Classroom Response and Communication Systems: Research Review and Theory

Jeremy Roschelle, SRI International
William R. Penuel, SRI International
Louis Abrahamson, Better Education, Inc.

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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

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Interest is growing in technologies that generalize and extend earlier "response systems" and "classroom communication systems," and enable teachers to improve instruction in classroom- or lecture hall-sized groups. Researchers report that instructors use the novel technological capabilities to enhance questioning and feedback, to motivate and monitor the participation of all students, to foster discussions of important concepts, and to energize and activate students' thinking. In their foundational summary of cognitive science and education, *How People Learn*, as well as in a subsequent paper, Bransford and colleagues cite this technology and the related pedagogy as one of the most promising for transforming classrooms to be more learner-, knowledge-, assessment-, and community-centered (Bransford, Brophy, & Williams, 2000; National Research Council, 1999). But as yet, research has taking place by researchers in different sub-communities, with little cross-fertilization and synthesis. As a step towards advancing future research, the first half of this paper presents our review of the research literature, particularly with regard to the popular use of these systems to enhance questioning and feedback. In the second half, we formulate tentative theoretical connections that could explain how pedagogy and technology together realize multiple desirable outcomes (see Figure 1).

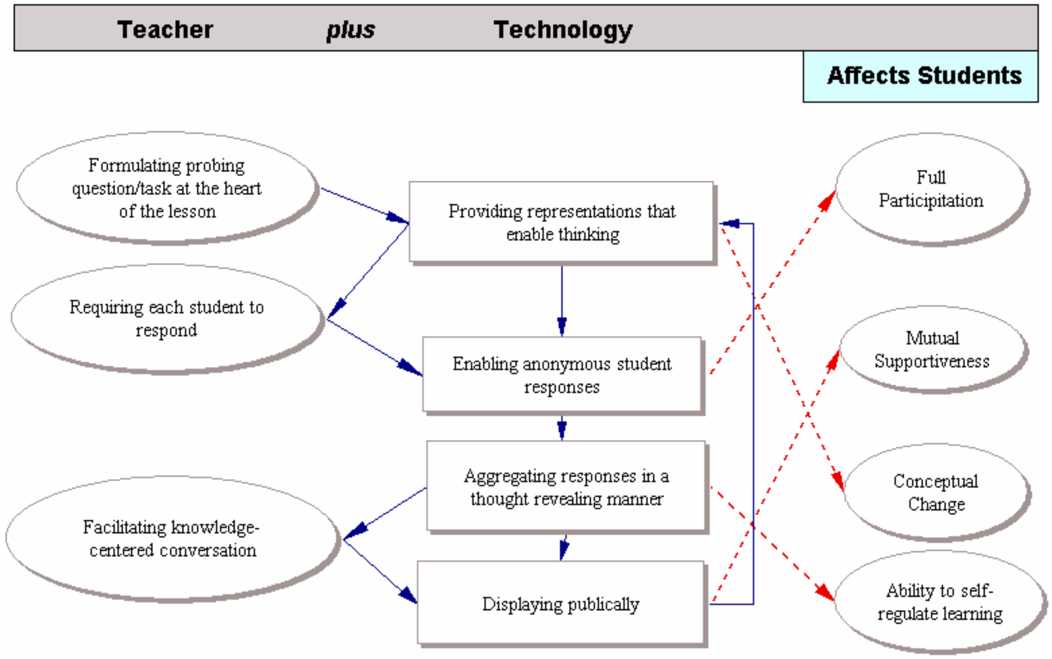

Figure 1: CATAALYST Pedagogy and Technology Integrate to Enhance Learning

CATAALYST

We have dubbed the mature form of this technology CATAALSYT, standing for "Classroom Aggregation Technology for Activating and Assessing Learning and Your Students' Thinking." It represents an expansion of earlier "response systems" technology to include an extensible set of subject-matter-specific representations.

The core capabilities of this technology allow the teacher to more efficiently and effectively:

1. Present a probing question at the heart of the subject matter.
2. Gather student responses rapidly and anonymously.
3. Quickly assemble a public, aggregate display (e.g. a histogram) that makes salient the variation in the group's ideas without disclosing individual contributions.

