Excerpted from:

# QUESTION DRIVEN INSTRUCTION: TEACHING SCIENCE (WELL) WITH AN AUDIENCE RESPONSE SYSTEM

Ian D. Beatty, William J. Leonard, William J. Gerace, and Robert J. Dufresne

*Physics Education Research Group*
*Scientific Reasoning Research Institute & Department of Physics*
*University of Massachusetts*
*Amherst, Massachusetts, USA*

## INTRODUCTION

Educational use of audience response systems (ARSs), a.k.a. "classroom response systems," is exploding in high schools and universities. One vendor claims over a million of their system's keypads have been used, in all 50 U.S. states and 10 countries worldwide, in thousands of K-12 schools and hundreds of universities (eInstruction, 2005). Several universities are beginning centralized programs to introduce and coordinate response system use across campus. A fringe technology ten years ago, ARS are entering the mainstream.

ARS have the potential to radically alter the instructional dynamic of our classrooms and impact student learning. However, for an instructor to realize this potential requires much more than merely learning to operate the technology. Response systems are a tool, not a solution. Their benefits are not conferred automatically; *how* they are used matters tremendously. To be fully effective, their use must be integrated into a larger, coherent pedagogic approach.

As part of the UMass Physics Education Research Group (UMPERG), we have worked with response systems for over a decade. In 1993 we began using *Classtalk*, a groundbreaking "classroom communication system" by Better Education Inc. In 1994 we received a U.S. National Science Foundation (NSF) grant (DUE-9453881) to deploy, develop pedagogy for, and study the impact of *Classtalk* (Dufresne *et al.*, 1996). In 1998 we began *Assessing-to-Learn*, an NSF-funded project (ESI-9730438) to seed response systems in secondary school physics classrooms and help teachers develop suitable pedagogic skills and perspectives (Beatty, 2000; Feldman & Capobianco, 2003). In 1999 we brought EduCue *PRS* (since purchased by GTCO CalComp and renamed *InterWrite PRS*) to UMass and began its dissemination across campus. As a sequel to *Assessing-to-Learn*, we are beginning a five-year NSF-funded project (ESI-0456124) to research secondary school science teachers' learning of response system pedagogy. Based on twelve years of experience with ARS — teaching, researching, and mentoring — we have developed a comprehensive perspective on the effective use of such systems for the teaching of science at both the secondary school and university levels.

In this chapter we will introduce that perspective. We will not attempt to describe how response systems work, report our personal experiences using them, or discuss detailed

Chapter 7 of *Audience Response Systems in Higher Education: Applications and Cases*, edited by David A. Banks. Idea Group Inc., Hershey PA. ISBN 1-59140-947-0 (hardcover), 1-59140-948-9 (paperback), 1-59140-949-7 (e-book). Preprint.

**Designing Questions**

The criteria for an effective QDI question are quite different from those for exam, quiz, and homework questions, and questions for formative assessment use should be engineered with great care. Elsewhere, we detail a theoretical framework for designing questions (Beatty *et al.*, submitted). In this section we present some general principles and suggestions.

Every question should serve an explicit pedagogic purpose: a specific activity to induce in students' minds, not just a piece of topic mater to cover. For example:

- Drawing out students' background knowledge and beliefs on a topic;
- Making students aware of their own and others' perceptions and interpretations of a situation;
- Discovering particular confusions, misconceptions, and knowledge gaps;
- Distinguishing similar concepts;
- Realizing connections or similarities between different concepts;
- Elaborating the understanding of a concept; and
- Exploring the implications of an idea in a new or extended context.

Computational or simple factual questions, and those that probe memory rather than understanding and reasoning, are of little value. Questions that have students compare two situations, or make predictions and explore causal relationships, are particularly powerful. Good questions push students to reason qualitatively and draw conclusions from a conceptual model. If an instructor can anticipate likely misunderstandings and points of confusion, she should design questions to "catch" students in those, get them articulated, and resolve them through discussion.

Unlike exam questions, ARS questions for QDI benefit from ambiguity. An ambiguous feature sensitizes students to the feature's importance and implications, teaches them to pay attention to subtleties, and motivates discussion of what aspects of a question are important and how they matter. In this way, students can be led to contemplate not just one question but a family of related questions. Similarly, including irrelevant information or omitting necessary information can be beneficial, helping students learn to evaluate what information an answer requires. Questions need not be "fair" or even well defined, since we seek not to evaluate students but rather to help them learn to reason, think defensively, and answer future questions — especially the vague, fuzzy kind often encountered outside the classroom. (However, some questions should be straightforward and provide students with confirmation that they do in fact "get" a particular topic: this is useful feedback to them, and also good psychology.)

