A Teaching with Technology White Paper

Classroom Response Systems

Ashley Deal | 11.30.2007

How to foster meaningful engagement among students is a long-standing question in large lecture halls. In effort to address this issue, electronic classroom response systems (CRS) have been tested and used in higher education classrooms since the 1960's.

The studies summarized in this paper show that CRS can facilitate the process of drawing out students' prior knowledge, maintaining student attention, and creating opportunities for meaningful engagement. They can also assist instructors in assessing student comprehension and developing classroom activities that allow for the application of key concepts to practical problems.

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Working Definition

There are three general categories of activities and equipment involved in using a classroom response system:

Instruction and questioning

Response and display

Data management and analysis

A classroom response system (CRS) is any system used in a face-to-face setting to poll students and gather immediate feedback in response to questions posed by instructors. A non-technical example of a CRS is an instructor asking students to raise their hands to agree or disagree with a given question. A slightly more sophisticated practice involves the use of colored flashcards, with each color corresponding to a possible response in a multiple-choice question.

Over the past 30 years, technologists have developed and refined electronic response systems that allow students to key in responses using transmitters (also called "remotes" or "clickers"). The main advantages of electronic response systems over non-technical methods for gathering feedback are the anonymity of responses, and the ability to immediately project response graphs overhead for the class to see. Electronic response systems can also store response data for future analysis and assessment.

There are three categories of activities and equipment involved in using a classroom response system: presentation and questioning, student response and display, and data management and analysis.

Instruction and questioning

Software for most classroom response systems has been designed to integrate with common presentation software, like Microsoft PowerPoint. Some additional effort is required to develop question slides, but since many instructors already use presentation software (particularly instructors in large lecture courses, where the use of CRS is most appealing), the extra effort is minimized.

The kinds of questions posed by the instructor can range from simple factual recall to questions designed specifically to reveal and challenge common misconceptions in a given topic. Development of effective questions is crucial to the success of teaching with CRS, and is discussed in detail in a later section.

In class, the instructor presents concepts and materials, interspersed with slides asking for feedback from students. Questions are typically in true or false or multiple choice format. Question slides can be placed in line with regular lecture presentations so instructors can gather feedback on the fly, without switching applications during the presentation. Students are typically given a short period of time to key in responses.

> Instructors can project response graphs overhead for the class to see, so students can compare their own responses to those of their classmates.

Response and display

Students key in responses using small remote transmitters. These transmitters send signals to a receiver that is connected to the instructor's laptop or lectern PC. Software on the instructor's machine instantly tabulates and graphs student responses, and these simple graphs can be displayed on the following presentation slide. One of the more compelling aspects of using CRS is that students can compare their own responses to the responses of other students in the class, which can encourage a level of metacognition that might not otherwise occur.

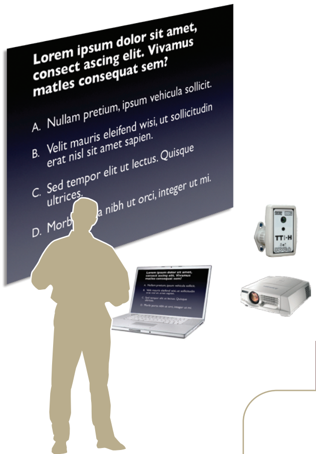
Once students see the distribution of responses, many instructors take the opportunity to encourage discussion, asking students to reconsider the question in groups and to reach an agreement about the best response. Instructors often follow the discussion with a second cycle of questioning, response, and display before wrapping up the presentation of a given concept. This approach is often referred to as "peer instruction."

Data management and analysis

Most classroom response systems allow instructors to export and save response data for future analysis and assessment. Some systems also integrate with course management systems, like Blackboard. This integration allows instructors to save and track student responses over the course of the semester, and simplifies the assessment process.

Classroom Response Systems: Technical Components and Interactions

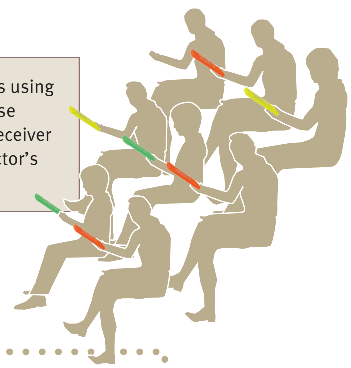
Instruction & Questioning



1 Instructor presents concepts and materials, interspersed with slides asking for feedback from students. Questions are typically in true or false or multiple choice format.

