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ABSTRACT

The Center for Learning Technologies in Urban Schools (LeTUS) is implementing a professional development program for science teachers to enact science curricula in a systemic reform initiative. This paper proposes a design approach for professional development in science education as a valuable way to re-conceptualize the process of fostering teacher learning. The paper presents an argument that professional development in science education, as a whole, has not been grounded in empirical research, and there is, therefore, a lack of sound design principles upon which to base professional development programs. One possible design model for professional development is posed in the context of the LeTUS systemic reform work, and evidence is given that illustrates the initial success of the model. (Contains 34 references.) (Author/WRM)

# Fostering Teacher Learning in Systemic Reform: A Design Proposal for Developing Professional Development

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### Abstract

The Center for Learning Technologies in Urban Schools (LeTUS) is implementing a professional development program for science teachers to enact science curricula in a systemic reform initiative. This paper proposes a design approach for professional development in science education as a valuable way to re-conceptualize the process of fostering teacher learning. The paper presents an argument that professional development in science education, as a whole, has not been grounded in empirical research, and there is therefore a lack of sound design principles upon which to base professional development programs. One possible design model for professional development is posed in the context of the LeTUS systemic reform work, and evidence is given that illustrates the initial success of the model.

# Fostering Teacher Learning in Systemic Reform: A Design Proposal for Developing Professional Development

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Recent movements, such as strengthened standards for both students and teachers, increased calls for accountability through student testing, and efforts to raise the status of teaching as a profession have led to a growing demand for teacher professional development. As Wilson and Berne (1999) put it, "Professional teachers require professional development." At the same time, report after report depicts the state of teacher professional development as deficient, particularly where technology is concerned (e.g., CEO Forum on Education and Technology, 1999; Education Week, 1997). Many times the deficiency is reported in terms of quantity, but the quality of professional development is a more important issue. In fact, though the number of professional development opportunities for teachers has increased during the past five years, there has been little concurrent growth in collective understanding about *what* makes for successful professional development, or what teachers *learn* from professional development (Wilson & Berne, 1999).

The lack of focus on professional development as an area for research is especially evident in the domain of science. Although practically every new program or innovation in science education has associated professional development opportunities, there has not been much systematic study of these opportunities (Marx, Freeman, Krajcik, & Blumenfeld, 1997); they are simply treated as necessary but ancillary components of the innovation. To compound this problem, where good research on professional development has been conducted (e.g., Carpenter, Fennema, & Franke, 1996; Marx, Freeman et al., 1997; Palincsar, Magnusson, Marano, Ford, & Brown, in press), it has focused on groups of volunteer teachers who are, more often than not, motivated to change or try something new. We are not aware of similar professional development research conducted in settings that we call "systemic," where change is implemented on a broad scale and teachers are, for the most part, not highly motivated. The latter situation is ultimately of greater practical importance to the general cause of reform.

## Professional Development Research in Science Education

The past several decades of research and development in science education reform have yielded many innovative curricula, tools, and ideas. One area, however, that has seen less overall progress is the development of new frameworks for professional development of science teachers (Marx, Freeman et al., 1997). The staff development literature rarely addresses science education directly, and in turn the science education literature has not until recently addressed issues of professional development at any length. However, there is a considerable literature on professional development in general, and in areas such as the teaching of reading--why should science education require its own, separate research in this area? A chief reason is that the content, materials, and teaching methods used in science education are different than those of other content areas. Given these differences, Wilson and Berne (1999) argue for the need for subject-specific professional development research. Tobin, Tippins, and Gallard (1994) are among the few researchers who have devoted considerable attention to teacher development in science, pointing to two practices as successful: connecting to teachers' existing knowledge and providing a supportive environment for change over time. Loucks-Horsley and colleagues (1998) present a typology of different forms of professional development in science teaching, but the framework is not linked to research on teacher learning. Kennedy (1999), evaluates specific programs in science, and found that programs that emphasized content learning by teachers were overall the most successful.

Unfortunately, teacher knowledge may be the most difficult thing to measure in professional development. End-of-workshop evaluations are commonplace in professional development, but they represent measures of teacher attitudes, not knowledge. As Fenstermacher (1994) has pointed out, reports of what teachers believe or reflect on may or may not actually be knowledge. To actually measure knowledge would require something that looks much like a test, whether it is actually administered on paper or given in the form of a structured interview, and this would likely only represent some aspect of the teacher's knowledge, specifically content knowledge (pedagogical knowledge of any sort would be difficult to measure or evaluate). Furthermore, to gather data on teacher content knowledge using such an instrument in highly problematic in a systemic reform environment. Given the current political climate for teachers, many may be reluctant to submit to a "test" or anything that feels like a test of their own knowledge. Certainly, a great deal of trust would be required between researcher and teacher before such an instrument could be used. Given the context of our work, systemic reform in an urban environment, such trust is difficult to build, and the use of tests is next to impossible. Given that as a constraint, we must find alternative avenues for gauging teacher knowledge.

## A Design Approach to Professional Development Research

By way of definition, we maintain that professional development is fundamentally about teacher learning: changes in the knowledge, beliefs, and attitudes that teachers possess that lead to the acquisition of new skills, new concepts, and new processes related to the work of teaching.

We argue that what is called for is a *design approach* for research on professional development. This is akin to the design experiments methodology called for by Collins (1990) and described by Brown (1992), which studies classrooms as learning systems and embraces the practical impossibility of conducted traditional controlled studies in real classroom settings. A design approach calls for close association, even partnership, between the research and the researched; it calls for an iterative approach to the introduction of new ideas and evaluation of progress; and it emphasizes the use of multiple methods to understand the phenomena being studied. We also emphasize the term *design* because we believe it is critical to the long term success of science education reform that the design of professional development receive at least as much careful attention as the development of new teaching methods, curricula, or technological tools. We have been developing a design approach on the creation and study of professional development as part of a larger program of systemic science education reform, and it is that effort that we describe in this paper.

