Impact of Professional Development on a Teacher and Her Students: A Case Study

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One of the most difficult challenges in research on teacher learning is identifying and documenting linkages between teacher learning, classroom practice, and student learning (Loucks-Horsley & Matsumoto, 1999; Wilson & Berne, 1999). Demonstrating convincing evidence of this proposed linkage is important, especially in a policy climate that emphasizes accountability in terms of student test performance (e.g., U.S. Department of Education, 2001). The development of rigorous academic standards (e.g., American Association for the Advancement of Science, 1993) and an increased emphasis on systemic reform (Smith & O'Day, 1991) as a means of fostering educational change pre-date the current accountability emphasis, but operate in combination with accountability to create a greater demand for high-quality teachers of science. Professional development is frequently cited as the cornerstone of any reform effort that hopes to create systemic changes leading to improved student performance on academic standards (Committee on Science and Mathematics Teacher Preparation, 2001), and many recent funding efforts have sought to focus attention on teacher learning and its role in fostering improved student learning.

Though it has long been assumed that improving teachers' knowledge leads to subsequent changes in practice that positively impact students' learning, there are relatively few studies that attempt to establish the veracity of this assumption, and methodological constraints in the extant studies raise questions related to their validity and applicability. One of the most frequently cited studies in this area relies on teacher self-report data about changes in their own practice and their students' learning (Garet, Porter, Desimone, Birman, & Yoon, 2001). Another study relies on state-level high stakes testing data, but the description of the professional development and classroom enactment is specified at only a general level because of the wide range of participants and contexts described in the study (Supovitz, Mahyer, & Kahle, 2000). The present study addresses these limitations by focusing on teacher learning within a specific science curriculum reform initiative, where the researchers have access to detailed information about the design of the professional development, classroom enactment practices, and both proximal and high-stakes student learning data over time. This research is part of a series of studies with the goal of defining and testing an approach to conducting research on professional development that illuminates the linkages between professional development and student learning, and also explores mediating changes in teachers' knowledge and beliefs. In the past we have reported on both the underlying logic of our approach (Fishman, Marx, Best, & Tal, 2003) and on the first tests of our approach to studying how teachers learned from specific instances of professional development and how that learning translated into changes in classroom practices and student learning (Kubitskey, Fishman, & Marx, 2003). This paper takes the next step, by using our research approach to conduct an in-depth case study of a single teacher in order to demonstrate the range of ways that professional development activities related to a particular curriculum unit impact her beliefs and knowledge, her classroom practices, and her students' learning.

We begin with a description of goals for a professional development program designed to support systemic adoption of inquiry-based curricula, and a model of teacher learning that describes the major elements of a teacher change process involving professional development. Next, we discuss our design approach to professional development that we use to create professional development aligned with our goals, and to assess the success of that professional development. Our design approach to professional development also allows us to conduct research into the characteristics of quality professional development in practice. We then report evidence in the form of a case study of one teacher that allows us to gauge the success of our professional development in meeting core goals, as well as demonstrating our design approach in use.

Literature Review and Theoretical Framework

Goals for Professional Development

We employ a set of goals for professional development that draws from a range of literature on teacher learning in science education and inquiry-oriented approaches to learning. Local and national professional development standards inform these goals designed to assist teachers in the implementation of the adopted inquiry-based science curriculum, (National Research Council, 1996; National Staff Development Council, 2001; Watkins Jr., 2003). These goals are:

1. Create an environment that encourages teacher *"buy-in."*
2. Create a *professional community of learners.*
3. Improve teacher *science content knowledge.*
4. Improve *pedagogy for science inquiry*.
5. Increase use of *inquiry science instruction.*
6. Increase *student learning of science*.

These goals fall into three distinct but interdependent categories: *social constructs* (buy-in and professional community), *content* (subject matter and pedagogy for inquiry), and *impact on practice* (practices in classrooms and student learning).

