and its implications for engineering teaching and learning, data is being collected from mechanical engineering students taking an introductory mechanics course using semi-structured interviews, minute papers, critical incident analysis, and questionnaires etc. Data on improvements in conceptual understanding are also being collected. The study examines differences in students responses to, and experiences of three different peer discussion sequences and the contribution of different feedback methods (i.e. computer-generated, peer-generated and tutor-provided) to learning.

Hall, S.R., Waitz, I., Brodeur, D.R., Soderholm, D.H., Nasr, R. "Adoption of Active Learning in a Lecture-based Engineering Class." *The 32nd ASEE/IEEE Frontiers in Education Conference, Boston, MA*, November 6–9, 2002.

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, peercoaching, course webpages, 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.

Nicol, D., Boyle, J. "Peer instruction versus class-wide discussion in large classes: a comparison of two interaction methods in the wired classroom." *Studies in Higher Education*, 28(4), 2003.

Following concerns about the poor conceptual understanding shown by science students, two US research groups have been experimenting with the use of 'classroom communication systems' (CCSs) to promote dialogue in large classes. CCS technology makes it easier to give students immediate feedback on concept tests and to manage peer and class discussions. Improvements in conceptual reasoning have been shown using these methods. However, these research groups have each piloted different discussion sequences. Hence, little is known about which sequence is best and under what circumstances. This study compares the effects of each sequence on students' experiences of learning engineering in a UK university. The research methods included interviews, a survey and a critical incident questionnaire. The results demonstrated that the type of dialogue and the discussion sequence have important effects on learning. The findings are discussed in relation to social constructivist theories of learning and in relation to the implications for teaching in wired classrooms.

Paschal, C., "Formative assessment in physiology teaching using a wireless classroom communication system." *Advances in Physiology Education*, 26(4), 2002.

Systems physiology, studied by biomedical engineers, is an analytical way to approach the homeostatic foundations of basic physiology. In many systems physiology courses, students attend lectures and are given homework and reading assignments to complete outside of class. The effectiveness of this traditional approach was compared with an approach in which a wireless classroom communication system was used to provide instant feedback on in-class learning activities and reading assignment quizzes. Homework was eliminated in this approach. The feedback system used stimulated 100% participation in class and facilitated rapid formative assessment. The results of this study indicate that learning of systems physiology concepts including physiology is at least, as if not more, effective when in-class quizzes and activities with instant feedback are used in place of traditional learning activities including homework. When results of this study are interpreted in light of possible effects of the September 11, 2001 terrorist attacks on student learning in the test group, it appears that the modified instruction may be more effective than the traditional instruction.

Su, Q. "Teaching innovation using a computerised audience response system." *The 2002 Australasian Universities Power Engineering Conference, Melbourne, Australia*, 2002.

During the last decade, Internet and web-based teaching has been widely used in education. However, in university teaching-learning activities, the face-to-face communication in lectures and tutorials are still the most important means of knowledge flow. Without improvement of these teaching and learning practices, any teaching method using advanced internet techniques would not make significant difference in educational standard. In this paper, the application of a computerised audience response system in lectures and tutorials is presented. It has been proved that this innovative method can make classroom teaching more effective and enjoyable for both the teacher and students.

van Dijk, L. A., van den Ber, G. C., van Keulen, H. "Interactive lectures in engineering education." *Eur. J. Eng. Educ.* 26(1), 15–18, 2001.

This article discusses an alternative approach to lecturing: the interactive lecture. In the literature, interactive teaching is forwarded as a means to increase the effectiveness of lectures. Members of lecturing staff still seem, however, reluctant to incorporate interactive teaching in their classes, as interaction reduces the time they can devote to explaining subject matter. Lecturers often voice the concern that they will not get enough material across in interactive lectures and that this consequently will negatively affect student learning. In order to establish whether or not the concerns of lecturers could be empirically verified, an experimental study was conducted. This study examined the effects of interactive teaching in lectures, using an interactive voting system and peer instruction, on: the attainment of learning objectives; student motivation; and student perception of the instruction offered. From the results a complex picture emerges. Results suggest that students may learn as much in interactive lectures compared with traditional lectures, but a traditional lecture may also result in active student involvement. The study indicated that interactive teaching will not automatically result in students who are more activated, and provided additional insight into conditions for successful interactive teaching. Finally, interactive teaching was shown to influence positively student motivation.

Law

Caron, P., Gely, R. "Taking back the law school classroom: using technology to foster active student learning." *Journal of Legal Education*, 54, December 2004.