We also talk about design in the same sense as that used by Simon (1996) to distinguish between programs of research that focus on the "artificial" as opposed to the "natural." Unlike a natural science, which intends to uncover truths about things as they are, a design science focuses on the creation of interfaces to mediate elements of a task environment for its users. In this sense, we begin our design process by making informed decisions about the initial design for professional development that is bounded by goals, resources, and constraints. We shape our ongoing development with ongoing data collection and analysis, employing re-design "on the run." In short, the design approach at many junctures more closely resembles engineering than science.

## A Design Approach for Teacher Professional Development

Richardson (1996) states that a chief objective of professional development should be to foster changes in teachers' knowledge, beliefs, and attitudes, because these components of teacher cognition show a strong correlation to teachers' classroom practices. We have developed a model for teacher learning in this research that places knowledge, beliefs, and attitudes (K/B/A) in an interactive relationship with change mechanisms that are mediated by professional development activities, the interpretation of student change or learning as represented by various forms of assessment, and through the practical experiences of classroom enactment. This model is represented graphically in Figure 1. In the paragraphs that follow, we will elaborate on each of its components.

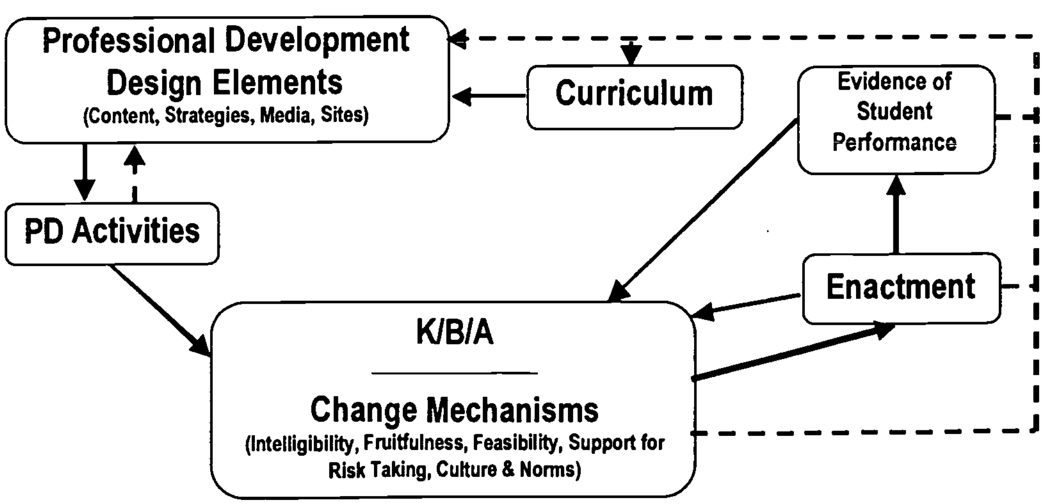


**Figure 1**. Model of design approach to professional development.

**K/B/A and Enactment**

In our work, we represent teachers' K/B/A in seven categories: Content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK) (Shulman, 1986, 1987); beliefs about self-efficacy as a science teacher and as a member of a broader scientific community (Dwyer, Ringstaff, & Sandholtz, 1991); attitudes towards technology (Czerniak, Haney, Lumpe, & Beck, 1998); and beliefs about system norms and contextual issues that impinge on innovation (Cohen, 1987). K/B/A is predicted to directly influence classroom enactment of curricula with technology, but enactment will interactively and reciprocally affect K/B/A (Richardson, 1996), through a process that will be described in the following sections. Both measurement of K/B/A and observations of teachers' enactment form a feedback mechanism to inform the re-design of professional development activities to foster greater change among teachers participating in our program.

**Change Mechanisms Affecting K/B/A**

Changes in teachers' K/B/A are linked a variety of mechanisms that are mediated by other components of the model. The first three mechanisms are cognitive, and have been described elsewhere in the research on cognitive conceptual change (Hewson, Beeth, & Thorley, 1998). Cognitive mechanisms include the perceived "intelligibility" of the innovation, the "feasibility" of the innovation, and the "fruitfulness" of the innovation. An innovation may not become intelligible to a teacher until he/she gets to see how another teacher uses it. Activities that increase intelligibility will affect CK, PK, and PCK. Teachers may not feel that using new curricula or technology is feasible for a variety of reasons, including their attitudes toward technology, their perceptions of self-efficacy for using technology, and combinations of underdeveloped CK, PK, or PCK with respect to the technology or science content. Perceptions of feasibility may be related to resource allocation. Have the appropriate resources (e.g., computer lab time) been made available to the teacher? Opportunities for hands-on practice with the curriculum or technology may affect all of these aspects of K/B/A. Arguments for the fruitfulness of using technology for teaching will come from evidence of improved student performance on assessments, among other places. Increased evidence of fruitfulness from using Model-It will affect both PCK for using the curriculum (suggesting the repetition of approaches that led to the success) and attitudes toward the curriculum.

"Support for risk taking" is a social change mechanism among teachers, such as might occur within a critical friends network (Costa & Kallick, 1993), or through testimonials from colleagues. These forms of peer relationships have been shown to influence adoption of innovations in the workplace (Fulk, Schmitz, & Steinfield, 1990). Teachers may be more inclined to try something out for the first time if they see that people they trust have tried it with success. This may lead both to increased feelings of self-efficacy (e.g., "If he can do it, I can do it.") and change in attitudes toward the technology (e.g., "Maybe this software is OK, if everyone is using it").

