CATAALYST

WORKSHOP REPORT:
ADVANCING RESEARCH ON THE TRANSFORMATIVE POTENTIAL OF INTERACTIVE PEDAGOGIES AND CLASSROOM NETWORKS

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Executive Summary

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

SRI International, in collaboration with the Better Education Foundation, hosted a conference to bring together a diverse group of educators, researchers, and industry representatives with two purposes:

1. To share knowledge among educators, researchers, and industry representatives who are experts with CATAALYST but who did not yet know each other.
2. To generate a research agenda that could provide educational leaders with implementation guidance and policy-makers with evidence of the effectiveness.

Leading experts in CATAALYST pedagogy, materials, and technology from different disciplinary backgrounds were invited; 95% of those invited were able to attend. Despite the thematic similarity of their work, many of the experts had never met. Participants gave the conference high ratings on an evaluation survey and unanimously urged NSF to fund further research and conferences in this area.

The conference mapped a range of dimensions along which CATAALYST implementations differ, including:

- Capabilities of the technology (from simpler response systems to more advanced classroom networks)
- Variations due to differing subject matter content and instructional objective
- Orientation to more content-neutral or content-rich technological capabilities
- Orientation to a feedback-oriented cybernetic metaphor (convergence) or a generativity-oriented complex systems metaphor (divergence) in pedagogy

The participants considered whether these dimensions were too diverse to make a single conference sensible, but determined that underlying commonalities across these variations—such as formative feedback, public displays, and their implications for teaching and learning—outweighed the divergent elements. In addition, researchers focusing on the various technology, content, and pedagogical models all appeared to agree that cooperation and collaboration would strengthen their research. One implication, however, is that no single study can do justice to the richness of CATAALYST phenomena in K-12 and university classrooms.

The conference also provided a forum for reflecting on the appropriateness of several cornerstone theoretical concepts as central elements of future research:

- "Formative assessment" was seen as a very strong construct for organizing future research for many traditional CATAALYST pedagogies, but was problematic for some advanced uses that focus on generativity and complex subject matter.
- "Shared public displays" were a cross-cutting element of all CATAALYST uses described. These displays comprised of student contributions to a shared problem and were used to drive deeper discussions among students. Cognitive and discourse analysis of these displays should be a strong feature of future research.
- Changes to "Motivation" and "Participation" were discussed throughout the conference, and some experts in these research areas were able to provide detailed accounts of how these constructs might apply and be measured in CATAALYST classrooms. Overall, however, the community had difficulties speaking about motivation and participation in concise, theoretically informed ways. Future work is needed to clarify the conception and operationalization of these constructs in further research.
- Participants using newer CATAALYST systems for complex subject matter articulated their theory in terms of "Generativity," "Agency," and "Harnessing Diversity." Further development of these constructs could be beneficial to studies of all CATAALYST uses.

Two important classes of research opportunities emerged in the conference. On the one hand, preliminary research has reached a point were Implementation and Effectiveness Research is now feasible. In addition to their knowledge of which main effects to look for in CATAALYST classrooms, the assembled experts have considerable sophistication in describing likely performance curves in CATAALYST implementations, the ways in which implementations might fail, the conditions necessary for success, and appropriate approaches for teacher professional development. Participants were interested both in effectiveness research (per NCLB) and research to address equity concerns within classrooms. On the other hand, participants recognized that existing learning theories and experimental designs may not be adequate for explaining the rich and interconnected phenomena observed in CATAALYST classrooms. Turning this to their advantage, this group proposed that the CATAALYST classroom could be an ideal laboratory for the development of a 21st Century Science of Learning. Such a theory of learning would give a better account of the complexity of social, emotional, personal, and cognitive interactions in a CATAALYST classroom, while yielding an account of the gradual transformation of classroom climate when teachers use CATAALYST over time.

Participants were eager for NSF to recognize the importance of CATAALYST in future competitions, and one team (including people who met for the first time at the conference) has submitted a proposal to IERI. Participants were also eager for NSF to sponsor further conferences and communications networks for scholarly exchange.

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Introduction

Classroom network technology holds significant promise for transforming whole-group instruction in science and mathematics, both in K-12 and university instruction. Research on pedagogically appropriate use of classroom networks, often referred to as "classroom communication systems" or "student response systems" describe improvements in students' content knowledge, motivation, and engagement as well as classroom participation (see Roschelle, Penuel, & Abrahamson, 2004). Newer, advanced applications of this technology provide students with different kinds of encounters with subject matter, allowing students to generate and contribute individual mathematical and scientific representations to a group display; this allows the teacher and students to discuss more complex and conceptually difficult subject matter (Kaput & Hegedus, 2002; Stroup, 2002). We have termed both older and newer pedagogical applications of this technology CATAALYST, "Classroom Aggregation Technology for Activating and Assessing Learning and Your Students' Thinking" because of the promise shown for improving teaching and learning. We use CATAALYST to refer simultaneously to the technology and the pedagogy it enables, as all prior reports agree that the teacher's role is significant and the technology should not be considered an isolated factor.