A question that elicits a spectrum of answers is generally more productive than one all students agree upon: it provides fodder for discussion and disagreement, leading to engagement and learning.

When designing sets of related or sequential questions, instructors should remember that students experience significant "cognitive load" when reading and interpreting a new scenario. Reusing a situation for multiple questions is efficient, allowing students to concentrate on the relevant aspects of the question at hand and realize the implications of features that do change. Conversely, asking questions with the same conceptual content set in completely different circumstances helps students learn to see through a situation's "surface features" to its "deep structure," and to distinguish the core principles from the details.

When and how a question is presented can shape the depth, quality, and character of resulting student thought and interaction. Students tend to assume that the question relates to whatever has recently transpired in the course, and will apply knowledge accordingly. This can lead to "pigeonhole" learning in which concepts are assimilated chronologically and only accessible within a narrow context, rather than being organized into an interlinked, versatile hierarchy. A careful instructor will mix questions of varying types and topics, and include integrative questions that connect recent ideas with earlier ones.

**Classroom Management**

Perhaps the most initially daunting (and ultimately exhilarating) aspect of QDI is the necessity of giving up control of the classroom. A lecture is predictable and controlled, with attention safely focused on the instructor. QDI, however, necessarily turns the classroom over to students for dialogue and debate. We must learn to manage the apparent chaos rather than attempting to rigidly control it. Furthermore, the principle of "agility" means we must be prepared — even eager — to modify or discard a lesson plan and extemporize.

Some basic attention-management techniques help considerably. For example, one challenge is to recapture students' attention after they have been discussing a formative assessment question among themselves. An ARS helps dramatically here: by collecting answers (with a time limit) and projecting the resulting histogram on a large screen, attention is redirected to the front of the classroom. Students are naturally curious about each other's answers. Another challenge we face is determining how much time to allow students for small-group discussion of a formative assessment question. Noise level is a clue: when a question is shown, the class is initially quiet as students read and digest it; the noise level then rises as they discuss the question, and begins to fall as they reach resolution. This is an appropriate time to collect answers, display the histogram, and begin the whole-class discussion.

Encouraging students to speak up during the whole-class discussion is crucial. When soliciting volunteers to argue for various answers, we should maintain a strict poker face and not divulge which answer (or answers) is (or are) correct (if any). Allow the students to challenge each other's arguments. If nobody will defend a particular position, ask if anyone else will speculate on the reasoning that might lead to such an answer. (Nothing motivates a student to speak up like having someone else misrepresent his position.) Paraphrasing a student's statements can be valuable, perhaps even necessary in an acoustically challenging room, but we must be careful to stay as close as possible to the student's vocabulary and check with the student that the paraphrase is satisfactory.

When we decide to drop our poker-face and offer a little illumination of our own, we should downplay notions of "correct" and "incorrect" lest we focus students' attention too much on getting the right answers rather than on reasoning and understanding. Instead of commenting that a particular answer or argument is wrong, we can often say “that would be correct *if*…”, indicating some similar situation or question for which it would be valid. This is not only less disconfirming to the student and less deterring to others, it is also more pedagogically productive for all the reasons that “compare and contrast” questions are powerful. We have found that often, students who appear to be offering a wrong answer are instead offering the right answer to the wrong question. Unless they are sensitized to this, telling them they are simply incorrect is confusing rather than enlightening.

Moderating a whole-class discussion presents us with the great danger of making the class instructor-centered rather than student-centered. Working from within students’ perceptions and arguments, rather than making assertions from authority, helps to avoid this. Similarly, if a question contains ambiguities or errors, allowing students to discover these or drawing them out during discussion is preferable to announcing corrections as the question is presented. We should strongly resist any temptation to read a presented question out loud or to talk while students are engaged in small-group dialogue and answering. If we seek active learning, we must give them space to do it!

**Tactical Decisions: Modeling Students’ Needs**

Though managing the classroom may be the most daunting aspect of QDI, modeling a class-full of students and deciding how best to interact with them is the most enduringly difficult aspect, and it is the very heart of the approach. It requires two distinct skills: modeling and interacting with an individual student, and handling an ensemble of individuals in parallel. Neither comes easily, and both can be truly mastered only by repeatedly trying, occasionally missing the mark, reflecting, and trying again. However, we offer some general advice to help the interested instructor get started.