Law schools (and indeed all of higher education) have witnessed an explosive growth in the use of technology in the classroom. Many law professors now deploy a wide array of technological bells and whistles, including PowerPoint slides, web-based course platforms, in-class Internet access, and the like. Students, in turn, increasingly come to class armed with laptop computers to harvest the fruits of the classroom experience. Yet in recent years there has been somewhat of a backlash, with various law professors arguing that this technology is interfering with, rather than improving, pedagogy in the classroom. According to the critics, this technology increases student

passivity and thus interferes with the active learning that should be the hallmark of a law school classroom. In addition, the critics complain that laptops provide too much competition for the students' attention, enticing them to play computer games or DVDs and, with in-class Internet access, to read and send email (or instant messages), shop on-line, or check out the latest political, financial, or sports news. This Article opens a new chapter in this debate, explaining how law professors can use both old and new technologies to increase student engagement in the classroom.

We first lay out the pedagogical case for creating an active learning environment in the law school classroom and then examine the critics' charge that technology impedes these goals. The Article offers a competing vision of how technology can be harnessed to increase active student learning and, in the process, empower students to resist their laptop's siren song. In particular, we describe how in our tax and labor law courses we combine both old (substituting word processing text for PowerPoint slides) and new (using handheld wireless transmitters) technologies to inject more active learning into the classroom.

Mathematics

Abrahamson, A.L. "An overview of teaching and learning research with classroom communication systems." *International Conference of the Teaching of Mathematics, Village of Pythagorean, Samos, Greece, 1998.*

Over two thousand years ago, Socrates realized that people understand more by answering a question, than by being told an answer. Now, science has helped to explain reasons behind this counter-intuitive idea, and shown why it works so well. But, there is a problem with Socratic teaching: it works well only in small classes. The CCS is an invention which ameliorates this problem and makes (forms of) Socratic teaching effective in classes of any size. This paper briefly summarizes five years of CCS research with pedagogical techniques in a range of disciplines, educational levels, and institutional settings.

Blodgett, D.L. "The effects of implementing an interactive student response system in a college algebra classroom." *Dissertation, 2006.*

(Abstract not available.)

Brown, J.D. "An evaluation of the Spitz student response system in teaching a course in logical and mathematical concepts." *Journal of Experimental Education, 40(3), p. 12-20, 1972.*

The statistical data of this study would tend to support the idea that the effect of attitude on achievement is independent of the method of instruction.

Bulter, M., Butler, F. "Introduction to Personal Response Systems and studies of their use." *Proceedings of the Second IASTED International Conference on Education and Technology*, p. 200-205, 2006.

This paper provides information about the use of a Personal Response System (PRS) in large lecture sections at West Virginia University. The authors give details on their employment of a PRS in sections of Liberal Arts Math and College Algebra, including setting up the necessary files, writing questions, incorporating questions into lectures, grading questions, and posting scores. In addition, preliminary data from two PRS studies is provided. The first study concerns Liberal Arts Math students' reactions to PRS use, and the effects PRS has on student performance. The second study involves the experiences of instructors from many disciplines using the technology. The results from the studies are generally positive, and support continued use of PRS. Finally, some plans for improvements of PRS use, and some future research questions to consider, are included.

Cline, K. "Classroom voting in mathematics." *Mathematics Teacher*, 100(2), 100-104, 2006.

(Abstract not available).

Cline, K., Zullo, H., & Parker, M. "Teaching with classroom voting." *Mathematical Association of America FOCUS*, 27(5), 22-23, 2007.

(Abstract not available.)

d'Inverno, R., Davis, H., White, S. "Using a personal response system for promoting student interaction." *Teaching Mathematics and Its Applications*, 22(4), 163-169, 2003.

We first describe the introduction of an electronic feedback system in a large lecture class in Engineering Mathematics designed to promote greater student interaction. We then look at the experience of using the system where it was primarily used to support the consolidation of key concepts in tutorials in Computer Science. We discuss the issue of how the introduction of such methods turned out to be as much a learning experience for the academics involved as for the students and consider the potential of these systems.

Miller, R.L., Santana-Vega, E., & Terrell, M.S.. “Can good questions and peer discussion improve calculus instruction?” *PRIMUS*, 16(3), 2006.

Preliminary report of the results of a project to introduce peer instruction into a multi-section first semester calculus course taught largely by novice instructors. This paper summarizes the instructional approaches instructors chose to use, and the subsequent results of student performance on common exams throughout the course of the term.

Medicine

Collins, L. “Livening up the classroom: Using audience response systems to promote active learning.” *Medical Reference Services Quarterly*, 26(1), 81-88, 2007.

(Abstract not available.)

Ganger, A., Jackson, M. “Wireless handheld computers in the preclinical undergraduate curriculum.” *Medical Education Online*, 8(3), 2003.