Review of the literature

Our goal was to understand what aspects of CATAALYST pedagogy might be ready for research on questions of systematic effectiveness. We found one well-developed strand that focuses on teacher questioning and feedback. Other, more advanced strands of theory, technology, and pedagogy are in active development (e.g., Hegedus & Kaput, 2003; Stroup et al., 2002) and could be synergistically integrated later. Our review organizes the existing literature on the "questioning" strand according to three conditions:

1. Success in addressing an important problem.

2. Converging evidence from a variety of settings.
3. A theory adequate to guide replication and generalization.

With regard to condition 1, we found ample converging evidence that supports a relationship between CATAALYST and student outcomes, particularly in physics, where a well-calibrated measure of conceptual change is available. Conceptual change is known to be an important and difficult classroom outcome to achieve (Confrey, 1990; McDermott, 1984; Smith, diSessa, & Roschelle, 1993). Mazur shows 10 years of continuous improvement in the pretest/posttest gains by successive classes of students on the Force Concept Inventory using his Peer Instruction pedagogy (Crouch & Mazur, 2001; Fagen, Crouch, & Mazur, 2002; Mazur, 1997). This pedagogy includes attention to motivation and adaptation of the lesson plan in response to formative assessment. At its heart is a practice of focused teacher questioning, aggregation of responses, and use of a public display of those responses to foster high-level reasoning among learners. Investigators have also documented a variety of improvements in student attitudes and classroom participation using related pedagogies with response systems (Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996).

With regard to condition 2, we found that consistent findings have been reported in a wide variety of settings beyond undergraduate physics. University settings include mathematics, physics, chemistry, biology, premedical education, business, and computer science. K-12 settings include middle school and high school mathematics, physics and chemistry, as well as elementary, middle school, and high school reading. A total of 26 studies report outcomes (listed in full paper). The most commonly reported outcomes are: greater student engagement (16 studies), increased understanding of subject matter (11), increased enjoyment of class (7), better group interaction (6), helping students gauge their own understanding (5), and teachers have better awareness of student difficulties (4).

This body of evidence, taken together, is suggestive of a real and important phenomenon at hand. However, none of the available studies rises to the present specification of "scientifically based research" that would allow inferences about causal relationships or that could form the basis for estimating the magnitude of the effect.

With regard to condition 3, our review found that existing research does not connect with the larger research base in education or psychology, which could be used to create an explanatory theory or model. We turn to this limitation in the next section.

Connections to a Broader Educational and Psychological Literature

We have developed three connections to prior bodies of theory and evidence, selecting for inclusion bodies of work that (a) deeply relate to reported CATAALYST phenomenology, (b) have been associated with strong effects on student outcomes in the literature, and (c) can provide guidance to further CATAALYST research.

1. Formative Assessment through Questioning and Feedback

Classrooms proceed through a sequential curricular structure. In most cases, the transition from topic to topic occurs merely because time has elapsed, without feedback to the teacher that the current topic has been mastered. Students receive little feedback before the examination. Against this background, one of the classroom interventions known to have the greatest impact on student outcomes is formative assessment (Black & Wiliam, 1998; Fuchs & Fuchs, 1986). When questioning and feedback is frequent and involves students actively in reflecting on what they know and how they learn, and when assessment data are used to inform and adjust the course of instruction, formative assessment can produce large gains (Black & Wiliam, 1998).

Formative assessment deserves to be the base of our theoretical account because the most obvious thing that CATAALYST does is to increase the ease with which teachers can engage all students in frequent formative assessment. Connecting CATAALYST to formative assessment makes a large literature on the quality of questioning and nature of feedback available to guide practice (Brady, Taylor, & Hamilton, 1989; Dillon, 1984; Gall, 1984; Lemke, 1990; Redfield & Rousseau, 1981; Samson, Strykowski, Weinstein, & Walberg, 1987).

2. Building Concepts through Contrasts and Student Discussion

The formative assessment literature does not tell us why CATAALYST innovators use particular representational forms to aggregate student responses— e.g., a histogram in early uses and, more recently, overlaid images or Cartesian coordinate systems. We propose understanding what kinds of representations work best for a questioning-oriented pedagogy in terms of two kinds of important contrasts:

1. Contrasts among ideas that are strongly related to the target concept.
2. Contrasts between an individual student’s idea and the ideas of the group.

In both cases, we use “contrast” to mean both similarities that have a positive relationship to the target concept and differences that have a negative relationship to the target concept.

