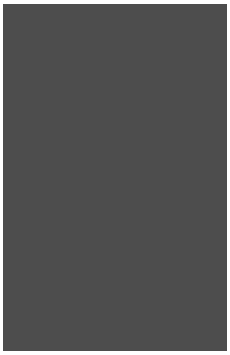

Clickers in the Classroom

How to Enhance Science Teaching Using Classroom Response Systems

Douglas Duncan
University of Colorado

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Foreword

Have you ever found yourself standing in front of your class in the middle of a lecture and wondering what in the world is going on in the minds of your students? You look around the classroom. Some students are busy scribbling in their notebooks. A few are dozing off. Many are staring blankly at the screen or blackboard. Or are they just daydreaming? You pause and ask, "Does anyone have any questions?" Silence. Those who were scribbling continue to scribble. The ones who were staring at the screen look down when they notice you looking in their direction. The ones who were dozing off now seem to be fast asleep. "Any questions?" you repeat. The lack of response is agonizing. What is going on in their minds? Did they all understand what you just told them, or are they so totally lost that they don't even know what to ask? If you are like me, chances are you will assume they are all right with the material and move on with the lecture. Most lectures are a one-way transfer of information from the lecturer to the students, and I discovered the hard way that this one-way transfer is very ineffective at helping students master information.

It doesn't have to be that way even if you have hundreds of students in your class. When I first developed the Peer Instruction method, the idea was to find a way to engage the students during class and provide myself (and them) with feedback about their understanding. Initially we used a show of hands, then flashcards. In 1993 we began experimenting with a wired network of handheld calculators to poll the students. Now, a number of commercial systems are available, and tens of thousands of students are being polled each day using wireless devices. The reasons for the explosive growth are simple: First, interactive teaching has been demonstrated to lead to considerably larger learning gains; second, after an instructor has been exposed to the feedback this method of teaching affords, it is impossible to go back to the passive lecture format and remain ignorant about what goes on in the minds of students.

If you have never taught interactively this book will introduce you interactive teaching and to the technology that is currently available to support

this method, and it will also provide you with a treasure chest of tips and pointers. Even if you are already using "clickers," as they are often referred to, you will find the material in this book to be invaluable and will discover new ways of improving your teaching technique. In either case, this book is bound to change your classes, and I am sure you will enjoy reading it as much as I did.

Eric Mazur
Harvard University

About the Author

Douglas Duncan is a faculty member in the Department of Astrophysical and Planetary Sciences of the University of Colorado, where he directs the Sommers Bausch Observatory and Fiske Planetarium. Doug began his career at the Carnegie Observatories and subsequently joined the staff of the Hubble Space Telescope. He then worked at the University of Chicago and the Adler Planetarium, beginning a trend of modernization and closer connection between research and teaching in planetariums, which has spread nationwide. He has served as National Education Coordinator for the American Astronomical Society, and in that capacity led efforts for better teaching and public communication throughout the United States. He has also served as a science commentator on National Public Radio. Doug's current focus is science education and research into "fossil stars"—which date back almost to the Big Bang.

Acknowledgments

I am pleased to dedicate this book to Mike Dubson, "father" of clickers at the University of Colorado and an unfailingly helpful and optimistic colleague—as well as the kind of science teacher all students should have. I'd like to give special thanks to Richard Rogers of the Provost's office of the University of Massachusetts, Amherst, for sharing the results obtained with clickers at UMass, and to April Trees and Michelle Jackson for sharing the results of their survey of 1,500 University of Colorado students.

My journey towards better science teaching was started years ago by Amy Southon, a particularly insightful and courageous educator, who challenged me to show whether all those smiling students leaving my lectures were learning what I wanted them to. It took me a decade, Amy, but now I know.

At CU I am privileged to have a remarkable group of colleagues who are truly dedicated and imaginative in their teaching. These include Fran Bagenal, Webster Cash, Erica Ellingson, Jason Glenn, Jim Green, Nick Gnedin, Dick McCray, Bob Pappalardo, Nick Schneider, John Stocke, Ted Snow, and Juri Toomre. Thanks also go to Noah Finkelstein, Steve Pollock, Kathy Perkins, Patricia Rankin, and Carl Weiman.