This report presents the results of a pilot project using wireless PDAs as teaching tools in an undergraduate medical curriculum. This technology was used to foster a transition from a passive to an interactive learning environment in the classroom and provided a solution for the implementation of computer-based exams for a large class. Wayne State Medical School recently provided model e570 Toshiba PocketPCs® (personal digital assistants or PDAs), network interface cards, and application software developed by CampusMobility® to 20 sophomore medical students. The pilot group of preclinical students used the PDAs to access web-based course content, for communication, scheduling, to participate in interactive teaching sessions, and to complete course evaluations. Another part of this pilot has been to utilize the PDAs for computer-based exams in a wireless environment. Server authentication that restricted access during the exams and a proctoring console to monitor and record the PDA screens will be described in this report. Results of a student satisfaction survey will be presented.

Halloran, L. “A comparison of two methods of teaching: computer managed instruction and keypad questions versus traditional classroom lecture.” *Comput. Nursing*, 13(6), 285–288, 1995.

(Abstract not available.)

Jackson, M., et al. "Wireless handheld computers in the undergraduate medical curriculum." *Medical Education Online*, 10(5), 2005.

Wayne State University Medical School has implemented wireless handheld computers or PocketPCs (PPCs) into all four years of the undergraduate curriculum. A transition from a passive to an interactive learning environment in the classroom, as well as administrative solutions for monitoring patient encounter data by students in their clinical rotations was fostered by this educational technology. Implementation of the wireless devices into the curriculum will be described in this report. This will include the technical specifications and justification for the required device, as well as a detailed discussion of the different applications used for educational and administrative purposes by the preclinical and clinical students. Outcomes from the educational and administrative aspects of the project will also be presented in this report.

Johnson, J. "Creating Learner-Centered Classrooms: Use of an Audience Response System in Pediatric Dentistry Education." *Journal of Dental Education*, 69(3), p. 378-381, 2005.

Research suggests that the exclusive use of lecture in the classroom hinders student learning. The advent of compact electronic wireless audience response systems has allowed for increased student participation in the classroom. Such technology is utilized in medical education. This article describes the use of an audience response system in a "quiz bowl" format to facilitate and improve the comprehension of student dentists in core concepts in pulp therapy for the pediatric patient.

Latessa, R., Mouw, D. "Use of an audience response system to augment interactive learning." *Family Medicine*, 37(1), 2005.

Little data exist about the use of an Audience Response System (ARS) as an interactive educational tool in medical teaching. The goals of our pilot study were to determine whether an ARS can enhance educational experiences of health care providers. Methods: The learners in the study were mainly physicians, and the educational topic was treating self, family, and friends. Results: The learners reported that the ARS made the presentation more fun, helped them be more attentive, and allowed them to learn more than in traditional lecture formats. Conclusions: An ARS has potential as a teaching tool in this setting.

Menon, A., et al. "Audience response made easy: using personal digital assistants as a classroom polling tool." *Journal of the American Medical Informatics Association*, 11(3), 2004.

Both teachers and students benefit from an interactive classroom. The teacher receives valuable input about effectiveness, student interest, and comprehension, whereas student participation, active learning, and enjoyment of the class are enhanced. Cost and deployment have limited the use of existing audience response systems, allowing anonymous linking of teachers and students in the classroom. These limitations can be circumvented, however, by use of personal digital assistants (PDAs), which are cheaper and widely used by students. In this study, the authors equipped a summer histology class of 12 students with PDAs and wireless Bluetooth cards to allow access to a central server. Teachers displayed questions in multiple-choice format as a Web page on the server and students responded with their PDAs, a process referred to as polling. Responses were immediately compiled, analyzed, and displayed. End-of-class survey results indicated that students were enthusiastic about the polling tool. The surveys also provided technical feedback that will be valuable in streamlining future trials.

Miller, R.G., Ashar, B.H., Getz, K.J. "Evaluation of an audience response system for the continuing education of health professionals." *Journal of Continuing Education in the Health Professions*, 23, p. 109–115, 2003.

Continuing medical education (CME) for physicians and other health personnel is becoming increasingly important in light of recertification requirements. Interactive learning is more effective and may be useful in a continuing education setting. This study examines the use of an audience response system (ARS) as an interactive learning tool for health care providers. Method: We conducted a national randomized controlled trial to evaluate the utility of an ARS to enhance attention and learning. Speakers at 42 clinical round table (CRT) programs in five regions across the United States were randomized to "use" or "no use" of an ARS during their lectures. We surveyed participants to collect data regarding presentation and speaker quality, impressions of the ARS, and knowledge of the material presented. We collected information from speakers regarding ease of use and overall opinions of the ARS. Results: A total of 283 surveys were completed (164 from participants using the ARS and 119 from participants not using the ARS). ARS participants rated the quality of the presentation, the quality of the speaker, and their level of attention more highly than non-ARS participants ($p < .05$). Knowledge scores (of material presented) were not significantly different between the two groups. Both participants and speakers felt that the ARS was easy to use and preferred to use the system in future CRTs. Discussion: Participants in CRTs with the ARS rated presentation and speaker quality more favorably than those participants in CRTs without the tool. Participant knowledge scores, however, were not significantly different. ARSs may provide easy-to-use tools to enhance attention and enthusiasm in CME learners.