Response & Display

2 Students key in their responses using small remote transmitters. These transmitters send signals to a receiver that is connected to the instructor's laptop or lectern PC.



3 Software on the instructors machine instantly tabulates and graphs student responses, and these simple graphs can be displayed on the following presentation slide.

Many instructors then ask students to discuss the responses in groups, and to reach an agreement about the best response. This discussion can be followed with a second cycle of questioning, response, and display.

Data Management & Analysis

4 Most classroom response systems allow instructors to export and save response data for future analysis and evaluation. Some systems also integrate with course management systems, like Blackboard, to simplify the assessment process.

Case Studies & Assessments

Most strategies for using CRS fall into one of three general categories of implementation:

Monitoring the classroom
Attendance, attention, completion of assigned readings

Audience-paced instruction
Real-time evaluation of student comprehension

Peer instruction
Question/response cycle combined with discussion and debate among students

High-enrollment courses present challenges to many basic principles and established best practices in teaching and learning. Instructors in large lecture courses often face difficulty drawing out prior knowledge or misconceptions, motivating students and maintaining their attention, creating opportunities for meaningful engagement, assessing student comprehension, and developing classroom activities that allow for the application of key concepts to practical problems. Yet high-enrollment lectures remain the norm for introductory courses in many disciplines, and instructors have long sought tools and teaching strategies to help overcome these challenges.

For over 40 years, electronic classroom response systems have been investigated as a potential bridge for the communication gap between lecturers and students. Early systems were hard-wired into classrooms, with an input device at each seat in a lecture hall. These systems were costly and difficult to use, given the lack of graphical user interface and the complexity of software for data manipulation and display.

Lecture courses can present challenges to basic principles and established best practices in teaching and learning.

Improvements to hardware and software solutions and vast changes to the technology landscape have created a resurgent interest in CRS in the past decade. New systems are much more affordable, often portable, and take advantage other technologies already in use in most large lecture halls (i.e., presentation software, lectern hardware, and projection systems).

There are essentially three levels of implementation of classroom response systems, each with progressively more change in pedagogical approach, and—as best we can determine through an examination of the relevant literature—increasing improvement in terms of learning outcomes.

At the most basic level of implementation, classroom response systems serve as means for the instructor to monitor the classroom. The instructor uses CRS to take attendance, to ensure some level of participation, and to increase the students' level of attention during the lecture. The instructor might also ask very basic questions about reading assignments as a means to verify whether students completed the reading. In this scenario, the instructor uses CRS as a way to encourage attendance and some basic level of attention and participation, but makes very few intentional changes to the sequence, delivery, or duration of lecturing on a given concept.

At the second level of implementation, the instructor uses CRS to gather real-time information about student comprehension of a given concept. From the responses, the instructor is able to determine whether she should spend more time explaining an idea, or if the majority of the class understands the idea, allowing her to move on to the next topic. The students help set the pace of instruction with clear indication of their comprehension or confusion.

The third approach to teaching with classroom response often involves a transformation in the instructor's teaching philosophy and strategies. This approach involves interspersing the presentation of concepts with question and response cycles, followed by periods of discussion where students defend their responses and try to persuade classmates with their reasoning. Discussions are typically wrapped up with another question and response cycle where students can indicate their new response to the same question.

Monitoring the Classroom

The motivation to use classroom response systems most commonly derives from a desire to stimulate student engagement. Instructors in large lecture halls often struggle against what Rand Guthrie and Anna Carlin call "the sea of slouching bodies and expressionless faces" (2004). Efforts to engage students with questions yield few volunteers, and instructors often cannot determine where their lectures succeed or fail until examination time.

Even at the most basic level of implementation, where the instructor makes very few intentional changes to the lecture strategy, it seems that the use of classroom response systems can contribute to an instructor's participation and attendance goals.

Certainly, attendance policies can be much harder to enforce in high-enrollment courses than in smaller courses. In an introductory Earth Science course at Penn State University, the instructor used CRS responses over the course of the semester as 15% of the final course grade (Greer and Heaney, 2004). Whether responses were correct or not was not a factor, only whether students participated. Mean attendance ranged from 81% to 84% over the four CRS semesters measured, compared to an estimated 50% by the midpoint of semesters without CRS. Head counts were also conducted to account for "the possibility that absent students had handed their remote control units to friends who entered responses on their behalf." Discrepancies between CRS attendance numbers and the results of head counts were typically +/- 2% (p. 348).