The National Science Foundation has invested over $11 million in applications of CATAALYST for improving STEM education. For the most part, the investment has been in the development of materials and in descriptive research. Descriptive research answers questions about "what is happening?" in classroom when teachers and students use CATAALYST. Our review of this research (Roschelle, Penuel, & Abrahamson, 2004) found that it points to consistent main effects—both student achievement and participation levels improve when teachers implement CATAALYST well. These main effects, however, have yet to be tested with an appropriate experimental research design. Moreover, little systematic implementation research exists that explores how CATAALYST instruction produces results described in the extant studies. New, more systematic research could have important implications because purchase and implementation of CATAALYST technologies are rapidly accelerating at both the university and K-12 levels. Effectiveness and implementation research is now needed.

Researchers and educators who have been studying and using CATAALYST come from many different fields, and do not all share common methods, theories or social networks. They include mathematicians (Kaput & Hegedus, 2002), physicists (Hake, 1998), learning scientists (Bransford, Brophy, & Williams, 2000), and communications researchers (Davis, 2002; Trees & Jackson, 2004). Users of classroom networks, including many university professors, have conducted their own research and developed pedagogies for effective use of the technology (see, for example, Mazur, 1997). Vendors of network technologies have also conducted their own studies (Robinson, 2002). From one vantage point, these different people share many attributes of a community—a common set of tools, strategies for using the tools that bear close resemblance to one another—but have not yet organized to produce the effectiveness or implementation research currently needed.

Conference Background

SRI International, in collaboration with the Better Education Foundation, designed and facilitated a conference that would bring together a diverse group of educators, researchers, and industry representatives to chart a research agenda for the future of classroom networks. The conference, as well as follow-up work to design more rigorous studies of the effects of classroom networks, was funded through the National Science Foundation's ROLE program (EHR/REC# 0337793).

The conference had two purposes: (1) to encourage knowledge-sharing among the community of educators, researchers, and industry representatives familiar with network technologies and (2) to generate an agenda for research that could provide policy-makers with evidence of the effectiveness of classroom networks. To encourage knowledge-sharing, we designed a conference agenda to maximize opportunities for participants to speak and interact in a range of session formats. To generate a research agenda, we organized the conference agenda to move from level setting through establishing a common theoretical vocabulary to developing outlines for research on the effectiveness of networked classrooms.

Our intent was to elicit ideas from experienced practitioners and learning sciences researchers for our own future work and also to foster thinking toward a broad, diverse array of research designs for studying the phenomena associated with classroom network technology and teaching. A total of 46 people attended the conference, including the PI team and six staff from SRI who served as "critical friends" to the community. The group included representatives from industry, research and development organizations, universities, and K-12 schools. Table 1 below lists the number of participants by institution, and the Appendix lists each of the participants and their affiliations. An informal survey revealed that despite the fact that most attendees had been active in research on this topic for 5–20 years, most attendees met each other for the first time at the conference.

Table 1. Number of Participants by Institution Type

Institution	Number
Industry Representatives	8
K-12 Teachers	4*
University Faculty	23
Research and Development Groups	11

** One attendee, a recently retired high school teacher, is now a university faculty member. For purposes of this report, he is counted as a K-12 teacher.*

Representatives of NSF were invited but were unable to attend. K-12 teachers represented the high school level only, an important omission in view of eInstruction reports that many of its customers are at the elementary level. One of the researchers present, Fred Hartline, and one industry representative, Steve Robinson, have conducted studies of classroom networks at the elementary level and shared their experiences.

Efforts were made to ensure that discussions and research designs considered the possible impacts of classroom networks on groups historically underrepresented in

STEM professions. As part of our panel presentations, we included discussions of how diverse classroom identities might shape participation in CATAALYST classrooms and asked project consultant Na'ilah Nasir, whose research focuses on this topic, to prepare a paper ahead of time for the group to consider and discuss. Participants with experience in systemic reform initiatives aimed at reducing achievement gaps were also important contributors to the conference, and these perspectives informed at least one research design emerging from the conference (see below). For more details on the structure and agenda of the conference, see Appendix 1.

At the end of the conference, a conference evaluation questionnaire was distributed to the conference participants. A total of 22 participants completed the questionnaire; this represents 63% of the external (non-SRI, non-PI) participants to the workshop. The survey solicited participants' evaluation of the workshop and its effectiveness.

Overall, as Table 2 indicates, participants endorsed the idea that the workshop provided them with ideas and theories to inform their research and contributed to the advancement of research on classroom networks.

Table 2. Participants' Perceptions of the Success of the Workshop

Question (Response Scale 1-7)	Minimum	Maximum	Mean
How useful was the workshop in giving you new ideas to inform your research?	4	7	5.7 (sd=0.84)
How useful was this workshop in making you more aware of theories and concepts that will help you further your research?	3	7	5.6 (sd=0.92)
If you do not already work in industry, was the opportunity to meet with people from industry useful for your research?	2	7	5.0 (sd=1.4)
How successful was this workshop in advancing research on the transformative potential of interactive pedagogies and classroom networks?	4	7	5.9 (sd=0.8)
How balanced was the workshop in terms of perspective on the systems and their uses?	2	7	5.4 (sd=1.3)

In addition, at the end of the workshop participants felt very strongly (M = 6.5 out of 7, SD = 0.93) that NSF should fund research in this area.

