Building Sustainable Science Curriculum: Acknowledging and Accommodating Local Adaptation

SASHA ALEXANDER BARAB
School of Education, Indiana University, Bloomington, IN 47405, USA

APRIL LYNN LUEHMANN
Warner Graduate School of Education, University of Rochester, Rochester, NY 14627, USA

Received 5 April 2002; revised 5 June 2002; accepted 15 August 2002

ABSTRACT: A core challenge facing science educators is how to develop and support the implementation of project-based, technology-rich science curriculum that is consistent with international calls for a "new approach" to science education while at the same time meeting the everyday needs of classroom teachers. In this article, we discuss the challenges of scaling out university-developed, project-based curricula, providing a contextualizing frame for the articles that constitute this current issue of *Science Education*. Specifically, we overview (1) what constitutes and why implement inquiry-based, project-focused learning environments, (2) the role of integrating technology to support their implementation, (3) the value of engaging in design experiments for their development, (4) the importance of allowing for local adaptation, and (5) the process of curricular diffusion. In our thinking, the process of dissemination is not simply "rubber-stamping" the same program into multiple contexts; rather, the process of large-scale adoption involves additional, individual teacher-directed design, fitting, and adaptation for local circumstances. *Sci Ed* **87:**454–467, 2003; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/sce.10083

INTRODUCTION

Over the last decade we have seen commissions, committees, and task forces in Britain (Millar & Osborne, 1998), Australia (Goodrum, Hackling, & Rennie, 2001), and the United States (American Association for the Advancement of Science, 1993; National Research Council, 1996, 2000) call for a "new approach" to science education. Central to these calls is a shift from a focus on supporting the acquisition of formal science content to promoting a culture of scientific literacy by engaging students in the language and ways of scientific inquiry. From a practical perspective, this shift is driven by a sense of growing disparity between the science education provided in schools and the needs and interests of the children who will be our future citizens. According to Millar and Osborne (1998), school science tends to be a preparatory education either for those who will become future scientists or for those attempting to pass standardized tests. In contrast, science in K-12 schools should be a part of the human quest and wonder for understanding the world (Dewey, 1938/1986),

Correspondence to: Sasha A. Barab; e-mail: sbarab@indiana.edu

with science offering a way of knowing and doing that can help students reach a deeper understanding of their world. From a pedagogical perspective, this shift in approach involves curriculum and teaching strategies that embed content in rich inquiry contexts through which learners come to appreciate both the content being learned and those situations in which the content has value (Barab & Landa, 1997; Barab et al., 1999; Brown, Collins, & Duguid, 1989; Cognition and Technology Group at Vanderbilt, 1993; Dewey, 1925/1981, 1931/1985; Roth, 1996).

Consistent with these lines of thinking, science educators are abandoning didactic, lecture-based modes of instruction in favor of more *participatory* models in which their students are collaboratively engaged in the process of scientific inquiry (Barab & Hay, 2001; Barab et al., 2000; Blumenfeld et al., 1996; Lehrer, Horvath, & Schauble, 1994; Linn & Hsi, 2000; Roth, 1996; Roth & McGinn, 1998; Ruopp et al., 1993). In fact, one of the central questions facing science educators is not whether learners should be doing science but how best we can support and engage active learners in the process of scientific inquiry. Toward this end, an increasing number of university-initiated projects have leveraged technology, and specifically the networked personal computer, to facilitate the establishment of rich learning contexts that provide associated tools and resources for supporting the learning/doing process. These early efforts have shed some light on the challenges and opportunities of building project-based curricula that are attractive to teachers, accommodate local adaptation, and support inquiry-based teaching and learning in public schools (Roschelle & Jackiw, 2000).

While educational researchers have developed innovative project-based curricula for K-12 classrooms, an examination of K-12 (and many university) classroom practices shows a more traditional picture (Brown et al., 1989; Lave, 1997; Resnick, 1987). Implementing project-based science curriculum is challenging in the context of standardized tests, 45-min class periods, large class sizes, and the emphasis on individual grades. These difficulties are exacerbated by the challenges inherent with new technology (Cuban, 1986; Postman, 1992). One of the primary challenges facing curriculum designers is that of engaging learners in meaningful scientific inquiry while still addressing science education goals that are important to the context of public schools. The present issue highlights the challenges and opportunities of developing sustainable project-based, technology-rich science curriculum by bringing together researchers from multiple institutions, whose work has focused on these topics, particularly with regard to the use of Internet content and functionality. Specifically, these authors discuss the interplay among the affordances and requirements of technology, curricular interventions, individual local classroom and district-wide cultures and environments, widespread curricular implementation, and sustained use over time.

Squire et al. (this issue) begin this issue by describing a series of four abbreviated case studies of teachers implementing an Internet-supported, project-based curriculum developed by the authors. Specifically, they examined the implementation of their project-based curriculum, focusing in on how the project-level question of the curriculum was contextualized to meet local needs. Their interest was on how researchers can develop innovative curricula that can be integrated within existing classroom cultures, yet still provide students (and teachers) with meaningful and sound learning opportunities. Their interpretations suggest that each teacher contextualized the project activities in terms of local factors and, additionally, their discussion highlights the central importance of school and classroom culture in determining the implemented experience. In this way, rather than viewing teachers as inheritors of university-developed curriculum, their findings suggest that teachers are users/makers, drawing on and adapting predeveloped materials in ways that they view as useful for their students and that are consistent with their personal pedagogical beliefs, classroom climate, and students' past experiences.