Eric Mazur at Harvard; Tim Slater and Gina Brissenden of the Conceptual Astronomy and Physics Education Research Team at the University of Arizona; Lorrie Shepard, Dean of Education at the University of Colorado; and Mary Ann Shea, Director of the Faculty Teaching Excellence Program—thank you for your inspiration. Thank you for the valuable feedback and suggestions I received from a number of reviewers including Javed Iqbal (University of British Columbia),

Adam Black, Stacie Kent, and Erin Gregg at Addison-Wesley believed my assertion that there is a lot more to clickers than pushing a button, and then helped me to produce a book I hope has broad appeal. When you are ready to write your own book, see them. They are terrific.

Finally, I am most pleased to thank all my students and teaching assistants in the courses I taught at the University of Chicago and now teach at the University of Colorado. Your thoughts, questions, and enthusiasm have challenged and motivated me.

1

Introduction

Introduction—Opportunities

You're a good teacher. You really care about whether your students learn. So as you lecture you watch their faces for clues and ask yourself, “Do they get it? Are they enthusiastic about what I'm saying?” You stop and ask them, “Does anybody have any questions?” Students nervously look at each other. No one raises a hand. Good, you think to yourself, no one had a question—they must be following my presentation and understanding the subject.

If you're an experienced teacher, you know you shouldn't make that assumption. Many students will not call attention to what they don’t know, especially in a large class. Research shows that instructors usually overestimate how much students learn. But now, *there’s a better way!* Technology has advanced to the point where classroom response systems—or “clickers”—allow a teacher to sample the thinking of all students, at any time, without students having to risk embarrassing themselves in front of their peers.

Here’s how the clicker system works. Each student has a transmitter (clicker) that looks very much like a small TV remote control. The clicker has a number of buttons labeled, for instance, a, b, c, d, and e. The classroom has one or more receivers that pick up the signals generated when a student pushes one of the buttons, and a computer equipped with appropriate software to record each student’s response. Class results are usually presented without student names attached, typically as a bar chart that can be projected in front of the classroom showing how many students answered a, b, c, d, and e.

Experience shows that the use of clickers *transforms* the classroom, mostly in very positive ways. Student involvement increases. Students are suddenly active participants in class, not merely passive listeners to a lecture. As described in Chapter 6, “Clickers and Cooperative or Peer Learning,” when students are allowed to discuss their answers with their neighbors before responding, the impact is even stronger. Another benefit is that class attendance increases. For instance, the University of Colorado

astronomy, planetary science, and physics faculty found that class attendance increased substantially, from 60–70% to 80–90%, after the introduction of clickers. The Illinois Institute of Technology (Burnstein & Lederman, 2001) reported 80–90% attendance in classes where clickers were used. Similar results have been reported from other universities. An important additional advantage to using clickers is that most faculty members enjoy the extra energy, variety, and student involvement clickers bring to a classroom.

Like any technology, though, clickers can be misused. This book will help you enjoy the benefits of clickers while avoiding the pitfalls. The wise use of clickers will help you:

a. Measure what students know before you start to teach them (pre-assessment)
b. Measure student attitudes
c. Find out if the students have done the reading
d. Get students to confront common misconceptions
e. Transform the way you do any demonstrations
f. Increase students' retention of what you teach
g. Test students' understanding
h. Make some kinds of grading and assessment easier
i. Facilitate testing of conceptual understanding
j. Facilitate discussion and peer instruction
k. Increase class attendance

The remainder of this book highlights how clickers can help you meet your own goals in teaching while avoiding pitfalls we've seen in clicker systems. See your Addison-Wesley sales representative for more information on ready-to-use questions with clickers in your particular course and technology packages they can offer you and your students.

You don't need to be an expert teacher to use clickers. You may be brand new. Or, you may be a busy researcher without a lot of time to devote to teaching, but someone who wants her or his students to really learn science. In either case, this book is for you.