Although the comparison numbers are estimates, not directly measured in a controlled setting, many other CRS studies report similar findings. Judson and Sawada conducted an extensive literature review on response systems, and report that research "from the 1960s through the late 1990s found that the use of electronic response systems made students more likely to attend class" (2002, p. 177).

Classroom response systems have been evaluated in several studies conducted in the context of continuing medical education (CME) lectures and seminars. Survey results from these and other studies indicate that student satisfaction increases in lectures using CRS (or ARS, audience response systems). Further, students report believing that the use of CRS has a positive impact on their performance.

Miller et. al. (2003) conducted a randomized controlled trial of audience response systems at 42 clinical round table programs across the country, and surveyed nearly 300 participants about their experience in ARS and non-ARS lectures.

Results showed that "participants who attended ARS lectures rated the quality of the talk, the speaker, and their level of attention significantly higher than the non-ARS group" (p. 112). While analysis did show that the differences between the two groups were statistically valid, the mean differences did not diverge to the degree that might be expected. Presentation quality was rated at a mean of 3.9 on a scale of 5 for non-ARS, and 4.0 for non-ARS. Speaker quality was rated 3.9 for non-ARS and 4.1 for ARS, while "ability of presentation to maintain attention and interest" was rated 4.2 for non-ARS, and 4.4 for ARS (p. 113).

> "As we gaze out at the sea of slouching bodies and expressionless faces, it is hard to resist wondering if students want less education and more entertainment."
>
> Rand W. Guthrie and Anna Carlin

The survey instrument in Miller's study also included a handful of questions assessing participants' understanding of the material presented, and results showed no significant difference in learning outcomes in ARS and non-ARS classes. The researchers theorize that the types of follow-up questions posed might not address differences in "long-term retention and application of knowledge" (p. 113).

In a separate study of CME lectures covering multiple years of classes offered with and without audience response systems, Copeland et. al. found that "lectures in which the ARS was used were significantly better rated than those in which the ARS was not used" (1998, p. 231). Over three years, mean ratings for lectures with ARS were about 3.47 on a scale of 1 to 4, compared to non-ARS lectures rated as 3.32. Even more telling, however, was a comparison of ratings from multiple lectures from a single speaker, two delivered with audience response, and one without. In the lectures delivered without audience response, the speaker received an average rating of 3.09 on a scale of 1 to 4. In a lecture delivered with audience response, the same speaker was rated at 3.74 (p. 232).

Another form of classroom monitoring with CRS is to present short quizzes at the beginning or end of a lecture period. Quizzes might cover homework or reading assignments, or basic concepts from the material covered in the previous or current lecture. In the Fall of 2004, Richard Hall and others at the University of Missouri, Rolla, conducted a pilot evaluation of classroom response systems in a General Chemistry course (2005). They opened each lecture with a brief quiz about the assigned readings, and found that the quizzes "served as a powerful motivator not just for attendance, but class preparation as well" (p. 5). Students reported that the quizzes helped them "learn what the professor was wanting us to get out of the reading," and that "you can see the areas you need to go back and look at when you get questions wrong" (p. 5).

In the same study, student responses to open-ended survey questions verified that interspersing lectures with CRS question/response cycles facilitates some level of increased engagement and metacognition. Students indicated that CRS "helped you pay attention in class because you knew you had a question coming," and that "it's a good way to know if you understand the material" (p. 5).

Evidence from these and other studies indicates that the use of CRS in the classroom, even at a basic level, can increase attendance rates, bring problem areas to the surface, and increase student satisfaction with lectures.

Audience-Paced Instruction

Once instructors can see plainly what students do and do not understand, the intuitive next step is to adjust the pace of presentation and explanation strategies accordingly. The second level of CRS implementation is a very natural extension of the first.

The previously discussed CRS pilot at the University of Missouri was in many ways a combination of all three levels of using CRS. In addition to quizzes on reading assignments and question cycles throughout lecture (classroom monitoring), the lectures were modified "based on student understanding as represented by the accuracy of their responses" (Hall et. al., 2005, p.3). This modification is the essence of audience-paced instruction. Students were also often allowed to discuss the questions with classmates before responding during the lecture. It is difficult to characterize this study as distinctly one type of CRS implementation. However, because the main focus of the study is on using CRS to increase engagement and assess comprehension in order to customize lecture presentation, we present and discuss their results primarily as classroom monitoring and audience-paced instruction.