Interacting “agilely” with a student is a modeling process closely analogous to the scientific method: observe, form a model, make a prediction based on the model, test the prediction, refine the model, and iterate (Gerace, 1992). In this context, we want to model both the student’s knowledge (especially the gaps) and her thinking processes (especially the weaker skills). In contrast to a traditional lecture, we must practice “active listening”: listening carefully and patiently to what she says and how her responses, questions, and other behaviors vary from what we expect. Even when we think we know what she is in the process of asking, we should let her finish: both out of respect and because every nuance of her utterance is valuable data. We will often answer a question with a question, not just rhetorically but to understand better why the student needs to ask hers. Our goal is not to answer her question, but to understand why she needs to ask it.

Rather than concentrating on the knowledge we wish to communicate, a less direct approach is often more effective: trying to figure out what prevents her from understanding, and then attacking the obstacles. This sleuthing out of the roots of confusion is an iterative and thoughtful process on our part. Of course, a rich knowledge of pedagogic theory and common points of confusion are useful. If we find ourselves stumped trying to help an individual, other students in the class can assist. They can often understand their peers better than we.

Clearly, carrying out such an attention-demanding, thorough process with every student in a full-sized class is impossible. We must try to track an array of typical or likely student mentalities, test the class for the accuracy of this array, and teach to it. For example, if a formative assessment question elicits a range of answers, we can ascribe a putative explanation to each one for why a student might select it, and that becomes our working model. Since we have probably prepared the answer set in advance, we should already have ideas about why each answer might be chosen. The distribution of class answers "fits" the model to the class.

This approach does not attach a model to any specific individual in the class. A complementary approach is to identify certain students as representatives of various sub-populations within the class, and then build and maintain as rich a model as possible of each. This can be very powerful: it is easier for us to think in detail about a real, specific individual than an abstract entity, and yet students generally have enough in common that by addressing one student's needs, we impact many. As a side benefit, the more we treat students as three-dimensional individuals, pay real attention to them, and try to understand their thinking, the more they will believe we care about them personally and are "on their side," and the less adversarial the instructional dynamic will be.

**Coaching**

QDI requires students to adopt a role they might not be accustomed to from more traditional instruction. Our experience is that the vast majority of students express positive feelings about ARS use and QDI after they have adjusted to it, but this adjustment takes time, and some initially greet it with fear and resentment. Students habituated to success under traditional instruction are most likely to be hostile: they have "mastered the game," and now the rules are being changed. Others object out of simple laziness: they are being asked to engage in thought and activity during class, and that is effortful and at times frustrating. They are also expected to complete assignments beforehand so as to be prepared for class. Many are uncomfortable with the idea that they are accountable for material not directly presented in lecture. Inducing students to become participating, invested learners is vital to the success of QDI, and meta-communication is our most powerful tool for achieving that. We can explain to students why we are doing what we are doing, at both the immediate and strategic levels, and how students will benefit. We can talk frankly about the obstacles students will likely encounter and how they can most effectively surmount them. In other words, we can explicitly address learning and communication as part of the "course material."

Some student perceptions merit particular attention. Initially, students will probably view formative assessment questions as mini-tests to be passed or failed. If this attitude is allowed to persist, it will sour them on the formative assessment approach and prevent them from fully and constructively engaging in the process. We must explicitly discuss the purpose of formative assessment and stress that the point is not to answer correctly, but to discover previously unnoticed aspects of the subject and of their own understanding. We must consistently reinforce this position by deemphasizing the correctness of answers and emphasizing reasoning and alternative interpretations. Assigning course credit for "correct" answers is massively counterproductive.

**Tactics for Questions** FTEP Learning goals workshop, February 2006

Here are some common tactics that may help you write questions to assess learning goals. (Beatty, 2005)

1. Remove inessential details to focus students' attention where you want it.

2. Have students compare two things. Their attention will naturally be drawn to the differences between them.

3. Ask a familiar question about an unfamiliar situation to draw students' attention to the ways the new situation differs from a familiar one.

4. Ask a series of two questions. The first is a trap intended to make students commit a common error. Before reviewing the first question, ask a second which makes them aware of the error they have just committed. This technique can help them discover the mistake they made.

5. Require students to use different representations. Ask them to explain in words the meaning of a mathematical formula. Ask them to use information from a graph in a mathematical formula. Ask them to graph data in a table.

6. Present students with a set of processes or objects and ask them to determine subsets within the items presented.

7. Direct the strategy to force students to use more than one method. If students commonly solve a type of problem one way, require that they use a different method.

8. Include extraneous information or omit necessary information so that students think more carefully about what they need to solve the problem. If they are always provided with only the information needed, an important part of the problem solving has been done for them. "Not enough information is given" can be the correct answer for some questions.