Finally, we also include "culture and norms" among our proposed change mechanisms. Culture and norms of the system or school are contextual factors related to the settings in which the innovation is to be carried out. This may be related to the culture and norms of the school. For instance, does the school principal support the curriculum? These factors will influence the attitudes of teachers toward the innovation. If the principal attends the summer work session, a teacher is likely to think, "This is important to him/her, I should find a way to make this work!"

These various change mechanisms are activated in teachers through a variety of means depicted in the model in Figure 1. "Professional development" is the topic of this paper, and will be discussed at length below. However, we do not want to suggest that formal professional development is the *only* or even the *most important* means by which these change mechanisms are exercised. Indeed, as Richardson (1994) points out, the formation of K/B/A and classroom enactment are interactive. Thus, the act of teaching provides opportunities for teachers to re-consider the intelligibility and feasibility of a particular activity. The object of teaching is to affect students' knowledge, and therefore "evidence of student performance" forms another important component of the model. But teachers have no means of directly gauging student performance without some form of external evidence (such as a test or final presentation or even simple behaviors). Evidence of student change, in is many forms, will most likely influence teachers' perceptions of the fruitfulness of the innovation.

We must stress at this time that, although we believe these change mechanisms to be significant in fostering growth in teachers' K/B/A, we do not have a solid understanding of the relationships between these change mechanisms and enactment. They are mostly useful in our model to provide a rationale for selecting one type of professional development activity over another (e.g., "Teachers do not understand the technology very well, if we give them more hands-on time to explore it, that may increase its *intelligibility* for them"). As our design research evolves, we will seek empirical evidence to help us unpack the relationships between K/B/A, change mechanisms, and enactment. For the moment, however, they are grouped together.

**Curriculum**

Curriculum is represented within its own box because it both shapes our professional development and is shaped by the results of professional development. We design curriculum, and that forms the core of the innovation that we help teachers to learn to enact through professional development. However, our notion of what is appropriate for curriculum is shaped by a combination of factors, such as state and district standards, but also by the ability of the teachers to enact the curriculum (as evidenced by "enactment" in our model) and by the performance of the students ("evidence of student performance"). Curriculum therefore plays a significant role in our overall model.

**Professional Development Design Elements**

The goal of any professional development activity focusing on content learning is to prepare teachers to enact the curriculum appropriately for its design in their classrooms. At the heart of this activity is, of course, teacher learning related to both preparation for instruction and the instructional activities themselves. What is taught or learned by teachers in the context of professional development is the "content" of teacher professional development. Teacher learning of content is facilitated by a range of strategies for professional development, which are conducted through various media that are part of the different sites for learning that comprise a professional development program. Any given professional development activity uses components from each of these elements. For example, an activity held during a Saturday workshop which focused on assessing students' written responses to a content question would involve print resources and face-to-face discussion, and would address the fostering of discourse and meaning making by students, as well as student knowledge of the content they were writing about. According to the Figure 1, these elements are then combined in this activity to focus on change mechanisms for the teacher, such as intelligibility or fruitfulness, as well as their K/B/A. Each of these components are inter-related in its relationship to the content for professional learning as shown in Figure 2 below.

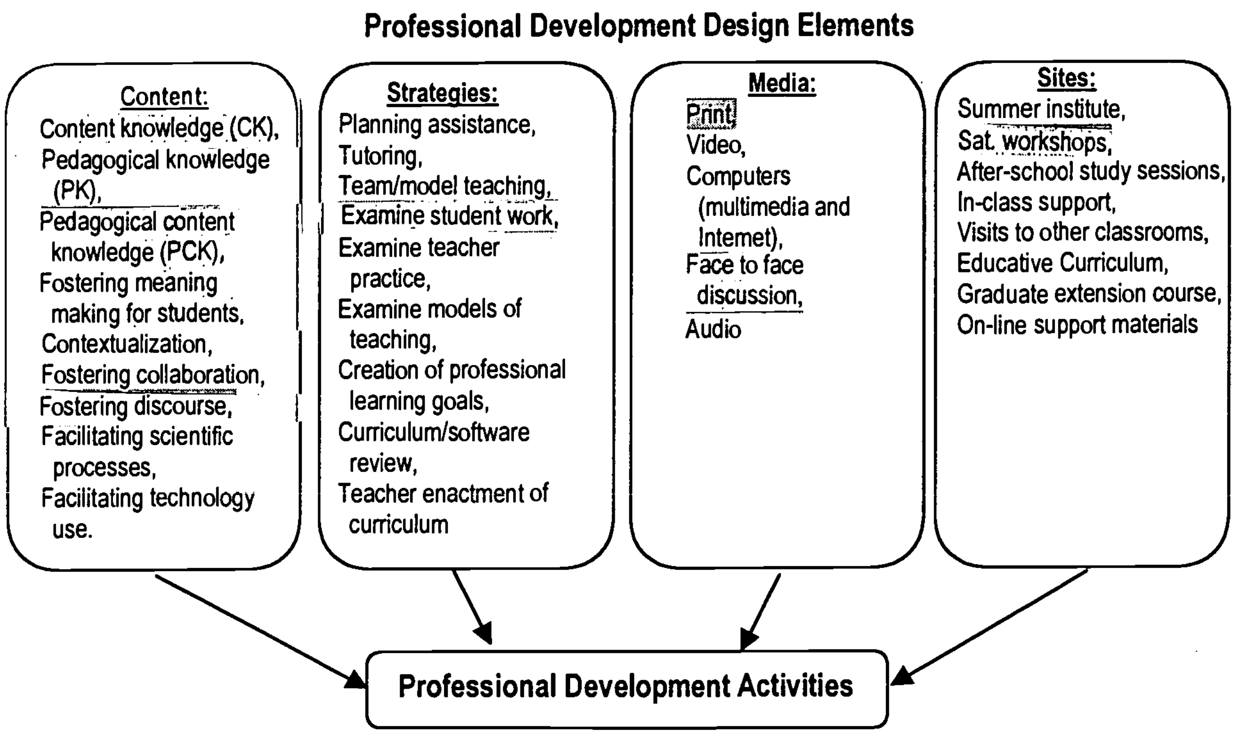


**Figure 2.** Design Elements of Professional Development Programs. The shaded items refer to the elements specified in the example in the text, which are combined together to form the PD activity.