Songer, Hartman, and McDonald (this issue) then address the challenge of taking what works with a select group of teachers and scaling it to have large-scale impact across many school and classroom sites. They reflect on this challenge in light of 9 years of implementing a technology-rich, inquiry-focused science environment across the nation—Kids as Global Scientists Weather (KGS) Program. The KGS Program is a suite of tools that include the curriculum, the KGS software, and, for those with whom they directly work, a systemic structure of teacher professional development with the goal of fostering students' deep conceptual understanding of weather content. The particular study presented here examines teacher and student data from five classrooms that successfully implemented the KGS curriculum environment, comparing the experience of supporting maverick teachers who simply find the program with those directly involved in the authors' urban systemic implementation research. By presenting data from and contrasting two different learning environment contexts, this research supports a comprehensive understanding of classroom-based inquiry science that is broader than many research studies that only focus on data based on exceptional teachers who tend to routinely be involved in innovative curricular efforts.

Linn, Clark, and Slotta (this issue) describe how the flexibly adaptive character of the Web-based Inquiry Science Environment (WISE) project supports local customization as one means to help teachers build sustainable science instruction. Two decades of research by Linn and her colleagues (Linn & Hsi, 2000) have resulted in effective designs for WISE inquiry curriculum and learning environment technology, as well as supports for teachers. Linn et al. describe the WISE partnership practices, the scaffolded knowledge integration framework, and the resulting learning environment. The paper analyzes the 25 projects in the WISE library, highlighting how the features of WISE support customization while implementing instructional patterns that follow the scaffolded knowledge integration framework. This paper highlights design strategies underpinning WISE and describes tensions in supporting widespread dissemination, specifically the challenges of allowing local adaptation yet maintaining curricular integrity.

Hickey (this issue) focuses on the more general assessment and program evaluation issues, which needs to be addressed if we are to expect these curricula to have widespread implementation. He advances a pragmatic, sociocultural framework for evaluating innovative science learning environments, addressing the core tensions that evaluation presents when there exists multiple teacher creators/users of the curriculum. These tensions include the tension between contemporary views of learning and conventional views of accountability, the tension of accommodating local adaptation while still allowing for cross-site comparisons and more global claims, and the conflicting conclusions that result from different theoretical perspectives on learning. With these goals in mind, he offers a dialectical approach to reconciling conflicting conclusions from different types of individual assessments and between individually oriented and socioculturally oriented assessments.

The core challenge facing each of these projects is *not* to design some "correct" version of curricula or assessment that will be implemented "wholecloth" by *willing* teachers, but to develop flexible support structures that facilitate local adaptation and ownership of each curriculum. Below, we provide an overview of the common threads and distinguishing features of these projects. We have selected those features that have direct ties to each of the discussed papers, while at the same time have implications more broadly for developing curricula that will be used by teachers in context of their classrooms. Specifically, we discuss what constitutes and why implement *inquiry-based*, *project-based environments*, the role of *technology* in supporting these environments, the notion of *design experiments* as a design-research methodology for *their* creation and evolution, the a priori expectation that designers should have for *local adaptation*, and the challenges of *curricular diffusion*. We then close with a discussion on the implications of supporting local adaptation while at the same time promoting reform-minded, inquiry-based teaching and learning activities.

This volume benefits from a strong commentary to help situate, synthesize, and propel the central concerns of this present issue. Fishman and Krajcik's concluding remarks contextualize these articles in terms of the systemic constraints through which teachers operate, reflecting on the practical challenges of supporting reform (Fishman and Krajcik, this issue). They review the program of research, the interpretations, and the claims being made in the articles, noting practical difficulties as well as theoretical obscurities. In their synthesis, they raise key operational questions about the challenges of implementing reform-minded classroom practices in the larger context of school accountability and public-school institutional constraints, highlighting the potential incongruities among supporting project-based learning and the everyday and systemic realities of secondary classrooms.

PROJECT-BASED, INQUIRY-FOCUSED LEARNING ENVIRONMENTS

Central to the calls for a new approach to science education is the importance of having students engage in scientific inquiry in the context of authentic and sustained scientific investigations in which they not only learn the content but also the language and the ways of inquiry in science (American Association for the Advancement of Science, 1993; Goodrum, Haekling, & Rennie, 2001; Millar & Osborne, 1998; National Research Council, 1996, 2000). This is consistent with theorists who have argued that the lecture format concentrates on the memorization of factual information and promotes the development of superficial understandings of concepts, knowledge that is nontransferable (*inert*) and that will be forgotten soon after the tests (Barab, Hay, Barnett, & Squire, 2001; Baxter, 1989; Cognition and Technology Group at Vanderbilt, 1993; Roth, 1996; Ruopp et al., 1993; Salomon, 1993; Whitehead, 1929). However, while identifying a problem and advancing a need are necessary, they are not sufficient for changing classroom practice.