Moredich, C., Moore, E. "Engaging students through the use of classroom response systems." *Nurse Educator*, 32(3), 113-116, 2007.

Nursing faculty strive to stimulate learning and actively engage students in the classroom. Developing new approaches to student engagement in large classrooms can be a challenging task. The use of a classroom response system encourages students to actively participate while learning essential nursing knowledge in a way that adheres to principles of adult learning.

Moy, J.R., et al. "Who wants to be a physician? An educational tool for reviewing pulmonary physiology." *Advances in Physiology Education*, 24(1), 2000.

Traditional review sessions are typically focused on instructor-based learning. However, experts in the field of higher education have long recommended teaching modalities that incorporate student-based active-learning strategies. Given this, we developed an educational game in pulmonary physiology for first-year medical students based loosely on the popular television game show *Who Wants To Be A Millionaire*. The purpose of our game, *Who Wants To Be A Physician*, was to provide students with an educational tool by which to review material previously presented in class. Our goal in designing this game was to encourage students to be active participants in their own learning process. The *Who Wants To Be A Physician* game was constructed in the form of a manual consisting of a bank of questions in various areas of pulmonary physiology: basic concepts, pulmonary mechanics, ventilation, pulmonary blood flow, pulmonary gas exchange, gas transport, and control of ventilation. Detailed answers are included in the manual to assist the instructor or player in comprehension of the material. In addition, an evaluation instrument was used to assess the effectiveness of this instructional tool in an academic setting. Specifically, the evaluation instrument addressed five major components, including goals and objectives, participation, content, components and organization, and summary and recommendations. Students responded positively to our game and the concept of active learning. Moreover, we are confident that this educational tool has enhanced the students' learning process and their ability to understand and retain information.

Pradhan, A., Sparano, D., Ananth, C. "The influence of an audience response system on knowledge retention: An application to resident education." *American Journal of Obstetrics and Gynecology*, 193(5), 2005.

Objective: The purpose of the study was to compare delivery methods of lecture material regarding contraceptive options by either traditional or interactive lecture style with the use of an audience response system with obstetrics and gynecology residents. Study Design: A prospective, randomized controlled trial that included 17 obstetrics and gynecology residents was conducted. Group differences and comparison of pre/posttest scores to evaluate efficacy of lecture styles were performed with the Student t test. Each participant completed an evaluation to assess usefulness of the audience response system. Results: Residents who received audience response system interactive lectures showed a 21% improvement between pretest and posttest scores; residents who received the standard lecture demonstrated a 2% improvement ($P = .018$). The evalua-

tion survey showed that 82% of residents thought that the audience response system was a helpful learning aid. Conclusion: The results of this randomized controlled trial demonstrate the effectiveness of audience response system for knowledge retention, which suggests that it may be an efficient teaching tool for residency education.

Rao, S.P., DiCarlo, S.E. "Peer instruction improves performance on quizzes." *Advances in Physiology Education*, 24(1), 2000.

Peer instruction is a cooperative-learning technique that promotes critical thinking, problem solving, and decision-making skills. Benson's think-pair-share and Mazur's peer-instruction techniques are simple cooperative exercises that promote student's participation in class and increase student's interaction with each other and with the instructor in a large classroom. We borrowed concepts from Benson and Mazur and applied these concepts to enhance student involvement during the respiratory component of the medical physiology class. The medical physiology class consisted of 256 first-year medical students. The peer-instruction technique was used for 10 classes. Each class of 50 min was divided into three or four short presentations of 12–20 min. Each presentation was followed by a one-question, multiple-choice quiz on the subject discussed. Questions ranged from simple recall to those testing complex intellectual activities. Students were given 1 min to think and to record their first answer. Subsequently, students were allowed 1 min to discuss their answers with their classmates and possibly correct their first response. The percentage of correct answers increased significantly ($P < 0.05$) after discussion for both recall and intellectual questions. These data demonstrate that pausing three to four times during a 50-min class to allow discussion of concepts enhanced the students level of understanding and ability to synthesize and integrate material.

Robertson, L.J. "Twelve tips for using a computerised interactive audience response system." *Medical Teacher*, 22(3), 2000.

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 computerised 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.

Schackow, T.E., et al. "Audience response system: effect on learning in family medicine residents." *Family Medicine*, 36(7), 2004.