Nearly all respondents stated that what they liked best about the workshop was meeting others working in this field. Specifically, they noted that they liked meeting people both within and outside of their own disciplines, meeting leaders in the field, and having the opportunity to explore ideas together. Five respondents noted the diversity of the participants and representation of a variety of perspectives with a shared agenda. They were enthusiastic about the opportunity for multiple constituencies to come together and get an understanding of various perspectives. Five respondents noted that the best feature of the workshop was the opportunity to have extended, substantive conversations in small groups. One respondent noted that these conversations allowed ideas to be brought closer to a working closure.

Key Ideas from the Conference

In this section, we summarize key ideas that emerged across multiple large and small group discussions. These ideas were identified from notes kept by small group facilitators and from conference notes kept by the conference report authors. They represent our own—rather than the group's—synthesis of the important ideas, discussions, agreements, and disagreements among different participants.

Reviewers of our NSF proposal charged us to make more sense of the diversity of CATAALYST systems and their uses. This conference presented an excellent opportunity to make headway on this issue. Throughout the conference, participants reacted to the diversity in the technologies, pedagogies, subject matter contents, and perspectives presented. We capture some of the key dimensions that were articulated here.

Differences in Technological Capabilities

Three vendors presented three quite different technical systems:

- *eInstruction* was representative of a traditional, simple response system. Key advantages of this system were its low cost, ease of installation, and usability.
- *Discourse* was representative of a sophisticated, language-oriented system. A key advantage to this system was the ability to incorporate continuous updates of phrases that students typed along with sophisticated ways to categorize students' input.
- *TI-Navigator* was representative of a sophisticated, mathematically oriented system. A key advantage of this system was the ability to build on the sophisticated mathematical and scientific capabilities of a graphing calculator and to produce group displays that contain mathematical/scientific visualizations and simulations.

As a set, these technologies represent key divergent characteristics of classroom network technologies available in the market: selected response input, language- and multimedia-oriented input, and subject-specific devices (graphing calculators).

Differences in Subject Matter Content

Among science educators, there has been great interest in tackling student misconceptions using CATAALYST systems—an interest in helping students deeply understand the foundations of the subject matter—to build converging understanding of "the expert model" of the key concepts in the domain. In contrast, a humanities educator pointed out that a key strategy in that subject area is to find an idea on the periphery and move it towards the center for group consideration as a way of understanding literary themes and ideas. Difference of opinion has a different status in each subject matter, and this can produce different pedagogical and content designs. For example, the language-oriented "Discourse" system transmits student input in an ongoing, flowing manner. In the science-oriented response systems,

students think and then choose a single response for input. When the group display reveals differences, they are instructed to convince each other of the "correct" answer.

Differences in subject matter content are particularly evident in the nature of the public display, which can be:

- A histogram representing the distribution of selected responses to misconception-provoking question
- A Cartesian graph representing the functions students have constructed
- A simulation in which students each control an individual agent
- A table of phrases that students have individually typed in response to a prompt

Differences in Social versus Content Orientation

Some participants identified themselves as having a content orientation; they valued public displays that contained substantive mathematics, language, or scientific content. These participants contrasted their preferred technology with response systems that do not easily convey rich content. They see the simpler selected response systems as capturing social information such as the level of agreement or disagreement in the classroom.

In reality, this characterization is not completely fair, as creative uses of the simple selected response systems can have a strong content dimension. John Bransford, for example, described using a response system in a bioengineering classroom. Students were asked to draw a free body diagram for a specified situation. They were then asked "which of these four free body diagrams is closest to the one you drew?" and their responses collected via a selected response system. When differences emerge, the discussion focuses on the content of the different free body diagrams. This use blends social and content orientations.

Differences in Convergence versus Divergence Orientation

Among assessment experts, CATAALYST is seen primarily as a means of engineering the pedagogical transactions in the classroom to incorporate early, more informative, and more substantive feedback. This cybernetic concept (c.f., Wiener, 1948) encourages teachers to act as "adaptive experts" (Bransford & Schwartz, 1999) and students to become more "self-regulative" (Butler & Winne, 1995). Among mathematics education researchers and some science education researchers, CATAALYST is seen first and foremost as a means of engaging students in doing more important, substantive mathematics within the classroom. Their fundamental metaphor is not *cybernetics*, but rather viewing the classroom as a *distributed system* in which the aggregation of individual student data can enable relative simple mathematical behaviors at the individual student level to result in the emergence of more complex group-level mathematical (or scientific) constructions. Rather than valuing *corrective feedback,* these researchers value *generation and harvesting of diversity*.

One simple way to abstract this distinction is to consider some CATAALYST uses as favoring *convergence* of student thinking towards a preferred concept or model whereas other CATAALYST uses favor *divergence* of student thinking towards a richer space of mathematical or scientific constructs.