These four elements (content, strategies, media, and sites) are elements that can be combined in various ways to create professional development. The various possible combinations become the design space for professional development, and this defines the range of possibilities which can possibly be explored in the design research process. These designs are intended to address all of the change mechanisms which impact teacher K/B/A and, in turn, enactment. Each teacher has a necessary threshold which must be achieved with respect to each of these change mechanisms before the innovation will be attempted. The elements of the professional development are intended to address these mechanisms, and recognize that the thresholds of each mechanism change over time. Next, we will expand upon each of these different elements.

Content for Professional Learning
The content of professional learning (what teachers learn) can be divided into content teachers need to understand in order to prepare for classroom instruction and content they must know that actually comprises classroom instruction. In the first category are: Strategies for planning; new forms of student assessment; and subject matter knowledge that relates to teaching strategies (PCK). In the second category are: Fostering meaning making for students; creating opportunities for contextualization; fostering collaboration; fostering discourse; facilitating scientific processes, including the use of tools, technologies, representations, and modeling; the content of the curriculum; and basic pedagogical knowledge such as classroom management.

Strategies
Many of the strategies used to foster teacher learning follow from a strategic framework we use to conceptualize our own professional development called CERA (Marx, Blumenfeld, Krajcik, & Soloway, 1997; Marx, Freeman et al., 1997). CERA stands for Collaborative construction of understanding; Enactment of new practices in classrooms; Reflection on practice; and Adaptation of materials and practices. CERA can provides a general backdrop for the collaboration of school district personnel responsible for policy decisions which affect professional development and other management issues, innovation designers, such as curriculum developers (as is the case in our specific situation, described later), professional development specialists who will be designing and enacting professional learning activities, and teachers involved in professional development. Specific strategies may vary considerably, but tend to be centered on one or more aspects of CERA. Specific strategies used in our work are described below, and listed in Figure 2.

Sites For Professional Learning
A site for professional learning simply denotes the place or context in which teacher learning may take place. Each of these sites draws upon the use of differing methods which fit the context of the site and media which are bounded by the site. Likewise, content and change mechanisms addressed within each site of professional learning vary according to the situational needs of the teachers involved. Traditional sites for professional learning include after-school in-service sessions, summer workshops, graduate-level coursework affiliated with a teacher's interests, and the ever present teacher enactment of curriculum in the classroom, which forces some level of learning from subsequent reflection and adaptation. Other sites may rely on the context of the district, as illustrated in our context, described later in this paper.

Media
The media through which professional development might be conducted are: Face-to-face interaction; video; audio; computers (dynamic multimedia, including the Internet); or print. These media might be combined in various ways; for instance, the Internet can be used to combine print, video, and audio. Video can be used as part of face-to-face interaction. Media are not as important as methods (c.f., Clark, 1983), but it is the case that certain media, such as the Internet, might lend themselves less well to certain kinds of change mechanisms, such as perceptions of feasibility.

## Background and Setting for Our Work

The Center for Highly Interactive Computing in Education (hi-ce) at the University of Michigan has been working in collaboration with the Detroit Public Schools to reform science education in the middle grades. This group has developed curriculum and software innovations as a part of the Center for Learning Technologies in Urban Schools (LeTUS). The Center is an NSF funded partnership between those institutions, Northwestern University, and the Chicago Public Schools with a mission of developing educational programs using pervasive technologies. The reform effort is centered on the design and use of innovative inquiry-based curricula and conceptual/data representation oriented software tools, and is enabled by creating professional development opportunities that address the needs of a diverse population of teachers. Below, we briefly describe the various components of the innovation that science teachers in this district are learning how to use.

## Designing for Both Scale *and* Systemic Reform in Large Urban Schools

There are challenges unique to large urban environments, including high teacher mobility rates, erratic content-area and technology specific preparation for teachers (with many teachers teaching out of their specialization), a lack of a substantial and "teacher friendly" technology base in many schools and classrooms, and high poverty among students. These challenges (and others) must be addressed by professional development if reform efforts are to be successful for individual teachers and students, scaleable to the needs of the whole school and district, and sustainable in both individual classrooms and the system as a whole. "Systemic reform" and "scalability" are critical in this context. By systemic reform, we refer to the efforts to overcome the uncoordinated nature of reform (Vinovskis, 1999), defined as a coordinated model that articulates the work of different levels and actors in a school system and that links the reform to standards and assessments. Scalability means that an innovation can operate in more than a handful of select and resource-rich classrooms or schools. Questions regarding scalability address methods for adding more users to an innovation. Systemic reform implies scaleable innovation, although a scaleable innovation may not be systemic, unless it explicitly addresses issues of coordination within the school system. Such issues might include coordination of the development and adoption of curriculum materials with assessment requirements, insuring that teacher professional development is provided to help enactment of the curriculum materials, and creation of teacher and administrator leadership capacity so that schools are able to make local decisions commensurate with the reform agenda. Systemic reform ultimately must be part of any scaling effort if it is to have long-lasting and wide-spread impact.