Background and Objectives: The use of an electronic audience response system (ARS) that promotes active participation during lectures has been shown to improve retention rates of factual information in nonmedical settings. This study (1) tested the hypothesis that the use of an ARS during didactic lectures can improve learning outcomes by family medicine residents and (2) identified factors influencing ARS-assisted learning outcomes in family medicine residents. **Methods:** We conducted a prospective controlled crossover study of 24 family medicine residents, comparing quiz scores after didactic lectures delivered either as ordinary didactic lectures that contained no interactive component, lectures with an interactive component (asking questions to participants), or lectures with ARS. **Results:** Post-lecture quiz scores (maximum score 7) were 4.25 ± 0.28 (61% correct) with non-interactive lectures, 6.50 ± 0.13 (n=22, 93% correct) following interactive lectures without ARS, and 6.70 ± 0.13 (n=23, 96% correct) following ARS lectures. The difference in scores following ARS or interactive lectures versus non-interactive lectures was significant ($P < .001$). Mean quiz scores declined over 1 month in all three of the lecture groups but remained highest in the ARS group. Neither lecture factors (monthly sequence number) nor resident factors (crossover group, postgraduate training year, In-Training Examination score, or post-call status) contributed to these differences, although post-call residents performed worse in all lecture groups. **Conclusions:** Both audience interaction and ARS equipment were associated with improved learning outcomes following lectures to family medicine residents.

Skiba, D. J. "Got large lecture hall classes? Use clickers." *Nursing Education Perspectives*, 27(5), 278-280, 2006.

(Abstract not available.)

Slain, D., et al. "An interactive response system to promote active learning in the doctor of pharmacy curriculum." *American Journal of Pharmaceutical Education*, 68(5), 2004.

Objective: The purpose of this study was to evaluate the impact of an interactive student response (ISR) system on student learning, interest, and satisfaction. **Methods:** Students enrolled in 3 courses, Clinical Pharmacokinetics, Medical Literature Evaluation, and Pathophysiology and Therapeutics, were taught using either a traditional lecture format (study year 1) or an ISR system format (study year 2). Primary outcomes of interest were performance on examinations and student attitudes. **Results:** Students using the ISR system had better scores on the Clinical Pharmacokinetics examination questions (mean scores, $82.6\% \pm 9.6\%$ vs $63.8\% \pm 8.3\%$, $p < 0.001$), on the cumulative final examination for Medical Literature Evaluation ($82.9\% \pm 11.5\%$ vs $78.0\% \pm 12.2\%$, $p = 0.016$), and on the evaluable "analysis type" examination questions in the Pathophysiology and Therapeutics course ($82.5\% \pm 8.7\%$ vs $77.4\% \pm 12.5\%$, $p = 0.0002$). Students using the ISR system in all 3 courses were positive about the system. **Conclusion:** The ISR system was a useful tool for encouraging active student learning and was well received by students. This sys-

tem can be efficiently used to gauge student understanding in the classroom and enhance student performance.

Uhari, M., Renko, M., Soini, H. “Experiences of using an interactive audience response system in lectures.” *BMC Medical Education*, 3(12), 2003.

Background: Lectures are good for presenting information and providing explanations, but because they lack active participation they have been neglected. **Methods:** Students' experiences were evaluated after exposing them to the use of voting during lectures in their pediatrics course. Questions were delivered to the students taking pediatrics course. Thirty-six students out of the total of 40 (90%) attended the opening lecture, at which the first survey concerning previous experiences of lectures was performed. Thirty-nine students (98%) answered the second series of questions at the end of the pediatrics course. **Results:** Most of the students felt that voting improved their activity during lectures, enhanced their learning, and that it was easier to make questions during lectures than earlier. **Conclusions:** The students gained new, exciting insights much more often during the pediatrics course than before. We as teachers found that voting during lectures could easily overcome some of the obstacles of good lecturing.

Philosophy

Stuart, S., Brown, M., Draper, S.W. “Using an electronic voting system in logic lectures: one practitioner’s application.” *Journal of Computer Assisted Learning*, 20(2), 2004.

This paper reports the introduction of electronic handsets, like those used on the television show ‘Who Wants To Be A Millionaire?’ into the teaching of philosophical logic. Logic lectures can provide quite a formidable challenge for many students, occasionally to the point of making them ill. Our rationale for introducing handsets was threefold: (i) to get the students thinking and talking about the subject in a public environment; (ii) to make them feel secure enough to answer questions in the lectures because the system enabled them to do this anonymously; and (iii) to build their confidence about their learning by their being able to see how they were progressing in relation to the rest of the students in the class. We have achieved all of these and more. Our experience has revealed that the use of handsets encourages a more dynamic form of student interaction in an environment – the lecture – that can, in the wrong hands, be utterly enervating, but they also provide an opportunity for the lecturer to respond to students’ difficulties at the time when they really matter. In this paper, we discuss our case of rapid adoption, our grounds for judging it a success, and what that success seems to have depended on.

Physics

Abrahamson, A.L. “Teaching with classroom communication system: What it involves and why it works.” *International Workshop, New Trends in Physics Teaching, Puebla, Mexico, 1999*.