Implication: One Community, Multiple Studies

The diversity of uses may have been an important reason why some participants raised on several occasions the question: "Is this one community of researchers?" Clearly at the onset of the workshop, it was not one community. Nor is it likely that this group was one community by the end of the workshop. Nonetheless, we were encouraged by the workshop to believe it is important to continue working with this diverse group as one community for several reasons:

- Participants shared very similar purposes and missions relating to improving education. For example, all hoped to create more active, effective, and engaging classrooms with more diversity of participation and a greater focus on deep conceptual mastery of science and mathematics.
- Participants described very similar changes in classrooms where teachers and students adopted their versions of CATAALYST.
- Participants will increasingly have access to converging technologies, TI-Navigator and Discourse being two examples that both subsume and extend simpler response system capabilities.
- Participants readily formed joint teams, articulated shared research objectives, and designed studies to further those objectives.
- Participants grew clearer in their own theoretical accounts and sharpened their distinctions as they encountered related but different work.
- Participants expressed the desire to continue to communicate as a group; plans for an edited volume were also discussed.

Overall, we believe that productive tensions would result from keeping this community together. Researchers will be better prompted to consider the relative virtues of cheaper and simpler response systems versus more advanced, expensive, and complex systems. Researchers will be required to make the case for the merits of general-purpose pedagogical strategies (e.g., increasing feedback) versus content-specific subject matter strategies (e.g., using a simulation for teaching a particular concept). Researchers will also have to debate the merits of a more traditional, well-established theoretical vocabulary (e.g., motivation) versus more modern, less-defined concepts (e.g., agency).

Yet, it is doubtful that one could capture with a single study or even a common set of studies the effects of these different types of systems for a number of reasons that participants pointed out. First, the systems are at different phases of development. Older systems may in fact be "ready" for more rigorous designs because the pedagogical strategies associated with them are better known and have been

catalogued in research articles and in at least one book. By contrast, what CATAALYST classrooms look like with newer systems is not well understood. And while they may be in many classrooms, they are somewhat less mature overall, making the kind of quasi-experimental or experimental design that might be appropriate for other systems inappropriate to conduct. Additionally, more subject-matter specific technology applications suggest more subject-matter specific research designs. Classroom communication systems can be used across the curriculum; mathematics-specific applications may be useful for a specific subject (or even topic) for a narrower range of grade levels.

Reflections on Cornerstone Constructs

In our prior review of the literature (Roschelle, Abrahamson, & Penuel, 2003), we proposed four theoretical constructs that could form the cornerstones of further research with CATAALYST systems. An important purpose of this conference was to gain insight into the viability of each construct within a larger research community. Below, we summarize the interactions of the community around each construct.

1. Formative Assessment

As previously discussed, formative assessment resonates deeply with some CATAALYST participants. One of the most obvious benefits of earlier response systems is that both students and teachers gain access to more rapid, informative feedback. Researchers who study "learning environment engineering" will likely continue to build upon this construct. An important advantage they gain is that formative assessment is well-understood and its effects are well-documented. Thus, such researchers are ready to move onto effectiveness and implementation research. In this research, they can consider factors such as the quality of the questions used, the teachers' management of classroom discussions, the teachers' expert adaptation of lesson structure, and the frequency and depth of CATAALYST use.

Formative assessment, however, does not resonate with researchers who value divergence and generativity and who emphasize more complex science and mathematics. Although informative, responsive "feedback" is also a prominent feature of the uses of CATAALYST they study, they are unlikely to find formative assessment to be a sufficient explanatory construct. Stroup, for example, prefers to describe the rapid, interactive cycle between user input and the public visualization as "play." Thus what some see as feedback, others see as playfulness. Playfulness has an important literature in child development, education games and simulations, and other research areas but is less commonly a construct in school-oriented research beyond early elementary school. Yet, some have argued that our goal should be "life-long kindergarten." (Resnick, 1998).

2. Conceptual Discourse Driven by Shared Group Displays

A centerpiece of every CATAALYST implementation that was described in the workshop is a public display. The content of the public display arises from the (often but not always anonymous) contributions of individual students but emphasizes patterns within or across the group. The public display is always used to drive classroom discussion that is focused on (a) fundamental or central concepts and (b) students' thinking about them. All conference participants shared the view that these discussions, occasioned by "making students' thinking visible," are extraordinarily rich teaching and learning events. The importance of teachers' *asking good questions* that effectively elicit high-value distinctions or comparisons and focus the conceptual discourse productively was frequently mentioned by conference participants in whole- and small-group discussions.

In one group focused on exploring research in a pre-service teacher program context, discussion centered on one possible commonality among a particular technological

affordance of systems that appears to be significant. That affordance is for *shared representational displays* that are comprised of student contributions (whatever they may be) and that become the focus of classroom discussion. All of the uses judged to be most effective involved some kind of elicitation of a student response and a visual representation of the class's aggregated responses that could be seen by teacher and student alike.