> Once instructors see plainly what students do and do not understand, the next step is to adjust the explanations and pace of presentation accordingly.

Upon completion of the CRS pilot course in Hall's study, students were surveyed regarding their perceptions of the usefulness of CRS. Most students agreed that CRS made class lectures more engaging (87%), and enhanced their learning in class lectures (73%). A smaller majority also agreed that CRS "made the lectures more motivational" (63%). Students were divided as to whether CRS made class more challenging, and most disagreed (63%) that CRS helped them better understand how course material related to "real world" problems (p. 4).

Hall's research group compared the grade distribution for the semester with classroom response to a previous semester without CRS. While they acknowledge a lack of specific control measures to assure consistent grading standards and to account for student ability across semesters, they report that "grades were substantially better" in semesters with CRS (p. 5). The percentage of students earning A's increased from 23% to 40%, and the percentage of students receiving C's or D's in the course decreased from 34% to 21% (p. 4).

The Penn State University study discussed in the classroom monitoring section also employed audience-paced feedback methods to "encourage active student participation" and allow "both students and instructors to gauge student comprehension instantaneously" (p.345).

Multiple instructors involved in this study, teaching various sections of an introductory science course. Although instructors "shared the same course syllabus, lecture outline, course structure, and grading scheme throughout each semester," they also developed their own questions and maintained their "own classroom 'style' during the semester" (p.347). From the description of their CRS implementation, it seems again that their approach can not be described exclusively as classroom monitoring, audience-paced feedback, or peer instruction. However, at a minimum instructors used CRS for real-time assessment of student understanding, and to directly address misconceptions that were revealed through questioning.

> The mean pass rate for traditional lecture sections was less than 60%, while for audience-paced instruction sections, it was over 80%.

Students were asked at the midpoint of the semester to participate in a brief anonymous survey to share their impressions on the effectiveness of CRS. A majority of students (65-77%) agreed that the use of CRS helped them gauge their understanding of course material, and 71-85% agreed that it reinforced important concepts presented in the lecture. Between 65% and 81% of students surveyed believed that the use of CRS in lecture helped them learn (p. 348–349).

Qualitative feedback offered in course evaluations emphasize that students appreciate the anonymity of CRS ("it gave shy kids the chance to participate," "I don't feel put on the spot"); that CRS encourages attendance ("gave you an incentive to go to class," "forces me to come to class"); and that CRS facilitates more engagement throughout the lecture ("helped everyone get involved in such a large class," "lets me see if I am understanding the lecture or not and it truly does give a nice break from straight lecturing"). Negative comments included frustration with attendance monitoring ("extremely expensive way to take attendance," "dislike the way the teacher uses the system"); cost ("one of the most expensive classes I have ever taken," "overrated and expensive"); and speculation that question and response cycles are not the most effective use of class time ("takes up class time when she should be lecturing") (p. 349).

Although students can be resistant to any additional expenses associated with classroom response systems, many instructors equate the cost of the transmitter to the purchase of a textbook. Transmitters range in price from about $20 for basic infrared systems to $125 for the higher-end radio frequency systems. Transmitters can also be sold at the end of a semester to help offset the cost. For more information on differences in available systems, see the Appendix.

Researchers at Eindhoven University compared survey and performance data for 2,500 students in course sections delivered with audience-paced instruction to equivalent data from 2,800 students in sections delivered in the traditional lecture format (Poulis et. al., 1998). This study showed that the mean pass rate for audience-paced instruction lectures "is significantly higher than where traditional methods have been employed" (p. 441). The mean pass rate for traditional sections was less than 60%, while for CRS sections it was over 80%. The researchers also note that the standard deviation was substantially lower in the CRS group, indicative of "a more consistent level of comprehension throughout any given class" (p. 441).

Certainly, this type of comparative performance data, gathered in a controlled experimental environment, is a more convincing measure than students' self-reported behavior and perceptions of the effectiveness of CRS or audience-paced instruction. What students believe and report to believe about their learning and behavior can differ significantly from what they actually do and learn. Taken together, the findings from the studies cited shed some light on the potential impact of using CRS to gauge student comprehension in order to tailor the lecture delivery.