## LeTUS/hi-ce Curriculum

Our work is rooted in inquiry-based pedagogy that is consistent with constructivist learning theories (Blumenfeld et al., 1991). The presumption is that students need opportunities to construct knowledge by solving real problems through asking and refining questions, designing and conducting investigations, gathering, analyzing, and interpreting information and data, drawing conclusions, and reporting findings. We refer to this process as project-based science (PBS; Blumenfeld et al., 1991; Krajcik, Czerniak, & Berger, 1999). Together with Detroit, we have developed four middle school science units: a sixth grade unit on mechanical advantage, seventh grade units on air quality and water quality, and an eighth grade unit on force and motion (Singer, Marx, Krajcik, & Clay-Chambers, in press). Our eventual goal is to develop enough units to comprise an entire middle school science sequence. Each unit is built upon national, state, and most importantly, local district standards. Our curriculum units are designed to last between eight and twelve weeks. Each includes: a) a driving question, encompassing worthwhile content that is meaningful to students and anchored in a real-world problem; b) investigations and artifact development that provide opportunities for students to learn concepts, apply information, and represent knowledge around the driving question; c) collaboration among students, teachers, and others in the community; and d) use of computational technological tools to promote inquiry. In addition, the curriculum materials include benchmark lessons that help students learn difficult concepts, illustrate important laboratory techniques, or develop investigation strategies (Krajcik et al., 1999). Furthermore, the curriculum materials themselves are intended to be "educative" for teachers (Ball & Cohen, 1996), helping to provide opportunities to learn about new teaching practices, content and classroom enactment from the materials themselves.

## LeTUS/hi-ce Software Tools

In conjunction with PBS pedagogy, we have developed a set of computational tools to support and scaffold inquiry based upon principles called learner centered design (LCD; Soloway, Guzdial, & Hay, 1994). LCD is founded on the idea that learners are a unique class of computer users, and thus require special forms of support from software interfaces in order to complete their tasks successfully. Furthermore, the tools can be used over and over again throughout a student's academic career in different science classes. The Investigators' Workshop is a suite of computational tools we developed to enable sustained inquiry (Krajcik, Blumenfeld, Marx, & Soloway, 2000). These tools support data collection, data visualization and analysis, dynamic modeling, planning, information gathering from the UM digital library, the Internet and web publishing (Jackson, Stratford, Krajcik, & Soloway, 1994; Krajcik et al., 2000). Some software, like Model-Builder, is designed for use at single computers, which do not need to be networked. Others use the Internet, such as Artemis, which is a front-end to a digital library tailored to young learners (Wallace, Kupperman, Krajcik, & Soloway, 2000).

## LeTUS/hi-ce Professional Development

The professional development program described in this paper is designed around curriculum and software innovations that were developed through the Center for Learning Technologies in Urban Schools (LeTUS), specifically the partnership with the University of Michigan and the Detroit Public Schools. This particular effort was aimed at changing practices of middle school science educators throughout the large district. Programs were piloted in two schools at first, reaching ten schools in the second year. In this third year, more than 45 teachers and administrators from 18 schools participated in the program. The eventual goal is to include all middle grades science teachers in the program, as Center curricula becomes *the* middle grades science curriculum for the district. The professional development program for LeTUS utilizes a dynamic design process to accommodate the diverse needs of such a large pool of teachers, as well as the changing knowledge base of teachers involved in such a scaling effort, so that the needs of teachers both experienced and new to the program are met.

At the outset of the program, a series of goals were established and communicated to all individuals involved in the program, which we intended as a benchmark for progress. Our implicit goals for professional development are complemented by a set of five explicit goals, which are communicated to all teachers as part of regular professional development activities. These goals are:

- to become active participants in a science teaching community;
- to learn how to enact and adapt inquiry-oriented, standards-based science curricula that employ new forms of pedagogy, learning technologies, content, and assessments;
- to understand how constructivism forms the basis for inquiry-based science;
- to develop strategies for managing change in the broader context of your school and district; and
- to actively participate in the evaluation and adaptation of curriculum and technology.

## Contextual Issues of Professional Development

While many of the elements of professional development previously described within this paper are generic in nature and can often be found among a wide range of professional development programs, we have found that the context of the professional development activity can have considerable impact on the nature of the specific design of the PD program. Below are listed the details of two of the elements of the LeTUS professional development work in the Detroit Public Schools. Context is less specific with respect to the form of media used to convey the innovation to the teachers. The content of the professional learning is embedded within the curricula that teachers were going to be using in their work with the Center.

### Strategies

Teachers collaborate with other teachers and teacher support personnel both in the planning and teaching processes. Strategies centered on collaboration in the planning process include discussion focusing on future teaching activities. Support personnel who are experienced in work with a particular curriculum program provide teachers with insights into issues which may arise in the classroom which can be accommodated through careful planning. Such collaboration also allows support personnel and experienced teachers to recognize potential barriers an individual teacher may have within their classroom, and thereby provide advance assistance in providing remedies, either through collaboration and discussion with the teacher or with other support personnel who have shared similar experiences or challenges. Often these advance discussions include tutorials in the use of a particular tool or learning method, or personalized instruction on science content.

Enactment related strategies for professional learning focus on the use of various tools and techniques to promote use of constructivist teaching techniques and inquiry-based science instruction. Primary amongst these is the actual enactment by the teacher of an inquiry-based curriculum unit. This enactment provides a base experience upon which the teacher gains valuable knowledge about aspects of inquiry learning and the use of supporting technologies. Educative curriculum materials provide ideas and strategies for use of these techniques within the content-laden curriculum, support personnel collaborate with teachers to assist in the enactment of the curriculum. Support personnel with experience in this form of pedagogy may model teach a particular lesson or activity, allowing teachers to observe and reflect upon the enactment before they try the activity themselves. Similarly, teachers and support personnel use team teaching experiences to allow teachers new to the curriculum and its pedagogical approaches an opportunity to enact these strategies along with the support personnel, again, to model such approaches during the actual enactment.