Educational technology researchers often think of the representational affordances of computers as unique and powerful, but the configuration in CATAALYST classrooms is different from a computer lab, a laptop classroom, or a classroom with a set of handheld computers for every student. All of these systems support one-to-one communication and even one-to-many communication; however, the additional aggregate-and-display power of CATAALYST classrooms provides additional resources to the classroom for instruction. First, the display provides a focus of *joint attention* that is more easily maintained than when students are focused on their own individual screens alone (even if everyone is looking at the same screen). Joint attention is particularly important for coordinating complex human activities, especially learning (Roschelle & Teasley, 1995). Second, the focus of this joint attention is *cognitive and conceptual*—students' thinking and target concepts—rather than activity or materials. Third, not only does aggregation technology enable parallel inputs or contributions from *all* students (not just serial input from a few students who know the right answer and volunteer it) but the *public display* of these contributions seems to inspire *fuller participation* from students. All students are able to contribute to knowledge-building activity in the classroom; they come to "see themselves" projected into the display space, a phenomenon a variety of researchers of CATAALYST classrooms commented upon in the conference panels.

Discussing the content of the shared displays appeared to be a pedagogical element common to different uses of the technologies. Each of the panelists from the first and third panels spoke of discussion in some way: promoting "active discussion," "turning to your neighbor and explaining" an answer in a large lecture class, or "having kids discuss first." Discussion serves multiple purposes, according to panelists. First, it gives students a chance to test their thinking, often after they have responded to a teacher question and gotten feedback as to how their idea compares to others'. Both "knowing that one is not alone" and "seeing we don't all agree" are important to preparing students for this kind of discussion. Second, discussion gives students a chance to revise their ideas; peer instruction, a technique written about by Eric Mazur and used by many of the practitioners at the conference, involves students in trying to convince another person of their point of view. Often, along the way, students' opinions change such that when the teacher poses the question again, students answer differently. In some more advanced applications of systems, discussing displays helps students to build models and concepts, such as the notion of a "family of functions" with the same slopes but different y-intercepts, which can be generated by asking students to construct individual lines with a particular slope on their own graphing calculator and then sharing it with the class via a network.

It is our opinion that analysis of the cognitive and social use of group-level displays should be an important cross-cutting element of all CATAALYST studies.

3. Motivation and Participation

When describing what they see in CATAALYST classrooms, almost all the conference participants described more active, involved, engaged, excited, happy students. It is, therefore, natural to assume that motivation could be an important analytical construct. This was hotly debated throughout the conference. Some participants saw motivation as a well-researched, established concept that was clearly relevant to the CATAALYST phenomena. Particular subtopics of motivational research that could be most applicable were goal orientation, attribution, and collective self-efficacy. One team within the workshop made strong progress towards defining a research design for studying motivation in the CATAALYST context. Other participants, however, saw motivation as an "old," overly general construct that is divorced from subtle understanding of mathematical and scientific content. It is possible that with a little more information about recent theory and research in motivation, these participants might oppose the concept less. In defense of motivational theory, one expert argued that scientists should prefer simpler, clearer explanations over more complex, less articulate ones.

There was more agreement that accounts of the function of "anonymity" or its opposite "self-identification" were problematic with regard to explaining why students become more involved or less withdrawn in CATAALYST environments. Especially in response systems, student input can be anonymous. But in practice, students are often immediately asked to discuss their answers, violating anonymity. Experienced practitioners suggested that the longer a classroom uses CATAALYST, the less important anonymity becomes. Some researchers also describe some form of "personal identification" of the students' self with an aspect of the public display. Those with social science backgrounds tended to find this equally problematic.

As with motivation, almost all conference participants described CATAALYST classroom as encouraging wider participation. But generally speaking, existing research does not move beyond anecdotes in measuring participation in a CATAALYST classroom. Three consultants described sophisticated frameworks for examining participation and exploring implications of CATAALYST for diverse students. For example, one framework (from social psychology) has dimensions of "communion" and "agency." Students may feel an increase in one but not the other dimension and different students may react differently. An important direction for future research is to conduct more careful, theoretically sound studies of participation and diversity.

4. Generativity

Generativity is an important emerging construct for studying CATAALYST systems. Generativity picks up the aspects of CATAALYST oriented to:

- Divergent thinking
- Distributed or complex systems metaphors

- Emergence of more complex and conceptually difficult content from simpler mathematical behaviors
- Advanced technological capabilities

Stroup shared an early draft of a paperthat offered an analytical framework for future CATAALYST research on generativity. Key constructs in this framework include space-creating play, participation, agency, and harnessing diversity. Rather than attempt to articulate Stroup's well argued points, we recommend his paper to interested readers.

Generativity is *also* an attribute of older technologies, but more subtly so. In a simple response system, students are asked to *generate* convincing explanations of a scientific experiment. While their generativity does not pass through the technology, it is an important aspect of the pedagogy that is coupled with use of the technology. A skilled teacher can harness the cognitive diversity of the classroom to draw out a range of compelling explanations and involve the class in more complex and conceptually difficult subject matter.

Generativity will continue to be an important construct for uses of CATAALYST such as participatory simulations. In addition, analyses of more traditional CATAALYST activities may benefit from considering the generative dimension.