Given the time and resource constraints of teachers and the fact that they are held publicly accountable through standardized tests, our efforts must result in the creation of usable and powerful tools to support teachers' needs for efficiency as well as effectiveness in the development of learning opportunities. In addition, we must propose methods for maintaining accountability that allow teachers to justify their usefulness (see Hickey, this issue). In response to these concerns, many educators are moving towards more project-based learning environments that support natural complexity of content, avoid oversimplification, engage students in the inquiry process, encourage collaboration, and present instruction in the context of authentic scientific investigations. These learning contexts are frequently collaborative in nature, and require students to work with others as they negotiate goals, tasks, practices, and meanings (Barab & Hay, 2001; Barab et al., 1999; Bell, Davis, & Linn, 1995; Blumenfeld et al., 1996; Savery & Duffy, 1996).

Barab et al. (2001) suggested that in project-based learning environments students are engaged as active participants in the learning process, setting their own learning goals (in relation to project challenges) and forging meaningful relations through their experiences as they investigate real-world issues. Young (1993) suggested that these environments should include ill-structured complex goals, an opportunity for the detection of irrelevant as well as relevant information, active/generative engagement in finding and defining problems as well as solving them, involvement of students' beliefs and values, and an opportunity to engage in collaborative activities. According to Blumenfeld and her colleagues (Blumenfeld et al., 1996, 2000; Krajcik et al., 1994), project-based learning models typically have at least four essential components: (1) a driving question that organizes a long-term, authentic investigation or design project, (2) the production of tangible, meaningful artifacts as the end products of the learning activity, (3) collaboration with any subset of a learner's community including peers, teachers, or members of society, and (4) the use of a cognitive tool such as the Internet to support the process of inquiry.

The teacher's role in these environments switches from one of *telling* students correct answers to *guiding* and *facilitating* learner activity, providing resources, just-in-time lectures, and Socratic questions to facilitate reflection in and on the learning process (Bednar et al., 1992; Dewey, 1931/1985; Linn & Slotta, 2000; Schön, 1987; Songer, 1996; Vygotsky, 1978). The task or project provides an anchor which grounds the array of classroom activities and thus the student learning (Barab & Landa, 1997) and serves as means to test the viability of individual and collective understandings. In performing such a project, students can test their own understandings against those of others and in terms of their applicability to the task or project at hand. It is through participation in such a task, and not simply the rote memorization of a set of science concepts, that meaningful learning and an appreciation for the language and ways of scientific inquiry occurs.

LEVERAGING TECHNOLOGY

Doing project-based learning in classrooms introduces new sets of challenges for the teacher/facilitator as well as the students. One of these challenges involves connecting students with a rich and diverse set of resources including media such as video, books, journals, etc., or collaborators such as peers or experts. Another challenge is to provide the process scaffolding or support students' need as they engage in authentic science activities such as collecting evidence, testing hypotheses, or formulating arguments. The affordances of technology, especially the personal computer and the Internet, offer means of supporting teachers as they face these and other challenges involved in having their classrooms doing authentic science projects (Barab, Hay, & Duffy, 1999; Barab et al., 2001; Bell et al., 1995; Linn & Hsi, 2000; Linn & Slotta, 2000; Luehmann, 2001; Songer, 1996; Songer, Lee, & Kam, 2002). Five specific uses of personal computing technologies to support student learning were outlined by Barab et al. (1998): Information Resource, Communication Tool, Content Contextualization, Construction Kit, and Visualization/Manipulation Tool (see Table 1). See also the National Research Council report on Fluency with Information Technology (1999) which describes what K-12 students should know about technology and calls for inquiry projects that foster capabilities, skills, and concepts.

TABLE 1
Five Uses to Which Educators Can Apply Technology (Barab, Hay, & Duffy, 1998)

General Use	Role
Information resource	Provide information to support learner inquiry (e.g., hypermedia, WWW, interactive CD ROMs)
Communication tool	Facilitate collaborative and distributed learning (e.g., asynchronous conferencing tools, teleapprenticeships)
Content contextualization	Situate the material to be learned within a rich context (e.g., anchored instruction, experiential simulations)
Construction kit	Provide concrete tools for building phenomena/understandings (e.g., LOGO, HTML, and VRML editors, HyperStudio)
Visualization/manipulation tool	Present phenomena for scrutiny and manipulation (e.g., visualization tools, model-based simulations)

These five uses are not features inherent to the technology as if technology was a self-contained entity; instead they refer to uses or roles that technology can serve within particular contexts. As such, Barab et al. (1998) described these as “situated potentials” that are actualized (and given shape) within the larger context of learner inquiry—a process that is highly contextualized to the particular classroom in which they are being used. An important challenge in leveraging technologies to support innovative science teaching and learning is to determine how to design curricula that effectively integrate the use of these tools in a coherent and authentic way in order to support sustained inquiry-based learning. Some K-12 examples of projects that have leveraged technology in the aforementioned ways include GLOBE (Global Learning and Observations to Benefit the Environment) (Finarelli, 1998), KIE (Knowledge Integration Environment) (Linn, 2000), KGS (Kids as Global Scientists) (Songer et al., 2002, this issue), LabNet (Ruopp et al., 1993), Computer as Learning Partner (Linn & Hsi, 2000), WISE (Linn, Clark, & Slotta, this issue), Model-It (Jackson et al., 1994), and The National Geographic Kids Network (Bradsher & Hogan, 1995; Copen, 1995; Karlan, Huberman, & Middlebrooks, 1997). GLOBE, as one example, is a hands-on science program created to enable K-12 students to collect and post environmental data on the World Wide Web (Finarelli, 1998; Means, 1998). This National Science Foundation (NSF) funded program involves students in almost 5000 schools from over 60 countries in this process. The data students collect is used to create vivid displays and contour maps providing students immediate feedback, which allows them to understand the part they have contributed to a much larger effort. The Knowledge Integration Environment (KIE), another example, is a Web-based program in which students use the Web to review evidence, engage in scaffolded discussion forums to develop shared criteria, recognize alternative viewpoints, and engage in sustained reasoning (Bell et al., 1995).