Peer Instruction

In this approach to teaching with CRS, the lecture process shifts from the "ballistic" model of knowledge transfer (plan and launch a lecture at the students, check later to see if you hit the target) to a more constructivist model, with the student actively building knowledge as a result of meaningful classroom interactions and activities.

Peer instruction (PI) was pioneered and has been evaluated extensively by Eric Mazur and others in the Department of Physics at Harvard University. Mazur and his colleague, Catherine Crouch, define peer instruction as the modification of "the traditional lecture format to include questions designed to engage students and uncover difficulties with the material" (2001, p. 970). They continue:

> "A class taught with PI is divided into a series of short presentations, each focused on a central point and followed by a related conceptual question.... Students are given one or two minutes to formulate individual answers and report their answers to the instructor. Students then discuss their answers with others sitting around them; the instructor urges students to try to convince each other of the correctness of their own answer by explaining the underlying reasoning. During the discussion, which typically lasts two to four minutes, the instructor moves around the room listening. Finally, the instructor calls an end to the discussion, polls students for their answers again (which may have changed based on the discussion), explains the answer, and moves on to the next topic" (p. 970).

These discussion periods help students understand the key concepts behind their answers, and facilitate a deeper, more practical comprehension than what might result from a traditional lecture. While electronic response systems are not essential to peer instruction, they certainly facilitate the process more efficiently and capture data more effectively than other methods of gathering feedback (polling by use of colored flash cards or show of hands).

There are many articles documenting the effectiveness of peer instruction (also described as "interactive engagement") in various settings. In one such assessment, Mazur and Crouch report on ten years of findings from physics courses at Harvard (2001). They analyze learning outcomes in terms of conceptual mastery, using test results from the Force Concept Inventory (FCI), and quantitative problem solving, using data from the Mechanics Baseline Test (MBT). (The FCI and MBT are standard assessments of student performance in physics. They are administered nationally as pre- and post-tests to evaluate and compare student learning in physics.)

The average normalized gain from pre- and post-test FCI doubled in the first year of implementing peer instruction in a calculus-based physics course. Furthermore, as the instructors refined their use of peer instruction and the choice of discussion questions (called "ConcepTests"), FCI results continued to improve (p. 971).

> The average normalized gain doubled in the first year of implementing peer instruction, and continued to grow each year as teaching methods were refined.

In 1990, the last year of traditional instruction, the FCI normalized gain was approximately 0.23. In 1991, the gain was 0.49, and that number increased every year until 1997, when it had reached 0.74. In 1998, they switched to algebra-based introductory physics, but FCI gains remained high at 0.65. In 1999, the course reverted to the traditional lec-

Case Studies & Assessments continued

ture format, and gains dropped again to 0.40. The following year, peer instruction was implemented again and the gain rose to 0.63 (p. 971).

> "No student gave the correct answer to the ConcepTests prior to discussion more than 80% of the time, indicating that even the strongest students are challenged..."

In the peer instruction courses, traditional problem solving is de-emphasized and students are required to learn and practice these skills "primarily through discussion sections and homework assignments" (p. 971). Nonetheless, students in PI classes fared better than traditionally taught cohorts on the MBT, a widely accepted assessment of physics problem-solving skills. The average score on the MBT increased "from 66% in 1990 with traditional instruction to 72% in 1991 with the introduction of PI" (p. 971). As with the FCI, student performance continued to rise as instructors refined the approach, reaching 79% in 1997. In another comparative problem-solving examination, the mean score increased from 63% with traditional instruction to 69% with peer instruction, and there were also "fewer extremely low scores" in the peer instruction group (p. 971).

In an analysis of all ConcepTest responses over the course of a semester, Crouch and Mazur found that, on average, 40% of students answered correctly both before and after peer discussion. Some 32% of students answered incorrectly at first but correctly after the discussion, while 22% of students answered incorrectly twice. Only 6% answered correctly first then changed to the incorrect answer after discussion. They also found that "no student gave the correct answer to the ConcepTests prior to discussion more than 80% of the time, indicating that even the strongest students are challenged by the ConcepTests" (p. 973).

The outcomes in the Department of Physics at Harvard are certainly convincing in terms of improved learning outcomes with peer instruction, and several other large-scale studies serve to corroborate these findings. In a variant approach to peer instruction, professors at Iowa State University attempt to achieve "virtually continuous instructor-student interaction through a 'fully interactive' physics lecture" (Meltzer and Manivannan, 2002, p. 639). Again, the use of CRS is not critical to the teaching approach, but serves to support and facilitate the methods employed.