While clickers may be reasonably simple to use, the benefit you and your students derive depends substantially on how you and they use them. If you restrict yourself to factual recall questions and have students answer individually, your students will concentrate on memorizing facts and may consider clicker use a waste of time. If, instead, you follow the recommendations of Chapter 6 and use clickers to facilitate peer discussions and conceptual thinking, your students' learning will be deeper and their enthusiasm will be much greater.

What to Expect

As mentioned before, clickers will transform your classroom. While doing so, they may also contradict the expectations of your students (if they haven't had a "clicker class" before); and a surprised student is not necessarily a happy student. Suddenly, their absences from class are automatically recorded. Students can't sit in the back of a large lecture hall not paying attention (or sleeping) when every student is questioned and answers are recorded several times per class. Don't expect students to automatically welcome these changes. It is essential that you discuss with them the benefits clickers bring; otherwise they may concentrate on the disadvantages and be unhappy.

The use of clickers with conceptually based questions or peer discussions, both of which we recommend, strikes at an even more fundamental expectation—what it *means* to learn. Many science classes are still taught in such a way that students can memorize what the teacher says and then later repeat this on an exam and earn an excellent grade. These students often think they've mastered a subject. Scientists know, however, that genuine understanding means taking a concept and applying it to different situations or different kinds of problems, and being able to explain it to someone else. Clickers make it relatively easy to test, immediately, if students can do so. Once again, we recommend that you discuss with your class what you expect them to know before you start testing their knowledge.

An excellent strategy with clickers is to ask thought-provoking questions and evaluate the responses. If the class is split among several different answers, tell students you are going to give them another chance to answer, but first they should turn to their right and left and discuss with their neighbors what the correct answer should be. As experienced learners know, explaining something to someone else is a great way to develop your own understanding. But pause to consider what you've done: You've just told students to *talk during class*. You are contradicting years of their schooling, and when you first suggest it, students will often think you don't really mean it. Once they discover you are serious, the classroom will erupt into animated discussion, so much so that you will probably have to raise your voice to get their attention again. As Mazur (1997) observes, these discussions usually move the group toward the correct answer rather than an incorrect one, and student understanding and retention increase tremendously. However, the active classroom—one that uses clickers, or one that uses clickers plus discussion—requires more effort than sitting and copying notes, which may surprise students. Chapter 9 discusses student opinions.

Since the changes described above are disconcerting to many students, even as they improve students' learning, it is *imperative* that you discuss your expectations of clicker use at the beginning of a term. Tell the students why they will be using them, and how they will benefit. Tell them what you

consider cheating when using clickers. Explain the topics discussed in Chapter 2 and follow the checklist in Chapter 11. You and your students will be much happier.

This book is designed to help you get the most out of clicker use. At the University of Colorado, we began using clickers in 2002 and by the spring of 2004 used 6,000 per semester. At the University of Massachusetts, Amherst, 8,000 were in use in the spring of 2004. Use is spreading quickly, and most faculty members are happy with the results. Survey results from these universities and others are presented later in this book. Chapter 2 presents reasons you should use clickers and how student learning is likely to increase as a result. Chapter 9 presents evidence that students believe clickers improve their learning and that most students enjoy using them—when they are used wisely. Some references are given for further reading and for more detailed data on student performance. The main goal of this book, though, is to be self-contained and immediately practical. Follow the advice here and you can use clickers well. They can be one of the most effective and exciting additions to teaching that you've seen in many years. Good luck!

2

Why Use a Classroom Response System?

Key Points

- Limitations of traditional lectures
- Engaging students in peer discussions
- Learning gains you can expect
- Attitude gains you can expect
- Instructors' opinions about using clickers

Limitations of Traditional Lectures

No matter how good a teacher you are, if you teach solely by lecture, you will lose the attention of many of your students just minutes or tens of minutes after your lecture has begun. An interactive system such as clickers can maintain a much higher level of student involvement.