Kids as Global Scientists (Songer, 1996; Songer et al., this issue) is an international program that uses the Web to connect students in grades K-12 from around the world and engage them in meaningful discussions around the topic of weather. Students engage in making sense of up-to-date live weather data which directly correlates with what they experienced walking to school that morning. Atmospheric scientists support students’ inquiry by serving as “weather specialists” and discussing student and teacher questions and ideas as they arise throughout the program. WISE is an online learning environment that engages K-12 students in collecting evidence, analyzing real world data, and participating in current scientific controversies (Linn et al., 2002, this issue; Linn & Hsi, 2000). The various curricula support students in accessing valuable resources on the Internet, logging their ideas and thoughts in personal “notebooks,” and collecting evidence in order to support or reject self-created and proposed hypotheses. All of these programs, as well as those described in this issue, are examples of innovative curricula that leverage technology to make project-based, inquiry-focused learning available to classrooms of science learners.

DESIGN EXPERIMENTS

The projects being discussed in this issue can be characterized as “design experiments” (Brown, 1992; Collins, 1992). Design experiments involve working with students, teachers, and other members of the community to introduce design innovations and to “trace” learning as it relates to each new intervention. Lessons learned are then cycled back in the next iteration of the design interventions, with a focused examination and reflection on how each release of the innovation impacts the learning process. Because design experiments develop theory based on practice, they are likely to lead to the development of designs that are trustworthy, credible, transferable, and ecologically valid (Barab et al., 2000; Roth, 1998). On one level, an outcome of an effective design experiment is to develop *the* curricular intervention; that is, the curricular intervention that has been modified to such a degree that it will work most usefully in the classroom. On another level, the desired outcome is a better understanding of the range and diversity of local needs as well as the necessary adjustments teachers (need to) make in order for the innovation to be useable and effective in a particular context. The implication to be derived from these articles is that useful design work never under-respects the role of the teacher—the goal is not to develop teacher-proof curriculum. Instead, each classroom implementation can be thought of as an important leg in the overall design experiment, innovating and implementing the curriculum in a manner that best fits each specific context. In other words, because implementation necessarily requires local adaptation, each and every curricular implementation can be considered its own design experiment.

As designers are beginning to develop an understanding of and agreement on the integral and essential role the teacher plays in the design, customization, and implementation of these innovative curricula and instructional strategies, the goal becomes to develop flexibly adaptive curricular interventions (Schwartz et al., 1999) as well as educative curriculum (Ball & Cohen, 1996) in which there is a commitment to develop innovations that afford mutual adaptability with both the teacher and the researcher learning from each other. Central to notions of mutual adaptability is the belief that curricular development should be viewed as a participatory process that continually evolves as researcher-designers and teacher-implementers interact and evolve the outcomes of their interactions.

A core challenge for designers is to package their curricular innovations in terms of activity sets with support for multiple customizable modules of implementation as opposed to only one project that contains multiple lesson plans (see Squire et al., this issue). This design communicates to teachers more clearly the curricular affordances and additionally more usefully accommodates to local classroom conditions. In addition, supports such as those integrated in educative curriculum assist teachers with diverse backgrounds and needs to consider reform-minded practices and advanced pedagogical strategies. If one assumes that teacher-designed adaptation is locally contextualized and will result in implemented curriculum that diverges from the designed curriculum (MsCaslin & Good, 1996), then clearly we need forms of assessment and evaluation that take into consideration and account for this diversity. Hickey (this issue) suggests that accountability frameworks must allow researchers, policy makers, and classroom teachers to examine the impact of these innovations that accommodate local divergence while at the same time allowing researchers to make noncontextually bounded claims of their impact.

Instead of the curriculum being treated as complete after a series of design experiments, a more useful treatment would be to evolve the curriculum through design research and then to develop scaffolding that will support teachers in the continuation of refinement through ongoing modifications as well as in the sharing of their experiences and lessons learned with each other. Richardson and Placier (2001) highlight the need for and benefits of reflective discussions between teachers for the purposes of understanding teachers' reform efforts:

> Many of the changes that are being studied . . . may not involve a completely conscious process. It often leads to change in tacit knowledge that becomes expressed only through reflection, a process that is enhanced through dialogue (p. 8).

For example, Barab and colleagues have developed a Web space that supports teachers in virtually visiting each other's classrooms to observe and discuss approaches to teaching mathematics and science topics, in sharing artifacts such as lesson plans, in collaboratively discussing the struggles of implementing a common curriculum, and in reflecting on their experiences implementing these lessons (Barab, MaKinster, Moore, Cunningham, & the ILF Design Team, 2001; Barab, MaKinster, & Scheckler, in press).