Implication: Sharpen Cornerstone Constructs

The conference suggests that a variety of existing and emerging constructs are viable as cornerstones for future studies, including formative assessment, group thought-revealing displays, motivation, participation, and generativity. Some of these will be more applicable to certain research purposes than others and it is premature to force convergence on a particular subset of constructs. Yet in every case (except perhaps for formative assessment), a critical issue for further research is to sharpen the application of the constructs to CATAALYST and to elucidate more clearly a suitable methodology for further research using the construct. The field has a good intuitive grasp of what happens when CATAALYST systems are deployed, but has considerable difficulty communicating in a more succinct, theoretical manner.

Two Different Research Opportunities

As the conference proceeded into small group work, two major clusters of research opportunities emerged. One cluster was motivated by the desire to shape the practical use of the CATAALYST systems that are rapidly penetrating the market, in a relatively short time-frame. Another cluster was motivated by the opportunity to use the richness and complex of CATAALYST phenomena to drive advances in the learning sciences (and improve learning, but in a longer time frame). We discuss each further below.

1. Effectiveness and Implementation Research

Penetration of CATAALYST into K-12 and university markets is accelerating rapidly. A majority of the participants at the conference were users of CATAALYST technology at the university level. Historically, both scholarship and use have been more widespread in higher education than at the K-12 level, but several panelists and vendors indicated this trend may be changing. eInstruction, for example, reports that sales at the elementary level are brisk; the company has been very successful with several district-wide adoptions of its technology. Texas Instruments, with its Navigator technology, is serving primarily students taking algebra in middle school and high school. Its penetration into this market has historically been very high; Navigator promises to leverage that market and add new capabilities to graphing calculators that are widely available in these settings.

The high school teachers who attended the conference have been regular users of classroom communication systems for several years now. They reported similar classroom dynamics and outcomes as professors in large lecture halls at universities, even though they said class size does matter. Discussion tends to happen more readily in small groups, observed one teacher, but support for the same community-building processes reported in the literature at the university level can be found at the high school level.

While adoption is rapidly occurring, participants reported that not every CATAALYST implementation succeeds. Several participants noted that teachers' and students' responses to the introduction of CATAALYST systems can strongly influence both their persistence in using the technology and effectiveness. Several panelists described "confusion" as an early reaction of teachers to using classroom networks; confusion that can last up to a year as teachers discover how to deal with the new information on student learning, and how to pose questions and develop tasks that yield useful insights into student thinking in their content area. Confusion arises also because teachers often come to rethink their teaching entirely, often in response to an "epiphany" regarding how inaccurate their estimates of student understanding really are.

For their part, students can resist the changed format of CATAALYST classrooms. They may, for example, object to the additional responsibility for learning placed on them. Individual students with different dispositions toward "agency" and "communion," as well as different levels of comfort and familiarity with particular classroom

communication patterns, may experience CATAALYST classrooms differently. Inevitably, users of these systems report there is some period of adjustment for students as they become familiar with the new dynamics of CATAALYST classrooms.

Additional factors that participants cited include:

- The difficulty of changing approaches to teaching and learning
- Teachers may feel a loss of autonomy and control or may find the technology intimidating.
- Students may go through the motions of using the system but not engage in deeper thinking
- Teachers may go through the motions of using the system but not really use or enable students to use the feedback generated by the system
- Increased feedback, if poorly communicated, could result in self-consciousness and avoidance

In one small group, researchers described three different adoption curves. In some uses of eInstruction, the implementation team has adopted a "walk before you run" philosophy that allows teachers to start using the technology to automate familiar processes (e.g., a pop quiz) without substantively impacting classroom pedagogy. This yields a very smooth, gradual adoption curve. In some uses of TI-Navigator, by way of contrast, teachers described a steep (but short) initial learning curve, followed by a plateau while teachers digested the capabilities of the system, followed by the possibility for deep teacher learning and pedagogical change. The deep learning portion of the curve can take teachers two to three years to reach. Finally, Eric Mazur described a "J" shaped curve. He insists in deep pedagogical change from the onset. This can cause an immediate drop in teacher performance while the teacher grapples with abandoning old habits and working in new, unfamiliar ways. Conceptualizing these adoption curves correctly will be important for future research, lest measurements take place at inappropriate times or assume linear growth where the actual performance grows in a nonlinear way.

Participants proposed new terms for describing an accomplished CATAALYST teacher. Several participants called advanced teaching with CATAALYST "Agile Teaching"—calling forth an image of a more responsive, flexible, poised teacher. Relating to this, John Bransford proposed "adaptive expert" as a characterization of the advanced teacher, suggesting both deep knowledge but also agility. Students may likewise become more "self-regulative." Dylan Wiliam provocatively challenged the participants to think about CATAALYST as a shift from a quality control (high stakes testing) metaphor to a quality assurance metaphor. In the classroom of an accomplished CATAALYST teacher, quality assurance would be a continuous, ongoing process.