The first kind of contrast (among instances in a domain) was studied extensively in early cognitive psychology, which showed that learners can induce a novel category rapidly (e.g., “blue squares”), when given a well-chosen sequence of cases (Ross, 2000; Smith, 1989). However, although practitioners use representations that highlight important contrasts, they do not display enough instances for induction to be the main mechanism at work. Well-selected contrasting cases, however, can help guide interpretation and create a basis of readiness for future learning. Experimental results show that contrasting cases prepare students to learn more from subsequent elaborations (Bransford & Schwartz, 1999).

In the case of CATAALYST, the second kind of contrast, in which each student sees his or her contribution in the context of the group aggregate is also prominent. We conjecture that this second contrast complements the first and results in better self-regulation— students are more able to engage with and make sense of feedback when it is feedback when they have thought about first and when they have a personal stake in the outcome (Butler & Winne, 1995). Indeed, engaging with cognitive conflict (or making prior knowledge visibly problematic) is an important prerequisite to conceptual change (Posner, Strike, Hewson, & Gertzog, 1982; Webb & Palincsar, 1996).

It could be that contrasts are sufficient to enhance achievement, but reports from the use of CATAALYST suggest that discussion (which may be among peers, small groups, or the whole class) emphasizing argumentation, elaboration, explanation, and comprehension is another essential element of the pedagogy. We conjecture this is necessary because the target concepts in science and mathematics are not as simple as “blue square”—learners must work out the relationships of a big idea to many supporting knowledge elements (Ausubel, 1965; diSessa, 1993; Minstrell, 1992). In learning about kinematics, for example, conversation can lead to “convergent conceptual change,” in which students guide each other, seeking a suitable differentiation and integration among the many ideas that comprise knowledge of the central idea (Roschelle, 1992; Webb & Palincsar, 1996). Further, research has demonstrated that appropriate technology-based representations can enhance both the quality of students’ discussion and what they learn (Cohen & Scardamalia, 1998; Hsi, 1997; Pea, 1994; Ryser, Beeler, & McKenzie, 1995; Suthers & Hundhausen, 2003). Tools that support manipulating dynamic notations and models are particularly important in mathematics (Kaput, 1992) and science (Penner, 2001). These tools were not available in simple response systems, but they are available in CATAALYST. We see CATAALYST as catalyzing the base conditions known to be necessary for successful group learning of mathematics and science.

3. A Shift to Mastery-Oriented Motivational Incentives

The first two elements of our theory seek to explain why CATAALYST improves achievement, but do less to explain why CATAALYST creates greater engagement and broader participation. Motivational “goal theories” focus on analyzing students’ reasons for engaging in achievement activities (Pintrich & Schrauben, 1992). Students pursue two major kinds of goals: “performance” goals, in which learners seek to maintain positive judgments of their ability and avoid negative judgments, and learning or “mastery” goals, in which students seek to increase their ability or master new tasks (Elliott & Dweck, 1988). Across a range of studies, researchers have found a consistent pattern: the adoption of learning goals tends to help students of all ability levels sustain engagement in a task, but the adoption of performance goals for low-ability students tends to lead them to avoid challenging tasks and attribute failure to poor ability rather than to their level of effort (Elliott & Dweck, 1988). Students’ individual goal orientations, moreover, can be shaped by powerful educational interventions like CATAALYST, especially in cases where students perceive classroom goal structures to be more learning or mastery focused (Ames & Archer, 1988; Griswold & Urdan, 2001; Maehr & Midgley, 1991).

We conjecture that CATAALYST facilitates students’ adoption of learning or mastery goals by highlighting the differences among ideas while at the same time downplaying the individual ownership of those ideas. CATAALYST displays can reduce what motivation theorists call “performance avoidance” goals, the desire to avoid the embarrassment of a poor performance. Second, CATAALYST questions tend to be used in a formative rather than summative fashion: students are expected to use the questions as challenging prompts for thinking rather than as opportunities to display competence.

Finally, CATAALYST creates accountability for all students—the teacher knows whether all students contributed and can see what each individual student contributed, if she likes. Thus, the powerful push of individual accountability is combined with the powerful pull of a focus on the quality of ideas, not the status of individual students (Davis, 2002).

Educational and Scientific Importance

Presentation of this review at AERA could be educationally important because the main effects of CATAALYST appear to address important educational concerns, such as enhancing student achievement, interest, and participation, and the converging evidence looks promising. Further, the underlying technology is becoming increasingly mature: robust, powerful, and affordable. We believe our review is scientifically important because we have connected the findings about CATAALYST coming from practitioners to a broader scientific and education literature, thus supporting additional research going forward.

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