Social Constructs

Professional learning communities leverage social aspects of knowledge construction (Putnam & Borko, 2000). To create a professional community of learners, teachers need to "buy-in" to the value for professional development (Supovitz & Zeif, 2000). Teacher buy-in results when teachers believe in the value of the professional development in supporting their instructional practice. This is not strictly cause and effect, as these may emerge simultaneously. For example, teachers may reluctantly attend required professional development, assuming it will be a waste of time, but are surprised to find the activities worthwhile. They engage in the community, and finding that helpful, find the professional development relevant. Thus participation in the community and "buy-in" are mutually constructed.

Professional communities of learners thrive where collaboration, experimentation and challenging discourse exists (Loucks-Horsley, Hewson, Love, & Stiles, 1998), and are an essential component of professional development (National Research Council, 1996). Teachers, by participating in professional development, situate themselves in a professional community of learners, though levels of participation vary. This does not guarantee improved teaching, and may in fact deter from such growth if the time is spent reinforcing misconceptions and/or discontent (McLaughlin & Talbert, 2001). However; if carefully moderated, participation in a professional community of learners can lead toward increased subject matter and pedagogical knowledge by creating an atmosphere for learning which takes advantage of the distributed expertise of the participants (Lave & Wenger, 1991). Also, teachers engaged in professional learning communities are more likely to improve their practice and that change has greater sustainability within those communities (Richardson & Placier, 2001).

Content Knowledge

Both national and state professional development standards include subject matter content and pedagogical knowledge as a necessary precursor to inquiry-oriented teaching (Blakeslee & Kahan, 1996; National Research Council, 1996). Subject matter content refers to the body of scientific knowledge teachers are expected to know to instruct children whereas pedagogical knowledge is that which supports teachers in instruction for understanding that has shifted from content/teacher-centered to student-centered (National Research Council, 1996). This proves problematic because many teachers are satisfied with "facts" and do not "buy-in" to a need for professional development, as they believe "facts" have served them well. Problematizing pedagogy is also difficult, as many experienced teachers do "labs" and "hands-on" activities with "cooperative learning groups" and thus believe they understand inquiry pedagogy. In both cases the teachers have not problematized their practice and do not "buy-in" to the need for professional development. Creating situations that challenge these beliefs increases the probability of teachers valuing professional development and engaging in learning both content and pedagogy.

Impact on Practice

Learning from professional development is not sufficient if it does not result in improved classroom instruction. Therefore, one essential goal of professional development is to influence teachers' classroom practices. Richardson (1996) suggests that such a change can occur after a change in teacher beliefs, thus reemphasizing the essential "buy-in" component of the professional development plan. Little research exists linking professional development participation to improved student learning (Garet et al., 2001; Loucks-Horsley & Matsumoto, 1999; Supovitz, 2001), and that which does is often anecdotal or based on self-reporting surveys across a wide range of programs which, although interesting in the aggregate, does little to inform specific professional development programs as it makes generalized claims in nonspecific contexts, despite the claim that professional development is context specific (Garet et al., 2001). Such work can inform professional development designs, but cannot define them. Instead, we turn to theories of teacher learning and change from a broad range of perspectives to inform our initial professional development design.

A Model to Describe Teacher Learning

Our model of teacher learning is shown in Figure 1, below. This model places teacher knowledge, beliefs, and attitudes in a reciprocal relationship with student learning, classroom enactment, and professional development activities themselves.

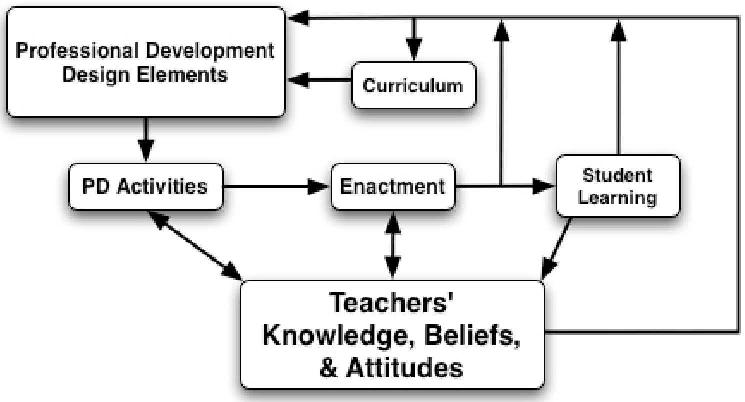

Figure 1. A model of teacher learning.