There are a wide variety of strategies for providing professional learning experiences which focus on the reflection and adaptation elements of the CERA model. On numerous occasions, teachers examine student work to consider student understandings and misunderstandings evident within the work and share strategies and interpretations with colleagues to respond to student misconceptions. Teachers also examine and reflect upon their own practice as well as that of other teachers (either through video or site visits of other teachers' classrooms during teaching activities) in varying professional learning settings, focusing of the utilization of inquiry learning techniques. Prior to some of these reflection experiences, these educators engage in the development of personal goals for professional learning, which then act as a guide for directing this reflection. Collaborative reflection occurs as teachers work with curriculum developers and software engineers to examine the materials and tools used in classrooms in order to refine these items for subsequent use. Finally, teachers are asked to reflect upon activities in workshops and professional learning institutes which are designed to model desired pedagogical practices and analyze how such techniques were utilized within the experience and how they might apply to individual classroom practice.

Sites For Professional Learning

Professional learning within the LeTUS program takes place in a variety of "sites" or settings. The primary site for professional learning is the "educative" curriculum unit, which is designed to provide opportunities for enactment of the desired practices within a content-focused framework. These curriculum units provide a guided set of activities to engage students in the learning of science content focusing on a contextualized driving question. The units utilize activities which alter the traditional pedagogy of teacher-centered, information transmission to include facilitation of student learning through a process of inquiry and investigation, while making use of a variety of technologies designed to help students understand challenging and complex concepts. Embedded within these curriculum units are reminders and questions designed to engage the reader in self-reflection upon their practice. The curriculum units are used within the other sites of professional learning as the context for much of the content of those learning.

Three of the sites for professional learning are similar in nature, but provide a variety of experiences for teachers and are able to address different pedagogical issues (as well as change mechanisms) because of their structure. The first of these, a summer institute, functions as the "kickoff" activity for most teachers involved in the program, in that it provides the orientation to the LeTUS program and its underlying pedagogical concepts. The summer institute begins with teachers performing an inquiry based investigation similar to that of the curricula they will use during the school year. This two week institute then addresses content and pedagogy issues through a focus on the eventual enactment of one of the LeTUS curricula while utilizing many of the collaboration and reflection/adaptation strategies listed prior. Since this institute is the first exposure for most to LeTUS curricula, software, and professional development programs, primary focus tends to be on social and contextual factors such as risk taking as well as the intelligibility of these programs, so that teachers are able to make sense of the program and are willing to "buy in" to utilizing the different curricula and underlying pedagogy during the school year.

During the school year, two other similar sites for professional learning are utilized. Saturday work sessions are held throughout the year to allow the body of educators involved in the LeTUS program the opportunity to collaborate together to address concerns regarding the actual enactment of the curriculum while introducing activities to encourage daily reflection on a variety of issues during the enactment. Work sessions supplement the summer institute in providing various types of information and ideas about the curricula teachers are using, including timely information to respond to classroom challenges encountered by the group in their present and (immediate) future teaching. Additionally, after-school study sessions are also used to respond to similar issues, but tend to have more limited agendas, due to a lack of time and a specific interest by the teachers participating. For instance, a large percentage of the teachers may attend a Saturday workshop which would address broader concepts of contextualization of general science concepts within the world encountered by students. A study session, on the other hand, may draw 5-10 teachers, as it may focus on a specific topic, such as the use of a particular piece of software or the concepts and strategies of water quality testing as used within a specific curriculum. Yet, both strategies focus on supporting teachers with very current issues (within 1-2 weeks of their actual use within a classroom).

An even more timely element of the professional learning experience comes through the use of in-class support personnel. These individuals are experienced teachers with and understanding of the underlying pedagogical concepts as well as the specific content and activities of the LeTUS curricula. The support personnel visit the teachers' classrooms to engage in four primary forms of support for teachers: cognitive/pedagogical understanding, in-class teaching assistance, technology related assistance, and logistical or documentation-related activities. Support personnel visit teachers during the process of the enactment of the curriculum unit.

There are two sites of professional learning associated specifically with the LeTUS program which are not as dependent upon the direct intervention of the LeTUS personnel as the previously mentioned items, yet still employ many of the strategies mentioned above. The first of these involves collaboration among teachers involved in the LeTUS program (as well as educators external to LeTUS efforts) by the process of visits to other classrooms and schools to see other teachers' enactment of various curricula or pedagogical approaches which focus on student collaboration using technology in inquiry-based studies. The other is implicit for teachers within the LeTUS program, but does not specifically include intervention or participation through other sites of professional learning; it is the actual enactment of the curriculum by teachers. As is evident within the professional learning model for teachers...

Two other sites for professional learning are to be included in the design model for professional development for LeTUS, though they have not been in place (nor has documentation of usage occurred) as of the writing of this paper. Teachers in the LeTUS program will have the opportunity to take graduate extension courses focusing on inquiry-based learning in middle grades science classrooms. Teachers will also have a series of on-line resources available to assist with content and curriculum specific concerns, with information and ideas which compliment the other forms of professional learning which are currently taking place. These sites are being created to assist with the scale-up efforts inherent within systemic reform programs, and will likely become more dominant as the number of teachers involved increases.

## Methods

Using the framework for teacher learning described earlier in this paper, we pose a research question which will help inform the design of future professional learning opportunities within a systemic reform program. This question is posed of individual teachers as well as the collective body of educators involved in the enactment of the innovation: *How do design elements of professional development influence change mechanisms for teachers?* This research question assumes that there is some degree of influence of professional development upon any or all of the mechanisms for change of individual teachers, and that these mechanisms can be evaluated at some level.

In order to examine this question, a variety of data are collected to give a picture of the impact of professional development programs, and to provide insight into potential modifications which must be made to the overall plan for professional development. While this paper does not address all of the data collected through these efforts, it does examine a number of activities and events that have factored into design of new professional learning activities. We will focus specifically on this data.