Comparing results from students in the fully interactive ISU courses to national results on the Conceptual Survey in Electricity and Magnetism shows even greater leaps in learning than those found at Harvard. The normalized pre- and post-test gains for interactive lectures was "triple those found in the national survey," which presumably consists of a sample of students primarily in traditional lecture classes. Normalized gains for ISU interactive courses were 0.68, compared to 0.22 in the national sample (p. 648).

And finally, Richard Hake conducted an analysis of 6,000 students' results on two national physics assessments, the Force Concept Inventory and the Mechanics Baseline Test (1998). By gathering and analyzing additional data on the type of instruction offered in these students' courses, Hake found that the 14 traditionally taught courses had an average normalized gain of 0.23±0.04. By contrast, the 48 courses that used interactive engagement methods like those outlined in the previous two studies showed an average normalized gain of 0.48±0.14 (p. 71).

These studies confirm that teaching methods that encourage active and meaningful participation and engagement on the part of the student can radically transform the nature and scope of learning that takes place. While CRS was not a central component of any of these evaluations, many instructors have found that the use of CRS can simplify and streamline information gathering and display in the interactive lecture hall.

Conclusion

Classroom response systems can bridge the communication gap between instructor and students, and facilitate high-engagement lectures.

This report is intended to serve as an overview of classroom response systems, and a summary of findings from formal evaluations of various implementation scenarios.

> Audience-paced and peer instruction can have a greater impact on learning outcomes, but also require a greater degree of deviation from the traditional lecture approach.

These studies show that classroom response systems can facilitate the process of drawing out prior knowledge, maintaining student attention, and creating opportunities for meaningful engagement. They can also assist instructors in assessing student comprehension and developing classroom activities that allow for the application of key concepts to practical problems. As with other educational technologies, the most successful implementations occur when instructors set clear educational goals, and facilitate the achievement of those goals through thoughtful, engaging learning activities.

Each of the three levels of implementation discussed—classroom monitoring, audience-paced instruction, and peer instruction—can have a positive impact on the learning experience and educational outcomes when thoughtfully deployed. Audience-paced and peer instruction show the most potential for impact in terms of learning outcomes, but also require a greater degree of deviation from the traditional lecture approach.

Support

If you are an instructor at Carnegie Mellon and are interested in discussing the use of classroom response systems in your class, please contact the:

Office of Technology for Education
ote@andrew.cmu.edu
412-268-5503

Our consultants will be happy to assist you with any phase of planning, designing, implementing, funding, and evaluating the use of technology tools and strategies for teaching.

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Conclusion continued

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About the Series

The purpose of the *Teaching With Technology White Paper* series is to provide Carnegie Mellon faculty and staff access to high-quality, research-based information with regard to a given classroom technology. These papers offer a general overview of the technology topic, summarize findings from available assessments and evaluations, and give direction toward further reading and online resources.

This series does not introduce original research findings from technology assessments or evaluations conducted at the Office of Technology for Education and/or Carnegie Mellon University. The papers serve as literature reviews, intended to provide scholarly integration and synthesis of the most sound and comprehensive studies documented at the time of publication.

Available Products

Appendix One

The most predominant sales model for classroom response systems is for a single company to provide all necessary hardware and software for the system. (The most common exception is when the product is a software-only solution, designed for use on existing wi-fi or wired networks. Such solutions are discussed in more detail in the next section.)

In many cases, software and receivers are provided at little or no cost, with most profit resulting from the sales of student transmitters. Many universities choose to pass along the full or partial cost of transmitters to the students, especially where systems are widely adopted and students can expect to use a single transmitter in multiple classes.

TurningPoint, from Turning Technologies, is one of the most versatile solutions on the market. Their software integrates completely into Microsoft PowerPoint, allowing professors to author, deliver, assess, and report from within PowerPoint. TurningPoint offers infrared and radio frequency versions of their student transmitters, and simple USB-based receivers. Virtual Keypad (or vPad) is available for wireless classrooms as a software alternative to transmitters and receivers.

InterWrite also offers both infrared and radio frequency transmitters. Unlike most transmitters on the market, both the IR and RF transmitters offer high and low "confidence level" keys, allowing students to indicate how confident they are in their answers. The RF transmitter screen can display 16 characters—more text on screen at once than most other systems. This allows for a self-paced testing functionality, where students can scroll through a series of questions and answer at their own pace.