When teachers discuss the struggles and opportunities of implementing a common curriculum, a dialogue of local contextualization exists in which each implementation of the curriculum becomes another instance of the design experiment. It is through continued dialogue that classroom innovations and what constitutes transformative practice become coconstructed, socially derived, and empirically grounded. It is also through these collaborative explorations that teachers can continually learn from each other's implementation struggles and successes, thus supporting and promoting the processes of change (Richarson & Placier, 2001). The "design experiment" in this case is distributed across teachers and is ongoing, as opposed to a completed trajectory that was overseen by the designer. The goal of this type of design experiment is both the outcome of an enhanced design as well as the creation of a means for offering customization support.

LOCAL ADAPTATION

Clearly, adoption of a curriculum is not a one-to-one mapping of the designed environment to the K-12 classroom. Instead we have argued that teachers must always adapt the curriculum for their local use. Songer et al. (this issue) concluded that "the idea of scaling is a misconception in that it implies rubber-stamping the same program." Central to our thinking is that the process of adoption itself involves additional design efforts to ensure a strong fit with local circumstances. Therefore, a central challenge for designers is how to develop curriculum and teacher scaffolds that support teachers in the adaptation of these curricula to meet the needs and goals of their local context and culture. Squire et al. (this issue) stated that "curriculum designers need to acknowledge that their designs are not self-sufficient entities; instead, during implementation, they become assimilated as part of the cultural systems in which they are being realized." Randi and Corno (1997) stated that, "What have often been documented as teachers' adaptations of innovations may have been teachers' innovations created in response to the contexts in which they work." We also view the process of adoption as a process of assimilation in which the curricula becomes integrated into the local K-12 contexts and cultures. The challenge is to support the integrity of the intervention, at the same time meeting the felt needs of the teacher.

A small study conducted recently by Luehmann (2002) identifies component tasks involved in the inevitable professional task of customization required of each teacher as they consider change in light of individual classroom contextual constraints: *identifying* local needs, *critiquing* the innovation in light of these needs; *visualizing* possible scenarios of implementation; and finally *making plans* or decisions regarding the implementation. Beginning during the appraisal of curricular innovations, teachers often critique the affordances and requirements of the innovation with respect to perceived local needs as they visualize the possible implementation. If a decision is made to adopt the innovation, teacher may use the opportunity afforded during appraisal to make decisions or plans with respect to upcoming implementation. Understanding teachers' work through these important processes will allow us to both support the novice in developing the skills to plan for and to a priori improve the fit of the innovation into the local culture. In addition, understanding these customization processes will allow us to better support all teachers when reform efforts challenge teachers to redefine their goals—a process that has ripple-effected implications for teachers' customizations: teachers will need to redefine local needs with respect to the new goals; the critique of the innovation may reflect a new understanding of how these needs are addressed; visualization of future implementation will need to consider the new classroom culture; and finally the plans or decisions made will reflect the work of these previous adjustments.

Given the involvement of teachers in the adoption, customization, and implementation process, we believe that teachers are more than receivers of predesigned curriculum from some informed curriculum maker. Squire et al. (this issue) stated that "traditional distinctions such as the users of the innovation and *makers* of the innovations disintegrate when one actually examines how technologies are used." In practice, teachers are continually remaking and contextualizing the innovation in terms of their local context. Crudely speaking, instead of the equation,

$$\text{Designed Curriculum} = \text{Implemented Experience}$$

we argue that

$$\begin{aligned}&\text{Teachers Perceptions} + \text{Designed Curriculum} + \text{Classroom Culture}\\ &\quad = \text{Implemented Experience}\end{aligned}$$

Teachers Perceptions of both the innovation as well as the culture they have contributed to defining for their classroom, to a large degree, influence the implemented experience.

In a study by Leuhmann (2001), 30 secondary science teachers were asked to identify the factors most important to them when appraising and considering an innovation for potential adoption (e.g., standards, student interests, cost). In fact, no single factor was identified by a majority of the participating teachers—highlighting the variability and not uniformity of the customization process. A cluster analysis of the identified factors resulted in the grouping of the teachers into five diverse groups defined by shared concerns: accountability focused, subject-matter focused, scaffolded optimists, logistically focused, and pedagogically savvy. It is not difficult to imagine that stark differences would exist between the customization and implementation of an innovation by a subject-matter focused teacher who is very concerned about students' understanding of the content compared to a logistically focused, teacher who is most concerned that the activities run smoothly and in the appropriated time frame. As a case in point, Squire et al. (this issue) highlight a subject-matter focused teacher whose customization and implementation differed drastically from the other teacher cases with respect to the depth and focus of the collaborative discussions around the scientific concepts.

Further and certainly related, we argue that "Classroom Culture," broadly conceived, potentially explains the largest portion of the variance in the "Implemented Experience." It is important to clarify that when we use the phrase "classroom culture" we are acknowledging available tools and resources (including computers, internet access, supplemental texts), classroom norms (including division of labor, rules, expectations), external classroom pressures (including administrative expectations, standardized testing, parental involvement), the students (including ability level, interests, class size) and, most importantly given her central role in mediating the impact of the other factors, the role of the teacher (including her pedagogical perspective, learning goals, interests, content expertise, memberships, school roles, self-efficacy, and experiences) (Luehmann, 2001). This is consistent with the findings of Squire et al. (this issue) in that the cases they researched suggest that "contextualizing the curriculum ultimately is a local phenomenon that arises as a result of a number of factors, including students' needs, students' goals, teachers' goals, local constraints, and teachers' pedagogical values." In fact, they further found that the most effective instantiations of their curricular innovations involved teachers rearranging the curriculum in novel ways that met local needs.