Participants recognized that in the initial stages of implementation of a CATAALYST system, both students and teachers will become aware of new information that is

available to them. Awareness, however, will not necessarily result in appropriate action to increase the quality of teaching and learning. Professional development will be required. An experienced group of teacher educators suggested a three-stage model of TPD for CATAALYST:

3. Introductory experience to generate awareness of CATAALYST and to educate teachers about the desirability of changing their classroom practices

4. In-depth teacher professional development (e.g., in the summer) that provides teachers with simple, reliable, well-specified uses of CATAALYST that are likely to result in an immediate (but not deep) success

5. Ongoing customized training and peer support as teachers begin to become "agile teachers" or "adaptive experts"

The wider policy context of the No Child Left Behind (NCLB) Act and the press for "scientifically-based research" in education were part of the discussion at different points. Some in the group advocated that we pay explicit attention to the demands for systemic, large-scale reform implicit in NCLB. They also suggested that to be adopted widespread, CATAALYST classrooms would have to demonstrate a positive impact on state-administered tests in core subject areas. Third, the equity focus of NCLB was emphasized by several participants, who suggested that research ought to investigate the extent to which CATAALYST classrooms facilitated participation of persons with diverse identities and that it ought to examine impacts on different groups (such as African Americans, low-income students, girls).

2. Classroom Laboratories for Advancing Learning Theory

One small group explored the idea that CATAALYST classrooms might be an ideal setting for exploring the kinds of learning that promote twenty-first century learning skills, including collaboration, problem-solving, and critical thinking. The appearance of effects at the classroom, group, and individual levels all make these classrooms interesting to study in this regard. This group emphasized, however, that traditional analysis of variance designs would be inadequate to measure learning in such settings; new modes of inquiry could be explored in CATAALYST classrooms to better reveal the phenomena that consistently emerge there.

A small group prepared an outline for a Request for Proposals (RFP) for future research in this area. The purpose of this RFP is to define a research agenda that will contribute to deepening our understanding and advancing our practices concerning how learners can be prepared for successful lives in a much more complex and interconnected world than any previous generation. As McCullough has recently observed, "the role of computing has changed: information technology has become ambient social infrastructure." (McCullough, 2004, p. 21) Computation as ambient social infrastructure has implications for many aspects of society. Among them is education.

This research agenda seeks to spur progress and greater sophistication along several dimensions: the capacity to identify new educational opportunities for engaging all

students in learning challenging curriculum; conceptions of the research questions that underlie the success or failure of interventions that take advantage of these opportunities; methodologies for systematic inquiry to explore the consequences of such interventions, the ability to anticipate and address the new learning, activity, and pedagogical structures that will arise from these new opportunities; and the new demands they will place on preparing learners, teachers, and other stakeholders with lifelong adaptive expertise in their work and living.

This group is preparing a write up of their RFP that describes their ideas in greater depth.

Outcomes from Conference

1. Research Designs for Studying the Impact of CATAALYST

There were four different groups that produced research designs to investigate the impact of CATAALYST. The foci of each of the research studies were:

- **Impact on motivation and engagement:** A study that would examine whether CATAALYST classrooms would be ones in which students would accept more responsibility for learning and show increased effort, persistence, and attention
- **Impact on instruction:** A study that would examine how CATAALYST technology supports teachers becoming more "data-guided" in their instruction, transforming how data about student understanding are collected, interpreted, and used
- **Adoption and impact in a systemic context:** A study that would focus on impact on district achievement in a core subject area (mathematics) targeting low-income and minority students
- **Impact on pre-service teachers:** A study that would investigate how learner participation in CATAALYST classrooms might transform pre-service teachers' conceptions of teaching and lead to greater adoption of these technologies once they join the teaching workforce

One group submitted a proposal to the IERI program in May 2004. This group included participants that met each other for the first time at the CATAALYST workshop.

2. Intellectual Property Concerns Raised

There was a high-energy discussion among a subgroup about intellectual property issues. Because of rapidly expanding commercial opportunities in this area, there is an unusually strong level of concern about intellectual property. Participants were attracted to notions of a "creative commons" (Lessig, 2001) and to mechanisms that ensured attribution of ideas, encouraged collegial sharing, and eliminated barriers to intellectual exchange of ideas. We urge NSF to pay attention to the intellectual property issue within any future efforts to coordinate or organize researchers in this area, as lack of attention to IP concerns may kill the prospects for collegial interaction.

3. Future Actions That NSF Should Consider

On our survey, roughly half the participants thought that after the conference, a community should be fostered in which both research and development can continue (12 respondents). Ideas included:

- Building a communication network.
- Exchanging ideas and experience.
- Encouraging more sharing on how the classroom works using CATAALYST.

- Reflecting and sustain interaction.
- Hosting follow-up meetings.

Recommended communication channels were:

- A website or mailing list.
- Meetings at major conferences such as AERA.
- A deep-dive follow-up workshop next year.
- A major conference for researchers and practitioners.

Several respondents (8) suggested that the group should work on specific research goals, such as creating a research agenda and vision for the next generation of CATAALYST and to push for NSF to fund research in this area. Consequently it would appear to be very appropriate to fund a Center for Learning and Teaching in this area.

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Appendix 1: Conference Structure

The conference was a working conference that included a variety of formats: panel presentations by researchers and practitioners, small group work focused on producing research designs to study the impact of CATAALYST on teaching and learning, whole group discussion of ideas, and informal demonstrations of emerging network technology. The conference opened Thursday evening, April 1, 2004 and continued through Saturday, April 3, 2004.