Teachers strive to be clear and understandable, to motivate and inspire their students. We do so at least in part because we expect that it will help our students learn. Certainly a dull, unclear presentation will discourage students and prevent their learning. But it is also true that *the lecture format itself* imposes limitations on one's ability to teach. Data show very clearly that the success of even an exemplary lecture is limited by the way students learn.

One basic limitation is the attention span of passive learners. Studies indicate that the full attention of students falls off remarkably quickly—in just minutes. IBM performed a study in which the students had strong motivation to learn: All were newly appointed managers, and the classes, taught at IBM headquarters, were an essential part of their jobs. Five classes of 20 students

each were studied. Because IBM considered it important that all these students did well, the company carefully studied many aspects of the classes. Observers found that at the beginning of each class, most students exhibited attentive behavior, but that attention diminished rapidly within 20 minutes. Observers watched each student and marked whether he or she was attentive, which formed an index that was equal to 100 when every student was paying attention, 50 when half were, and so on. The average number of students paying attention during a standard lecture was 47. When the lecture was changed to a style in which the teacher actively engaged students with questions, the attention average rose to 68. The observers also noted that in a typical class, 10–20% of the students dominated the discussion. The remaining 80–90% contributed only occasionally. In an effort to improve students' participation, IBM built a prototype interactive classroom in which a student response system allowed every student to respond to teachers' questions. A computer system immediately displayed student responses in graphical form. When the same criteria used to measure students' attentiveness was applied to the classroom with student response units, the attentiveness index was found to be 83. Testing showed that the students in the class with the response system scored significantly higher than the students in the traditional classroom. Students were asked to rate how much they liked the response system, on a scale from 1 to 7, and the average was 6.6. More detail may be found in Horowitz (1988).

IBM conducted the tests described above in 1984–85. Twenty years later, technology has advanced greatly and classroom response systems are available at a fraction of the cost of the IBM prototype. But the way students learn has not changed, and studies in universities have documented that the "fade" in attention during a lecture is a universal phenomenon. Teachers can deal with this by using classroom response systems to "fight the fade" (cf. Pollock, 2004).

For more evidence that traditional lectures fail to produce as much long-lasting learning as we would like, consider the following example from Nobel Laureate Carl Weiman (2004). Weiman is a strong advocate of the use of clickers during lectures and demonstrations. He reports the following example of trying to teach how a violin works—that the body of a violin is essential for amplifying the sound of the strings. Most students have the misconception (or preconception) that the strings make all the sound.

> Explaining about sound and how a violin works. I show class a violin and tell them that the strings cannot move enough air to produce much sound, so actually the sound comes from the wood in the back. Point inside violin to show how there is a sound post so strings can move the

bridge and sound post causes back of violin to move and make sound. 15 minutes later in the lecture I asked students a question—the sound they hear from a violin is produced by a. mostly strings, b. mostly by the wood in the violin back, c. both equally, d. none of the above.

Your multiple-choice question is: What fraction of students do you think got the correct answer?

a. 0%
b. 10%
c. 30%
d. 70%
e. 90%

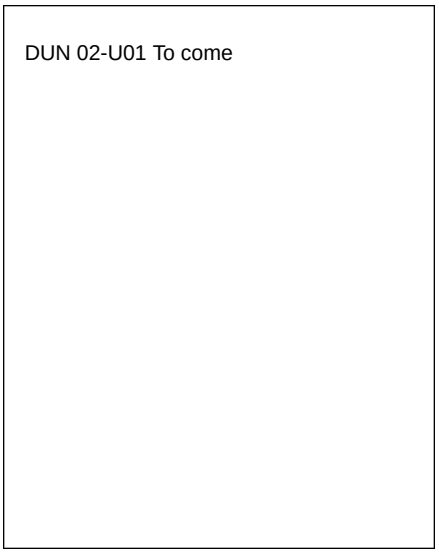
Test your own expectations and choose a, b, c, d, or e. Remember that the question was asked just 15 minutes later, and in the same lecture that the material was taught.

The result was "b." Only 10% of students gave the correct answer. This is a dramatic example of what is now widely known: An explanation, even a good, clear one (in this case with a demonstration!) often fails to reach students who have misconceptions. Something more active is needed.