It is this observation that led Randi and Corno (1997) to conclude that "classroom innovations are thus coconstructed and socially derived" (p. 1166). While Songer et al. (this issue) also found much local contextualization, especially among the maverick teachers, issues of local adaptation were more complex when they used a systemic approach. Here the teachers, while still adapting the curriculum to meet local needs, were doing so under more challenging constraints (e.g., larger class sizes, more diverse learners and behavior problems, higher profile accountability), leading towards local adoption that resulted in a less reform-type classroom instruction.

CURRICULAR DIFFUSION

As we have suggested above, teachers serve as the gatekeepers to their classrooms, deciding which curriculum and pedagogical strategies they will use. University designers who have a primary goal of having their innovation adopted may perceive teachers as potential obstacles who can prevent or support widespread diffusion. We argue that this perspective is both an inefficient and ineffective position for those interested in promoting educational reform. Cuban (1986) argued, “The password that will unlock the classroom door remains in the teacher’s head; understanding what questions teachers ask and what criteria they apply is essential to unlocking that door” (p. 71). We believe that it is a great asset of our educational system that the one who knows best his/her own abilities and limitations, the cognitive and affective makeup of the class, the abilities and interests of the students, what could potentially be accomplished under the very real constraints of the local situation (including fire drills, parent involvement, available resources, standardized test pressures, etc.) is the person who has the final word on what is allowed into the classroom and to what degree (Luehmann, 2001). The teacher is held directly accountable for the academic as well as motivational successes and failures, accomplishments and limitations of the classroom experiences, and it is therefore the teacher who should maintain the autonomy necessary to make the decisions such as whether or not to use a particular technology-rich project-based curriculum.

Though national and state calls are pushing for teachers to use technology in their classroom in meaningful ways and to engage students in authentic and sustained inquiry, the decision to adopt this type of curricular option is still, by Roger’s definition, an “optional innovation-decision” in that teachers often have the autonomy to make these decisions on an individual basis (Roger, 1995). Not surprisingly, Randi and Corno (1997) in a review of the literature found that “context plays an important role in informing teachers’ decisions” (p. 1190). Specifically, their review suggests that curricular choices and instructional decisions are influenced by student characteristics, teachers’ beliefs and values, practical theories developed from practice, the nature of the curricular content, and the teachers’ knowledge of the subject area.

When considering whether or not teachers would adopt a new curricular option, one underlying question often being asked is, Does this curricular option entice teachers to change? The research on teacher-controlled change reveals that “biography, experience, perhaps personality, and context play a role in the change choices that individual makes” (Richardson & Placier, 2001). An innovation, though offering potential benefits that the current practices do not, by definition also involves newness and therefore a degree of uncertainty (Rogers, 1995). Furthermore, what might appear beneficial to the designer might not be perceived as beneficial by a consumer especially when considered in light of perceived costs. Cuban (1986) distinguishes first-order changes, those that involve only minor changes in organization, from second-order changes, those that involve different ways of thinking, teaching, and learning. For many schools, and certainly when one moves toward more systemic implementation, these innovations require second-order changes for many of the participants—a challenge highlighted by Krajcik and Fishman (this issue).

CONCLUSIONS

While university-based researchers can develop successful and innovative "boutique" projects that may impact a handful of highly motivated teachers with whom we work directly, these innovations do not usually result in the large-scale dissemination and long-term sustainability necessary for truly bringing about educational change. This issue brings together educators who have been developing and researching innovative science curricula to share and reflect on the challenges and opportunities of developing and supporting the diffusion of technology-rich, inquiry-focused, project-based science curriculum. A central goal of each of the projects is to design an environment for learning that will be broadly available (via the Internet), allowing teachers who were not part of the design team to use it in their classrooms. The authors share data on how different teachers use a common curriculum in their classroom, highlighting contextual issues that educators must consider if they want to develop truly disseminable curriculum. The collection of articles assembled for this issue suggests that the process of dissemination is not simply "rubber-stamping" the same program into multiple contexts; rather, the process of large-scale adoption involves additional, individual teacher-directed design, fitting, and adaptation for local circumstances.

We have suggested that a central challenge is how designers can develop curriculum and teacher supports that are flexibly adaptive, allowing teachers to customize the curriculum to circumstances of their local use. Additionally, each of the papers has a reform agenda as part of their curricular innovation, highlighting the challenges of supporting curricular diffusion in which local adoption entails teachers being willing to embrace change—potentially requiring the reform of their own practice. Here, the goal is not to determine how to convince teachers to implement predesigned environments, but to create supports that facilitate ongoing dialogue between makers and users that enhance the future iterations of both efforts and allow teachers to more productively customize these environments in terms of their classroom context.

True reform is a collaborative process and involves working with teachers as partners. Our next steps in this reform-driven endeavor involve taking what we are learning with highly motivated teachers, understanding the key differences between working with and supporting this unique population and those involved under less voluntary and therefore probably less enthusiastic circumstances, scaling out through reflective and participatory systemic interventions, developing flexibly adaptive curricula that can be easily customized and still maintain its project-based integrity, and developing accountability frameworks that support teachers in innovating these environments and at the same time support them in justifying their effectiveness. The collection of articles in this issue addresses each of these issues, with the goal of providing useful insights so that others may more successfully navigate the challenges of supporting curricular and pedagogical reform in theory and, more importantly, in practice. The fact that these manuscripts have raised so many provocative questions speaks to the need for continuing dialogue and deliberation on how science educators can best facilitate and support reform-minded classroom practice.