The conference opening provided participants with an overview of the goals of the conference and a chance for participants to help construct a "collective history" of this area of research. Participants were invited to place significant milestones of their own participation in technology development, research, and practice with CATAALYST systems. This activity continued into the breakfast hour of the first full day of the conference, when the participants reviewed the aggregate of the individual trajectories as a group.

The first morning of the conference consisted of three panel presentations by practitioners and researchers. The first panel included primarily practitioners from K-12 and university settings; this panel was asked to speak to the question, "What does teaching in CATAALYST classrooms look like?" The second panel included primarily learning sciences researchers, who were tasked with addressing the questions, "What are the necessary inputs to CATAALYST and what are the effects?" and "What are the relevant insights from the learning sciences to explaining the CATAALYST phenomenon described in the current research?" The third panel comprised researchers dealing with advanced systems and pedagogical ideas as well as selected industry representatives. They were asked to address the question, "What's next for CATAALYST?"

During the lunch hour, demonstrations of new network technologies and software were provided by both vendors and researchers. Several researchers also brought posters that described their work with networked classrooms. These demonstrations were repeated the following day during the lunch hour.

The afternoon session began with a panel presentation by the consultants to the grant from the learning sciences community. This panel was asked to address the question, ""What are the issues and topics to consider in theorizing CATAALYST outcomes?" This discussion was also set the stage for the work of small groups to develop a research agenda for the field.

Following the panel, a group brainstorming session yielded several categories of important hypothesized outcomes for research. Individuals chose an outcome group to work with to elaborate on the observable aspects of the hypothesized outcome, the conditions and practices needed to bring it about, and the professional development that might be required for teachers to be able to use the technology effectively to produce the outcome. The day closed with each group reporting back to the whole conference what it discussed, followed by reflections on the day from Eric Mazur of

Harvard University, a physicist who has written extensively about teaching in CATAALYST classrooms.

The second full day of the conference began with presentations by a researcher, a practitioner, and a vendor focused on the topic of what CATAALYST classrooms looks like. For much of the rest of the day, conference participants worked in new small group configurations to delve deeper into CATAALYST. Based on the previous day's discussion, the conference facilitators chose the possible areas of focus for the different groups. These were written on poster-sized pieces of paper which were fastened to the walls around the room, and participants were asked to vote for the top three groups they would be most interested in joining by placing sticky dots next to the topic. In addition, participants were invited to write down issues they thought particular groups should address on that group's piece of paper. Those topics with the most dots were then reviewed and participants were asked to join one of those groups. Depending on the topic, participants in each group were asked to develop a research design that addressed a particular question for that group or to elaborate on a plan for continuing discussion or action on that topic.

After sharing their designs with the whole group, participants again broke into small groups to discuss the conference and what ought to happen next with respect to the group that had gathered together at the meeting. The participants reconvened to share their ideas.

To complete the conference, two participants, Roy Pea of Stanford University and Frank Demana of The Ohio State University, gave closing remarks on what they saw as the significance of the conference.

In our evaluation, five respondents noted that what was best about the workshop was the opportunity to have extended substantive conversations in small groups. One respondent noted that this allowed ideas to be brought closer to a working closure. Another respondent noted that the openness of the entire group was the best part of the workshop. Three respondents noted that what was best was meeting others who exposed them to new uses of CATAALYST systems.

Two respondents had different perceptions about what was best about the conference. One cited the panels as the best aspect of the conference, while another noted that what was best was the opportunity to "identify the fundamental nature of issues of learning and knowing that are raised and occasioned by the advent of these technologies."

Respondents to the survey did offer perspectives on what did not work as well at the conference. One respondent noted that there was a problem with the clarity of the mission, writing, "…at times the objectives of the sessions were not clear to some of the discussions, and presentations meandered." One respondent noted that the workshop did not succeed in "establishing some core features, environmental issues, of a CATAALYST classroom." Two respondents noted that focusing the group discussions could be problematic.

Some responses also pointed out the difficulty of communicating across disciplinary and theoretical lines. One wrote, "I can't think of anything I would have changed, so this is not a criticism, but I don't think we managed to build on each other's expertise well. Partly this is a consequence of the different jargon used, and partly because we don't (yet) know each other. That is why we need another workshop." Another mentioned that the teachers needed to talk more and be more specific, while two other responses referred to the use of "jargon-speak" and "buzz words."

Still others suggested that a better balance of perspectives would have improved the conference. One lamented, for example, the absence of funding organizations from the conference. Another wrote, "There was an overemphasis on higher ED + Math + Science/overemphasis on TI and instruction systems—it would be good to review characteristics of existing systems/ an overrepresentation of participants from these areas/absence of focus on elements and low achieving schools." Finally, others suggested that a need for better representation of K-12 teachers and administrators, as well as "more people who can bridge and translate from cognitive research community to classroom teachers."

Finally, two respondents suggested adding two different kinds of experiences to the workshop. One suggested the workshop would have benefited from showing a video in which the technology was being used. Another suggested that we should have used a classroom communication system as part of the workshop structure, not just in the demonstrations.