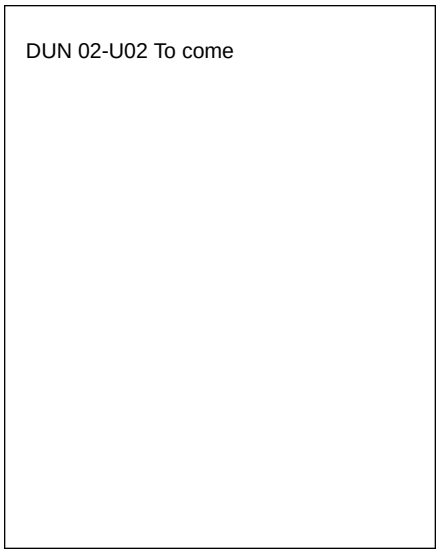
Engaging Students in Peer Discussions

Clickers are useful in fighting the "fade" of attention that occurs during lectures. Engaging students can mean more than just holding their attention, however. Clickers are ideally suited to bring about more student involvement through peer instruction or peer discussion. In this approach, teachers use clickers to survey student answers to a thought-provoking conceptual question. If the classroom response system indicates a diversity of opinion, teachers give students several minutes to discuss the question with their neighbors in the lecture hall. It has long been known that teaching someone else helps to understand an idea, and compelling evidence presented in Chapter 6 shows that this relatively easy-to-implement technique can significantly increase student learning. Appendix 2 presents evidence that peer instruction can also greatly raise interest in and enjoyment of science among nonscience majors.

As the photographs show, lecturing has not changed much in two millennia. With the advent of classroom response systems, however, that need not remain the case.



Ancient lecture hall



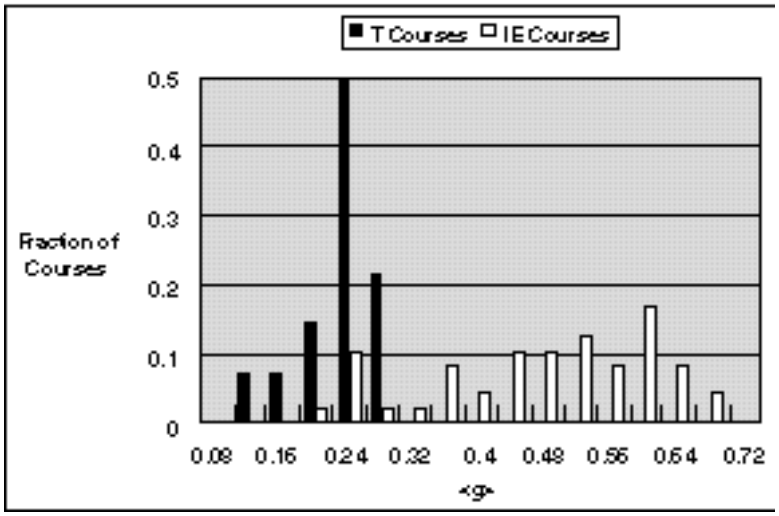
Modern lecture hall

Learning Gains You Can Expect

A large body of research shows that classroom methods that actively involve students result in substantially greater learning than pure lecturing does. Active learning methods may involve working in studio settings or on projects (e.g., McDermott et al., 2002; Laws, 2004), interactive lecture demonstrations (Sokoloff & Thornton, 1996), or peer discussions during lectures about conceptual questions—questions that probe the meaning of a subject, not just the ability to calculate. (See Appendix 3.) Clickers work particularly well with peer discussions, as described in Chapter 6.

Some of the clearest documentation of the success of more active teaching approaches can be found in physics, as the field of physics education research has been active for many years. An important aspect of that field is the existence of several testing instruments such as the *Force Concept Inventory* (Hestenes et al., 1992), which, even though they are multiple-choice tests, are generally agreed to be good probes of students' conceptual understanding. Such instruments are generally developed through research, often on the basis of interviews with many students, that identifies students' most common misconceptions. The misconceptions are then used to create the "distractors," or wrong answers, on the tests. Such tests work remarkably well in identifying whether students have learned important concepts, and the tests can be given to large numbers of students.