REFERENCES

American Association for the Advancement of Science. (1993). Benchmarks for science literacy. New York: Oxford University Press.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is—or might be—the role of curriculum materials in teacher learning and instructional reform? Educational Researcher, 25, 6–8, 14.

Barab, S. A., Cherkes-Julkowski, M., Swenson, R., Garrett, S., Shaw, R. E., & Young, M. (1999). Principles of self-organization: Ecologizing the learner–facilitator system. The Journal of The Learning Sciences, 8(3/4), 349–390.

Barab, S. A., & Hay, K. (2001). Doing science at the elbows of scientists: Issues related to the scientist apprentice camp. Journal of Research in Science Teaching, 38(1), 70–102.

Barab, S. A., Hay, K. E., Barnett, M. G., & Keating, T. (2000). Virtual solar system project: Building understanding through model building. Journal of Research in Science Teaching, 37(7), 719–756.

Barab, S. A., Hay, K. E., Barnett, M. G., & Squire, K. (2001). Constructing virtual worlds: Tracing the historical development of learner practices/understandings. Cognition and Instruction, 19(1), 47–94.

Barab, S. A., Hay, K., & Duffy, T. (1998). Grounded constructions and how technology can help. Technology Trends, 43(2), 15–23.

Barab, S. A., & Landa, A. (1997). Designing effective interdisciplinary anchors. Educational Leadership, 54(6), 52–55.

Barab, S., MaKinster, J. G., Moore, J., Cunningham, D., & the ILF Design Team (2001). Designing and building an online community: The struggle to support sociability in the Inquiry Learning Forum. Educational Technology Research and Development, 49(4), 71–96.

Barab, S. A., MaKinster, J., & Scheckler, R. (in press). Characterizing system dualities: Building online community. In S. A. Barab, R. Kling, R., & J. Gray (Eds.), Designing for virtual communities in the service of learning. Cambridge, MA: Cambridge University Press.

Baxter, J. (1989). A constructivist approach to astronomy in the National Curriculum. Physics Education, 26, 38–45.

Bednar, A. K., Cunningham, D., Duffy, T. M., & Perry, D. J. (1992). Theory into practice: How do we link? In T. Duffy & D. Jonassen (Eds.), Constructivism and the technology of instruction (pp. 17–34). Hillsdale, NJ: Erlbaum.

Bell, P., Davis, E. A., & Linn, M. C. (1995). The knowledge integration environment: Theory and design. In J. L. Schnase & E. L. Cunnius (Eds.), Proceedings of the Computer Supported Collaborative Learning Conference, CSCL '95, Bloomington, IN (pp. 14–21). Mahwah, NJ: Erlbaum.

Blumenfeld, P. C., Fishman, B. J., Krajcik, J. S., Marx, R. W., & Soloway, E. (2000). Creating useable innovations in systemic reform: Scaling up technology-embedded project-based science in urban schools. Educational Psychologist, 35(3), 149–164.

Blumenfeld, P. C., Marx, R. W., Soloway, E., & Krajcik, J. (1996). Learning with peers: From small group cooperation to collaborative communities. Educational Researcher, 25(8), 37–40.

Bradsher, M., & Hogan, L. (1995 Oct.) The kids network: Student scientists pool resources. Educational Leadership, 53, 38–43.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. The Journal of Learning Sciences, 2, 141–178.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32–42.

Cognition and Technology Group at Vanderbilt. (1993). Anchored instruction and situated cognition revisited. Educational Technology, 33, 52–70.

Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), New directions in educational technology (pp. 15–22). New York: Springer.

Copen, P. (1995). Connecting classrooms through telecommunications. Educational Leadership, 53(2), 44–47.

Cuban, L. (1986). Teachers and machines: The classroom use of technology since 1920. New York: Teachers College Press.

Dewey, J. (1925/1981). Experience and nature. In Jo Ann Boydston (Ed.), John Dewey: The later works (Vol. 1). Carbondale, IL: Southern Illinois University Press.

Dewey, J. (1931/1985). Context and thought. In Jo Ann Boydston (Ed.), John Dewey: The later works, Vol. 6 (pp. 3–21). Carbondale, IL: Southern Illinois University Press.

Dewey, J. (1938/1986). Logic: The theory of inquiry. In Jo Ann Boydston (Ed.), John Dewey: The later works (Vol. 12). Carbondale, IL: Southern Illinois University Press.

Finarelli, M. G. (1998). GLOBE: A worldwide environmental science and education partnership. Journal of Science Education and Technology, 7(1), 77–84.

Goodrum, D., Hackling, M., Rennie, L. (2001). The status and quality of teaching and learning of science in Australian schools: A research report prepared for the department of education, training and youth affairs. DETYA, Commonwealth Department of Education, Training and Youth Affairs. Available at http://www.detya.gov.au/schools/Publications/2001/science/index.htm.

Jackson, S. L., Stratford, S. J., Krajcik, J. S., & Soloway, E. (1994). Making dynamic modeling accessible to precollege science students. Interactive Learning Environments, 4(3), 233–257.