In July 1992, NSF awarded a grant to a small startup company called Better Education Inc. to develop a new tool for teaching known as a Classroom Communication System (CCS). Collaborators on this work included some of the outstanding people in education research in the USA. The results of this grant have been far-reaching. This technology has been shown to act both as a facilitator and as a catalyst for improved teaching and learning. The pedagogy that it spawns seems to have a remarkable quality that not only helps students to learn better but also makes their classrooms more active, lively, and happy places. These results emanate from a wide range of disciplines including chemistry, biology, mathematics, political science, law, psychology, reading comprehension, business negotiation, & history. But, it all started with PHYSICS, because all of the original researchers were physicists. These included Eric Mazur, Bill Gerace, Jose Mestre, Alan Van Heuvelen, Jim Minstrell, David Hestenes, Gregg Swackhamer, Bob Dufresne, Fred Reif, Jill Larkin, George Webb, and Bill Leonard. This session will demonstrate and discuss the pedagogies and describe how and why they work.

Beatty, I., Gerace, W., Leonard, W., Dufresne, R. “Designing effective questions for classroom response system teaching.” *American Journal of Physics*, 74(1), p. 31-39, 2006.

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.

Bullock, D.W., et al. “Enhancing the student-instructor interaction frequency.” *The Physics Teacher*, 40, December 2002.

A 100-fold increase in the frequency of student–teacher interaction has been achieved in a large-enrollment classroom. Students answer in-class questions using personalized hand-held transmitters. Outside the classroom, personalized homework sets are generated and collected via the Internet.

Burnstein, R.A., Lederman, L.M. "Using wireless keypads in lecture classes." *The Physics Teacher*, 39, January 2001.

Experience using a wireless keypad system for five years in class rooms is discussed. This system is designed to increase student participation. The data can be displayed to students quickly and/or saved. The system is flexible and can accommodate a wide variety of teaching styles.

Burnstein, R.A., Lederman, L.M. "Comparison of different commercial wireless keypad systems." *The Physics Teacher*, 41, May 2003.

Wireless keypad systems have been in limited use for the past 10 years in the classroom. [1,2] Such systems can be used to quiz students in real time during the class, thus engaging students more directly in the lecture. Nonetheless, until recently widespread use of such keypad systems has been limited for several reasons. First, the original systems were relatively expensive but perhaps more important was the reluctance on the part of faculty to change the existing passive lecture format. [4,5] However, problems associated with large lecture classes [6] and the validation of the concept of "interactive engagement" from the high-statistics study of Hake [7] has changed the opinions of many. In addition the desirability of peer learning, [8] which is enhanced with a response system, has also been accepted. At the present time a number of commercial systems are available. The purpose of this paper is to present a comparison and summary of what is commercially available and a reminder that keypads are a dramatically effective teaching and learning tool.

Crouch, C.H., Mazur, E. "Peer instruction: ten years of experience and results." *American Journal of Physics*, 69(9), 2001.

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.

Dufresne, R.J., Gerace, W.J., Leonard, W.J., Mestre, J.P., Wenk, L. "Classtalk: A classroom communication system for active learning." *Journal of Computing in Higher Education*, 7(2), p. 3-47, 1996.

Traditional methods for teaching science courses at the post-secondary level employ a lecture format of instruction in which the majority of students are passively listening to the instructor and jotting down notes. Current views of learning and instruction challenge the wisdom of this traditional pedagogic practice by stressing the need for the learner to play an active role in constructing knowledge. The emerging technology of classroom communication systems offers a promising tool for helping instructors create a more interactive, student-centered classroom, especially when teaching large courses. In this paper we describe our experiences teaching physics with a classroom communication system called Classtalk. Classtalk facilitated the presentation of questions for small group work, as well as the collection of student answers and the display of histograms showing how the class answered, all of which fed into a class-wide discussion of students' reasoning. We found Classtalk to be a useful tool not only for engaging students in active learning during the lecture hour, but also for enhancing the overall communication within the classroom. Equally important, students were very positive about Classtalk-facilitated instruction and believed that they learned more during class than they would have during a traditional lecture.

Dufresne, R.J., Gerace, W.J., Leonard, W.J., and Mestre, J.P. "ASK-IT/A2L: Assessing Student Knowledge with Instructional Technology." *University of Massachusetts Physics Education Research Group, UMPERG Technical Report PERG-2000#09-SEP#1-28pp*, 2000.

The ASK-IT/Assessing-to-Learn (A2L) project is an attempt to bring a strategic approach to learning, instruction, and communication. ASK-IT/A2L seeks to integrate formative assessment and classroom response system use with physics instruction at both the high school and college levels. In this guide, we present a structure for discussing the new mindset students need in an ASK-IT/A2L classroom, consisting of twelve "habits of mind" for students to develop. To help teachers plan instruction, we present a model of five stages of cognitive development that most students need to follow to develop desirable knowledge and skills. We show how a typical lesson might be organized around "items," the smallest unit of ASK-IT/A2L lesson planning: questions, problems, or tasks given to students to work on individually or in groups. To help with item creation, we present our model-based design paradigm and suggest tips for avoiding common pitfalls and ways to match up cognitive goals with habits of mind. Finally, we apply the habits of mind to the metacognition of teachers and students.