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eInstruction offers a basic, inexpensive classroom response system. Although the software was designed to be used easily with presentation software like PowerPoint, there is currently no direct integration between these applications. Similarly, while most systems integrate fairly directly with Blackboard, file manipulation is required to use eInstruction PRS data in Blackboard's gradebooks. The transmitters are fairly inexpensive to purchase, but require the purchase of a new activation code each semester. Activation currently costs $12 to $18.

Available Products

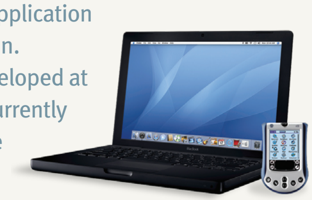
Appendix One, continued

H-ITT boasts the lowest system cost on the market. It offers only infrared transmitters, but its receivers have a wider pick-up range than most other infrared systems (a 180-degree cone, compared to 90 degrees on other systems). H-ITT comes with two separate software packages: one is used in class to collect and view responses, and the other is used to manage and grade responses over the course of the semester. Each remote costs about $25, and there are no activation fees. The receiver costs about $200, and one receiver must be purchased for every 50 remotes.

Qwizdom places heavy emphasis on the physical design of their transmitters. The large text display on both instructor and student remotes allows for one-to-one communication, a feature not supported on any other system reviewed here. Receivers and software are free, but the remotes cost about $100 apiece. The price is high compared to other transmitters, but they are intended to be purchased once and used for the duration of a student's college career.

TI-Navigator, from Texas Instruments, uses radio-frequency hubs to connect student's calculators to the teacher's PC. The system seems to focus most heavily on mathematics applications for obvious reasons, but it is unclear as to whether the calculators can be used for more general questions and polling. The system is fairly costly, pricing at around $4000 (not including calculators) for a 32-student classroom. Its advantages over other classroom response systems are specific to math applications.

Many classroom response systems are being developed solely as software applications that are designed to run over Wi-Fi on existing portable devices, like laptops and Pocket PCs. **Numina II** is a browser-based application developed at the University of North Carolina, Wilmington. **Class in Hand** is software for the Pocket PC that was developed at Wake Forest University. Both of these applications are currently free to use. For those who are more comfortable with the accountability and support of a retail product, **ETS Discourse** is the commercial equivalent.



System Comparison

Appendix Two

Infrared, radio frequency, and Wi-Fi systems each have advantages and disadvantages, and deciding which system is best depends heavily upon the needs and priorities for a given context.

System	Advantages	Disadvantages
Infrared	Infrared (IR) systems basically use the same line-of-sight technology that is used in household television remotes. They have the lowest overall equipment cost. There are no interference issues from classroom to classroom, as signals do not go beyond the walls of the room. Because the clickers must be aimed directly at the receivers in order to work (and thus have high visibility in the classroom), they also reduce the likelihood that students will bring in each other's transmitters when responses are used for attendance or participation grades.	Most IR systems often offer only one-way communication, which does not allow for confirmation when student's response has been received. They also require the placement of receivers in line-of-sight of students, which often means permanent or semi-permanent installation. Each receiver can only support between 40 and 80 transmitters (depending on manufacturer), so multiple receivers are necessary for larger classes. In very large classes, signal reception can be unreliable and have a shorter range. Clicker administration and management can also be expensive.
Radio Frequency	In radio frequency (RF) systems, the receiver does not have to be placed in line-of-sight of students, allowing for increased portability in hardware solutions. Signal reception is more reliable and has a longer range. RF systems also allow for two-way communication, so clickers can confirm when student's response has been received.	Low visibility might make it easier for students to cheat the system by bringing in each other's transmitters when responses are used for attendance or participation grades. RF clickers are more expensive than IR. There is a higher likelihood of interference issues as RF clickers can operate on the same frequencies as Wi-Fi and other RF devices. Clicker administration and management can be expensive.
Wi-Fi	Wi-Fi systems use a web-based interface for student interaction. These systems allow for text entry and open-ended responses. Students can use a wide variety of Wi-Fi devices. Uses the existing campus wireless infrastructure.	Requires students to have a Wi-Fi computing device. Fewer choices currently available in the marketplace.

Adapted from the University of Minnesota Office of Classroom Management's "Student Response Systems Overview"
http://www.classroom.umn.edu/notes/support_srs.asp