Teachers who become involved in the LeTUS program are given an initial survey to collect background information about their educational and teaching experience and to inquire about beliefs and attitude about concepts of science, science education, technology and its use in classrooms, and the schools and children with whom they work. This extensive survey presents a picture of the teachers' K/B/A before they begin involvement in the LeTUS professional development programs. A small group of teachers are also interviewed at different points in their participation to further examine their beliefs and attitudes about these issues and to help describe the influence that the LeTUS program has had on their teaching and learning.

There is extensive documentation of the large group professional development activities which allows a mapping of beliefs and attitudes for individual teachers (as well as the group) to specific PD activities or goals, which in turn, may provide insight into teachers' perceptions of content, pedagogy, student abilities, etc. (content of PD) presented or addressed within the PD activity. This can provide information about subsequent needs for professional learning for these teachers, and drive the design of new PD activities. Documentation of large scale PD activities takes place in a variety of formats. First of all, in the planning of any such activity (Summer Institute sessions, Saturday work sessions, after-school study sessions), a set of goals and plan of activities are developed, which are presented explicitly to all participants at the beginning of the session. These documents may provide a map of the design which went into the PD activity, including the priorities and concerns for that particular session. The actual activities of any such session are then video-recorded during the session, so as to note the actual events of the activity (which may differ from planned events). Often, these activities may involve the creation of some artifact, such as a list of brainstormed items for teachers to consider when enacting a particular segment of the curriculum. These artifacts are collected at the end of any activity so that they may provide further representation of the ideas and perceptions of teachers as they are involved in the PD activity. Finally, an evaluation/reflection form is completed by teachers participating in the event. This not only serves to provide feedback on the overall value of the workshop as perceived by teachers, but also asks that they focus on the specific goals of the workshop as well as their own professional learning needs, and evaluate specific activities of the session for their impact on these factors.

Similar, though not as thorough, documentation occurs for individualized support for teachers. Support personnel maintain a planning and event calendar for each teacher they work with, noting specific topics and issues which are addressed (or are planned by teachers to be addressed) in the classroom, and keeping track of when support visits occur and the purpose of these visits. Following a specific visit, the support teacher will record field notes on the events which occurred in the classroom during their visit and on the ways in which they provided support to the teacher. In some instances, video documentation is also collected during one of these visits, in planned agreement with the classroom teacher. These notes not only provide documentation for long term analysis of individual and collective teacher needs and activities, but they also provide notes for immediate use in providing support for the following days or weeks. Support members also meet regularly to share ideas and concerns brought back from their experiences in the classroom to develop strategies for working with varying teacher needs. Their feedback is crucial in the development of other professional development programs, such as the Saturday workshops, the development of the educative curricula, and development of on-line resources for teachers. Finally, evaluation of in-class support is requested of teachers near the end of a unit, which provides information about the types of support requested by the teacher and the value of the support received in varying categories.

## Research Findings and Input for an Iterative Design Process.

### Example 1: Research to Demonstrate Teachers' Changing K/B/A

As mentioned previously, one of the necessary elements of the professional development process is to address any and all of the change mechanisms which, in turn, affect teachers' K/B/A sufficiently so that any one of them is not a perceived barrier for a given teacher to refrain from the enactment of the innovation in their teaching. Documentation of teacher responses in interviews and work session evaluations provides research input to the design process which can help focus future PD activities. Additionally, the field notes of in-class support personnel provides feedback on the actual impact of the PD activity in the classroom by describing the actual enactment of an activity or topic addressed in the PD activity. Finally, video documentation of the PD activities and classroom sessions can provide further information as to the impact of the PD activity on the teachers' K/B/A. By mapping these responses or comments to specific strategies or activities of the work session, we can examine whether or not a teacher (or the collective group of teachers) has altered his or her K/B/A as a result of the PD activity, and subsequent PD needs may then be determined. Table 1 below suggests a mapping of these comments to address the desired change mechanisms or K/B/A for a sample set of PD activities.

**Table 1.** PD Design Elements and Evidence of Their Impact on Teachers K/B/A.

| Content | PD Activity Addressing Content | Evidence of Change in K/B/A |
|---|---|---|
| Pedagogical Knowledge (PK) – Creating effective collaboration within groups of students | ♦ Collaboration Activity in Summer Institute (Broken Squares activity, which calls for groups to assemble a series of squares from random shapes without communicating with the group, and subsequent debriefing and reflection)<br>♦ Discussion with teacher following observation of classroom activities designed to encourage collaboration among students. Discussion was with In-Class Support person who focused on getting the teacher to reflect on the impact of their activity. | ♦ Observations of teachers' engagement in the activity during the Summer Institute and subsequent discussion revealed that teachers often never considered many issues in the design of classroom activities involving grouping of students., but were now aware of these issues.<br>♦ Observations of classroom practice reveal that a particular teacher who was averse to using student groups prior to these activities was now establishing a set of practices encouraging student collaboration, including physical grouping of students, sharing of tasks among students, and group oriented tasks and assignments.<br>♦ Comments from the teacher to in-class support personnel revealed a belief in the use of collaboration, and sought out additional input regarding specific activities which could be used in subsequent class activities. |
| Beliefs about contextual norms | ♦ Brainstorm activity in the summer institute which brought up issues which must be addressed by teachers in planning for the enactment.<br>♦ Subsequent discussion activity which encouraged small groups of teachers to develop plans for addressing contextual issues within their schools or classrooms to prepare for enactment.<br>♦ Teachers negotiate with administrators to coordinate the curriculum enactment in their school. | ♦ Artifacts from the summer institute included a list of all of the brainstormed planning concerns which need to be addressed on a school or classroom level in order for the enactment to occur successfully.<br>♦ Field notes of in-school support personnel reveal that teachers have coordinated curricula, schedules, and room assignments to allow access to computers and to allow students to be involved in contextualizing activities which require advance preparation and specialized settings or facilities. |
| Content Knowledge (CK) – Knowledge of Newton's 1st Law of Motion | ♦ Investigation activity held during the summer institute had teachers using a ballistic cart to attempt to demonstrate Newton's 1st Law of Motion.<br>♦ Teachers' enactment of the curriculum which used a similar activity to demonstrate the Law. | ♦ Artifacts of the summer institute reveal that many teachers initially speculated an incorrect understanding of the application of this Law.<br>♦ Subsequent artifacts, including video documentation of teacher discussion and presentations reveal that a teacher in question now was able to describe an application of Newton's Laws on their own.<br>♦ Field notes from the in-class support person reveal that the teacher was able to engage successfully in the activity in class and guide student discussion so that students could also understand this concept.<br>♦ Evaluation from the summer institute reveals that the teacher perceives a change in her knowledge of this concept. |