Dufresne, R.J., Gerace, W.J. "Assessing-to-learn: formative assessment in physics instruction." *The Physics Teacher*, 42, October 2004.

Assessment designed to enhance teaching and learning is called “formative assessment.” During formative assessment, teachers and students seek information about the state of student learning and then use the acquired information to adapt teaching and learning to meet student needs. “Classroom formative assessment” (CFA) requires that teachers explicitly engage in formative assessment during classroom learning activities. At a basic level, CFA occurs naturally and is a common part of most instructional settings. Nevertheless, the systematic practice of CFA is rare in secondary and post-secondary science education. Here we provide suggestions for those interested in formative assessment for use in teaching introductory physics. A simple model of classroom formative assessment is presented. Included are examples of formative assessment activities and suggestions for implementation.

Falconer, K., Joshua, M., Wyckoff, S., Sawada, D. “Effect of reformed courses in physics and physical science on student conceptual understanding.” *National Association for Research In Science Teaching, St. Louis, MO, 2001.*

This paper describes major changes undertaken in two undergraduate physics courses from traditional lecture method to an inquiry-based method that facilitates active student engagement and changes in the modeling approach to learning. Students' conceptual understanding of physics concepts were evaluated by quasi-experimental design, and the Reform Teaching Observation Protocol (RTOP) was used to evaluate instructors for reformed teaching practice.

Fies, C. “Classroom Response Systems: What Do They Add to an Active Learning Environment?” *Dissertation, University of Texas at Austin, 2005.*

This study investigated the impact of completely anonymous Classroom Response Systems (CRS) use on learning outcomes and student attitudes in a large university physical science course for pre-service teachers. As students were expected to have read the textbook prior to class, class time was devoted primarily to conceptual introductions followed by small group discussions of qualitative questions. In the treatment condition, each group provided a single response anonymously using CRS. The control group responded individually and publicly by show of hands. Responses formed the basis for further discussion in both cases. Anonymity of responses in the control condition was expected to enhance participation and to provide more reliable formative assessment for the instructor, thus enhancing subsequent instruction and learning.

Gonzalez-Espada, W. J., & Bullock, D. W. “Innovative applications of classroom response systems: Investigating students' item response times in relation to final course grade, gender,

general point average, and high school ACT scores.” *Electronic Journal for the Integration of Technology in Education*, 6, 2007.

With the introduction of classroom response systems (CRS) in physics classrooms, instructors are now able to examine assessment parameters that are commonly described in the standardized assessment literature but were not previously available. The purpose of this research was to examine the relationship between students’ item response time for answering multiple-choice questions posed in an Introduction to Physical Science course offered during the summer of 2004 and variables such as gender, grade point average, ACT scores, and final grades. It was found that (a) for about 1/3 of the participants, there was a significant difference between the average response time for items answered correctly and incorrectly, (b) there was a significant negative correlation between the average response time for items answered correctly and both ACT scores and final score in Introduction to Physical Science, even if item difficulty is accounted for, and (c) there was no significant correlation between the average response time for items answered incorrectly and our variables of interest.

Mestre, J.P., Gerace, W.J., Dufresne, R.J., Leonard, W.J. “Promoting Active Learning in Large Classes Using a Classroom Communication System.” *International Conference on Undergraduate Physics Education*, College Park, MD, 1996.

We provide an overview of an instructional strategy aimed at promoting active learning in introductory physics courses. Although a classroom communication system called Classtalk was used to facilitate the interactions among students, and between the students and the instructor, the use of Classtalk is not essential for implementing the instructional strategies described herein. A major focus of this article is a discussion of the types of questions that we have found work well in generating group, and class-wide discussions of physics concepts. We also discuss the types of reasoning used by students to answer specific conceptual questions.

Mazur, Eric, “Peer Instruction: A User’s Manual.” *Prentice Hall*, 1997.

Presents an entirely new approach to introductory physics within a calculus-based conceptual and a mathematical framework. It offers an approach to presenting the material that is more gradual than existing books on the subject. Peer Instruction: A User's Manual develops the full conceptual framework of each chapter within the first section of that chapter while addressing questions common to that topic. The material in this section concentrates on the underlying ideas and paints the big picture, whenever possible without equations. The second part of each chapter then develops the rigorous mathematical framework linked to the material presented in the first part. Each chapter also includes a short set of qualitative, conceptual questions at the end of the first section designed to strengthen the focus on the conceptual framework and facilitate understanding of the mathematical framework. The book is written in a lively, engaging style that an-

anticipates the questions readers will have, articulates them, and answers them in a direct dialogue with the reader.