Karlan, J., Huberman, M., & Middlebrooks, S. (1997) The challenges of bringing the Kids Network to the classroom. In S. Raizen & E. Britton (Eds.), Bold Ventures: Case studies of U.S. innovations in science education (Vol. 2). Boston, MA: Kluwer Academic Publishers.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., & Soloway, E. (1994). A collaborative model for helping middle grade science teacher learn project-based instruction. The Elementary School Journal, 94, 483–497.

Lave, J. (1997). The culture of acquisition and the practice of understanding. In D. Kirshner & J. A. Whitson (Eds.), Situated cognition: Social, semiotic, and psychological perspectives (pp. 63–82). Mahwah, NJ: Erlbaum.

Lehrer, R., Horvath, J., & Schauble, L. (1994). Developing model-based reasoning. Interactive Learning Environments, 4(3), 219–231.

Linn, M. C. (2000). Designing the knowledge integration environment: The partnership inquiry process (special issue). International Journal of Science Education, 22, 781–796.

Linn, M. C., & Hsi, S. (2000). Computers, teachers, peers: Science learning partners. Mahwah, NJ: Erlbaum.

Luehmann, A. L. (2001). Factors affecting secondary science teachers' appraisal and adoption of technology-rich project-based learning environments. Unpublished doctoral dissertation, The University of Michigan, Ann Arbor.

Luehmann, A. L. (2002). Understanding the appraisal and customization process of secondary science teachers. Paper presented at the annual meeting of the American Educational Research Association: New Orleans, LA.

McCaslin, M., & Good, T. (1996). The informal curriculum. In D. Berliner & R. Calfee (Eds.), Handbook of educational psychology (pp. 622–673). New York: Macmillan.

Means, B. (1998). Melding authentic science, technology, and inquiry-based teaching: Experiences of the GLOBE program. Journal of Science Education and Technology, 7(1), 97–105.

Millar, R., & Osborne, J. (Eds.). (1998). Beyond 2000: Science education for the future. London: Nuffield Foundation.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

National Research Council. (2000). Inquiry and the National Science Education Standards. Washington, DC: National Academy Press. Available at http://www.nap.edu/catalog/9596.html.

Postman, N. (1992). Technopoly: The surrender of culture to technology. New York: Alfred A. Knopf.

Randi, J., & Corno, L. (1997). Teachers as innovators. In B. J. Biddle, T. L. Good, & I. F. Goodson (Eds.), The international handbook of teachers and teaching (Vol. II, pp. 1163–1221). Dordrecht, The Netherlands: Kluwer.

Resnick, L. B. (1987). Learning in school and out. Educational Researcher, 16, 13–20.

Richardson, V., & Placier, P. (2001). Teacher change. In V. Richardson (Ed.), Handbook of Research on Teaching. Washington, DC: American Educational Research Association.

Rogers, E. (1995). Diffusion of innovations (4th ed.). New York: Free Press.

Roth, W.-M. (1996). Knowledge diffusion in a grade 4–5 classroom during a unit of civil engineering: An analysis of a classroom community in terms of its changing resources and practices. Cognition and Instruction, 14, 170–220.

Roth, W. M., & McGinn, M. K. (1998). Knowing, researching, and reporting science Education: Lessons from science and technology studies. Journal of Research in Science Teaching, 35(2), 213–235.

Roschelle, J., & Jackiw, N. (2000). Technology design as educational research: Interweaving Imagination, Inquiry & Impact. In A. Kelly & R. Lesh (Eds.), Research design in mathematics & science education (pp. 777–797). Mahwah, NJ: Erlbaum.

Ruopp, R., Gal, S., Drayton, B., & Pfister, M. (1993). LabNet: Toward a community of practice. Hillsdale, NJ: Erlbaum.

Salomon, G. (Ed.). (1993). Distributed cognitions: Psychological and educational considerations. New York: Cambridge University Press.

Savery, J., & Duffy, T. (1996). Problem based learning. An instructional model and its constructionist framework. In B. Wilson (Ed.), Constructivist learning environments: Case studies in instructional design (pp. 135–148). Englewood Cliffs, NJ: Educational Technology Publications.

Scharwtz, D., Lin, X., Brophy, S., & Bransford, J. (1999). Toward the development of flexiblity adaptive instructional design. In C. Reigeluth (Ed.), Instructional-design theories and models: A new paradigm of instructional theory (Vol. II, pp. 183–214). Mahwah, NJ: Erlbaum.

Schön, D. A. (1987). Educating the reflective practitioner: Toward a new design for teaching and learning in professions. San Francisco, CA: Jossey-Bass.

Songer, N. B. (1996). Exploring learning opportunities in coordinated network-enhanced classrooms: A case of kids as global scientists. The Journal of the Learning Sciences, 5, 297–327.

Songer, N. B., Lee, H.-S., & Kam, R. (2002). Technology-rich inquiry science in urban classrooms: What are the barriers to inquiry pedagogy? Journal of Research in Science Teaching, 39(2), 128–150.

Vygotsky, L. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Wenger, E. (1998). Communities of practice: Learning, meaning, and identity. Cambridge, MA: Cambridge University Press.

Whitehead, A. N. (1929). The aims of education and other essays. New York: Macmillan.

Young, M. (1993). Instructional design for situated learning. Educational Technology Research and Development, 41, 43–58.