Hake (1998) used the Force Concept Inventory (FCI) to survey the learning gains of 6,000 students in 62 physics classes at a number of learning institutions. Since students often start with different levels of knowledge, results are reported as normalized learning gains. A "normalized gain" is the fraction of possible improvement a student achieves. For example, a student who scores 40% correct on the FCI the first week of a class could possibly improve 60% during the term. If the student achieves 70% when retaking the FCI at the end of the term, the normalized gain, $<g>$, is 30% improvement/60% possible improvement = 0.5. A key result from Hake's paper is shown here, where T marks the courses taught with traditional lectures and IE marks the courses taught with interactive educational methods.



This graph shows that even the best traditional lecture courses produced only about a quarter of the possible learning gains. Furthermore, the difference between excellent lecturers and poor ones was surprisingly small. Even the worst of the more interactive classes did better than most of the lecture classes. Hake also found that the worst interactive results all came from classes where the instructor was not well-trained in interactive methods or where there were serious equipment problems. These results certainly encourage clicker use and argue strongly for introducing at least some active methods into lecture classes.

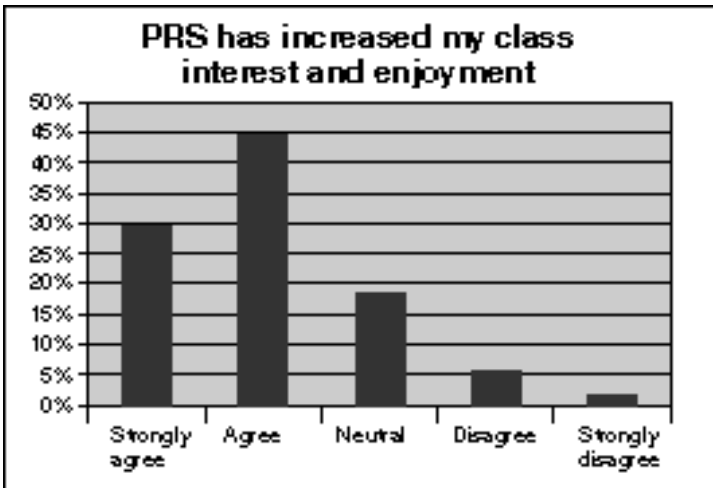
Just using clickers in class does not mean that your class will immediately achieve the results of an interactive education course. But clickers are especially well adapted for use in peer instruction, an interactive technique that is easy to start with just a small number of peer discussion questions, as

described in Chapters 6 and 7. However, the best peer instruction carefully integrates into the overall curriculum the conceptual questions students are asked to discuss and answer. Furthermore, as mentioned in Appendix 3, midterm and final exams are designed to test conceptual knowledge. Our advice is to start with a limited number of clicker questions, evaluate how happy *you* are with the results, and proceed from there.

Attitude Gains You Can Expect

Although the main goal of instructors is for students to learn, student attitudes toward your subject should not be ignored. If we truly believe that learning is a lifelong process, we will be happier with a student who leaves a course thinking the subject matter was interesting and involving rather than one who leaves thinking it was irrelevant and boring. Appendix 2 presents a compendium of the comments of students in a large lecture course when peer discussion was introduced. Because the course was taught for 4 years before clickers were available, the comments were engendered by peer instruction, not clicker use. It is clear that these nonscience majors found peer discussion involving and interesting, and equally clear that previously they had not felt that way about science classes.

At the University of Massachusetts, students were directly asked how clicker use affected their class enjoyment. Typical results for a class of several hundred follow.



Instructors' Opinions about Using Clickers

Most instructors are enthusiastic about using clickers and feel that some practice makes the experience better. The following typical verbatim comments are from the survey of Trees and Jackson (2003):

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

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

> "Compared to . . . conventional lectures it's a world of difference—more engagement, better feedback in both directions, makes large classes feel much smaller."

> "Students did seem really interested in seeing how the questions were answered by their classmates. They would react when they saw the graph."