Milner-Bolotin, M., “Tips for using a peer response system in a large introductory physics class.” *The Physics Teacher*, 42, April 2004.

Teaching a large introductory physics course can be a challenge for a young physics instructor, and making a large physics lecture interactive may seem almost impossible. The most difficult part about the large class is that due to its size there is very little real-time interaction between the students and the lecturer. The instructor often does not know how well the students understand the lecture or how actively they are involved in it. The lack of real-time communication might make it very difficult and misleading for both the students and the instructor. Fortunately, recently we witnessed the proliferation of technological tools that can help the instructor get instantaneous feedback during the lecture. One of these tools is the peer response system (PRS).¹

Poulis, J., Massen, C., Robens, E., Gilbert, M. “Physics lecturing with audience-paced feedback.” *American Journal of Physics*, 66, p. 439–441, 1998.

For some time we have experimented at the Eindhoven University of Technology with a system which provides students with an electronic feedback path to the lecturer, audience paced feedback (APF). In this paper we describe this APF system, and give indications of its effectiveness.

Reay, N.W., et al. “Toward the effective use of voting machines in physics lectures.” *American Journal of Physics*, 73(6), 2005.

A “voting machine” is a generic name for wireless-keypad in-class polling systems used by students to answer multiple-choice questions during lectures. We present our experiences gained while distributing and using voting machine modules. Using voting machines with carefully designed sets of multiple-choice questions and instantaneous voting summaries improved classroom dynamics and provided students with several opportunities per concept to test their understanding. Three question sets developed for the electricity and magnetism quarter of a year-long introductory physics course are included as examples.

Sharma, M.D., et al. “An investigation of the effectiveness of electronic classroom communication systems in large lectures.” *Australasian Journal of Educational Technology*, 21(2), 2005.

Since 2002 we have been investigating the use of an electronic classroom communication system in large first year lecture classes. Handheld keypads were distributed to teams of students during a lecture class. Students used the keypads to answer two step multiple choice problems after a discussion within their group. The questions were generated using students' answers from previous exams. We have evaluated our use of the classroom communication system using a survey about how comfortable students are with this type of interaction. In addition, we have tried to determine if the use of the classroom communication system can be linked to student performance on exams. Our results show that students are comfortable with this technology and feel that, on the whole, interactive lectures are useful. At a first glance, there is an improvement in students' exam performance, but there are too many competing factors to clearly say that this improvement is solely due to the use of the classroom communication system. Even though this paper is based in physics and a physics example is used to illustrate points, the technique can be applied to other discipline areas.

Political Science

Kam, C.D., Sommer, B. "Real-time polling technology in a public opinion course." PS: Political Science & Politics, *Cambridge University Press*, 39, p. 113-117, 2006.

Many instructors face challenges in engaging students in lecture courses. In the fall of 2004, we incorporated innovative, real-time polling technology into an upper-division political science course on Public Opinion. The polling technology channeled students' technological savvy in the service of several pedagogical goals. The technology increased student engagement and reinforced the substance of the course material. It also provided students with topically relevant experiences in answering survey questions and allowed students to feel more comfortable in expressing their opinions during discussions.

Psychology

Ewing, A. T. "Increasing classroom engagement through the use of technology." *Maricopa Institute of Learning Fellowship*, 2004

Cognitive psychologists suggest that learning is best achieved by having students actively engaged. This study examined the effectiveness of student response systems (SRS), a new technology designed to increase active engagement of students by using wireless keypads that enable students responses to a question or prompt to be quickly recorded and portrayed on a classroom projector. Exam scores, course grades, and course evaluation responses of Social Psychology students (n=23) and Statistics students (n=29) using SRS, were compared to control groups taking the same courses without SRS.

Overall final course grade comparisons were not statistically different in either study. Data showed mixed evidence of statistically significant changes in test scores and course satisfaction associated with the use of SRS. In Social Psychology, 1 exam comparison out of 3 showed significantly higher scores when SRS were used. One exam comparison out of 4 in Statistics showed significant improvement with SRS. However, final questionnaires revealed that students in both courses overwhelmingly liked to use SRS. They strongly indicated that the use of SRS was fun, increased their participation, was effective to their learning experience, and helped them stay mentally engaged and accountable. They also strongly disagreed with the statement that SRS were an annoying waste of time. These data support the future use of SRS.

Lee, J. B., Bainum, C. K. "Do clickers depersonalize the classroom? An evaluation by shy students." *Paper presented at the 86th Annual Convention of the Western Psychological Association, Palm Springs, California, 2006.*

(Abstract not available.)

Statistics

Wit, E. "Who wants to be... The Use of a Personal Response System in Statistics Teaching." *MSOR Connections*, 3(2), May 2003.

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.