<u>**Example 2: Research Which Influences the Design of Professional Development.**</u>

As with any educational program, sometimes, the effect of the effort does not match the design of the effort. When this occurs, the effect of the effort needs to be examined to determine what happened to the original design to alter its desired outcome. Such is the case with professional development programs as well, especially when working with a diverse group of teachers. The previous examples note individual changes in K/B/A as well as the constructs which aided these teachers in the change process. However, most of the professional development efforts are designed for a large groups, and so, must try to attend to collective needs. This again becomes a design challenge, which can be assisted through the use of a variety of data.

Such was the case with a Saturday workshop held in March 2000. This workshop focused on acquainting 12 teachers with two primary elements of the water quality curriculum: the use of Model Builder, a software tool used by students to define and visualize complex relationships (in this case, related to concepts of a watershed), and the preparation and implementation of an activity designed to have students build physical models of a watershed, noting water runoff, topography, etc. The activities used tutorial strategies and relied upon small groups informing each other, with each group containing an experienced teacher who had enacted this activity in a classroom at least once before (though not necessarily using pedagogical practices which encouraged understanding by all students). However, despite several attempts to facilitate this activity, observation of the models created showed little evidence of any knowledge building other than a familiarity with the aspects of the software. Evaluation forms revealed that those with experience felt they had learned nothing new, and were still unsure of how to successfully utilize the tool in their classroom. The same evaluations revealed that teachers new to this tool either felt completely lost or extremely confident in their ability to use it, despite the observations and artifacts of this session which would contradict this.

This information was used to design a subsequent Saturday workshop on the same topic. Evidence from the prior workshop noted that the group as a whole was only familiar with the software, but did not completely understand concepts embedded within it, such as graphical representations of relationships, or pedagogical principles involved in getting students to use these tools. Using this, and evidence from pre-post tests on the water curriculum unit around which this collection of workshops was focused (which demonstrated that students are particularly challenged by line graph representations of data, which are used in this software tool), the professional development activity was designed to focus on student work. In this manner, teachers would not only gain familiarity and comfort in the use of this software, but they would also examine student challenges in working with this tool. Sample models were created to demonstrate student challenges with graphing, as well as other research based challenges (Krajcik et al., 2000) in using these tools. Teachers were asked to review the models and, within small groups, develop assessment strategies to evaluate student learning. They then focused on developing strategies for using this tool with their students, including the introduction of the tool, focus on content modeled in the software, and management strategies for working with groups of students using this tool. Subsequent evaluations and artifacts created from this PD activity showed more understanding of the use of this tool as well as greater perceptions of understanding of the pedagogy by the teachers. In-class support personnel notes from the field will reveal the effect of this activity on enactment, and may provide additional input for supplemental professional learning centered on this software tool or the scientific concepts embedded within the activity.

## Conclusion

The design process for professional development requires a program of research on the impact and effectiveness of professional development activities. This research cannot simply focus on standard evaluative remarks by teachers on their perception of the professional development activities. Rather, the research must address elements of the design framework which impact teacher learning. As stated in the description of the design of the program for professional learning, individual teachers all have a perceived "path" of learning which will lead them from traditional transmission models of teaching to inquiry-based approaches to instruction. Our design approach attempts to create a system of professional development for innovations in systemic reform environments that will address these multi-faceted needs.

Using the framework for teacher learning described earlier in this paper, we pose a research question which will help inform the design of future professional learning opportunities within a systemic reform program. This question is posed of individual teachers as well as the collective body of educators involved in the enactment of the innovation: How do design elements of professional development influence change mechanisms for teachers? This research question assumes that there is some degree of influence of professional development upon any or all of the mechanisms for change of individual teachers, and that these mechanisms can be evaluated at some level. In order to answer this question, each of the following issues must be tracked to give a sense of how the professional development program is influencing possible change mechanisms, and thereby the K/B/A of teachers:

- What are the necessary "thresholds" of each of the change mechanisms for teachers to attempt to enact and adapt an innovation in their own teaching?

- Are the professional learning programs addressing all of the change mechanisms adequately to promote change for all teachers involved?
- What is the content of the professional development efforts? Is this changing over time to address the "trajectory" for long-term teacher learning?
- What are the changes over time in each of these elements? How do the change mechanisms and related K/B/A of teachers vary with exposure and experience in the reform program? How are the professional development activities modified to address this variance?

To date, we have preliminary evidence to support our initial design decisions with respect to professional development. We have been able to react to data about teachers' needs and past professional development results in order to develop new professional development opportunities that better address teachers' needs. As this work continues, we will turn our attention towards: fine tuning our data collection mechanisms; seeking a more refined understanding of the relationship between conceptual change mechanisms and teachers' evolving K/B/A; and the continual evolution of our professional development designs themselves based upon our research. Design is never finished.

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