We take teachers' knowledge, beliefs, and attitudes to be the aspects of teacher cognition that are affected by participation in professional development; they are therefore central to our model of teacher learning in professional development. We characterize teacher knowledge using the major categories of content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK) described by Shulman (1986; 1987). We also acknowledge two distinct *classes* of knowledge, defined by Ryle (1949) as "knowing that" and "knowing how." Teachers' "knowing that" is the body of knowledge teachers express when describing their understanding. Teachers' "knowing how," on the other hand, manifests itself in teacher practice. We follow Richardson's (1996) stance that teachers' knowledge, beliefs, and attitudes are formed interactively with classroom practice (or enactment), with each one sometimes preceding the other. Our model of teacher learning therefore links enactment directly and reciprocally to teachers' knowledge, beliefs, and attitudes.

Evidence of student learning can provide a powerful impetus for changing teachers' knowledge, beliefs, and attitudes. As they teach, teachers intuitively look to their students for feedback about the instruction. Sometimes this feedback is affective in nature (e.g., "My students enjoyed themselves," or "My students were all engaged in what we were doing."). Sometimes this feedback is cognitive in nature (e.g., "My students' answers were evidence that they understood the concepts being taught."). In either case, this information forms a key component of a feedback loop for teachers (Richardson, 1996). Evidence of student performance can come from immediate, close, proximal, distal, or remote sources of assessment (Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002). Immediate measures of student performance include examinations of student journals or notebooks, while close assessments might include teachers' judgments of student learning from observing their interactions in class, or from embedded assessments in curriculum materials. Large-scale standardized assessments that are aligned with curriculum frameworks are considered distal to classroom practice, while national-level assessments are remote.

We argue that "curriculum" holds a central place in any model of teacher learning, because curriculum represents that which teachers are directed to teach in classrooms (Cohen & Ball, 1999). Ideally, all professional development, whether it is focused on curriculum materials or not, will help teachers to successfully enact the curriculum to teach the students. In our work, which is focused on helping teachers enact *particular* inquiry-oriented materials, curricula is *central* to our overall professional development efforts. Some researchers have argued that curriculum materials are themselves a potential source of professional development, when they are designed to be "educative" (Ball & Cohen, 1996).

In order to meet our ultimate goal for professional development, improved student learning, we use our model of teacher learning to guide the design of our professional development. We are less concerned with identifying a distinct "moment" at which learning might occur, and more concerned with understanding the impact of the amalgam of opportunities for teacher learning on student learning. Thus we employ an iterative approach to professional development design that adapts to meet the needs of both the teachers and the students whom they teach, discussed below as part of the methods used in this study.

Professional Development Design Research

To examine the combinations of characteristics within any particular professional development activity, we developed a design research approach that is cyclical in nature (see Figure 2). Our professional development is first informed by the national science *standards* (e.g., American Association for the Advancement of Science, 1993) and curriculum materials based on those standards (Singer, Marx, Krajcik, & Clay-Chambers, 2000), in order to ascertain *what we want students to learn*. We investigate *evidence of student performance* by evaluating student artifacts, classroom behavior, and pre- and posttests aligned with the curriculum units. Using this information, we develop an initial *professional development design* to inform the teachers' practice. After teachers participate in a professional development activity, we interview selected teachers about their attitudes and beliefs about the professional development; what they found helpful and why, what they would use in the classroom, etc., in order to *evaluate the professional development*. We then *observe classroom teaching* during the enactment of a lesson covered in the professional development. We interview teachers after their enactment of the observed lesson, asking for reflection on the activity and whom they credit for influencing their instruction. We collect student artifacts and give pre- and post tests to *evaluate student performance* and use this information to redesign future professional development.

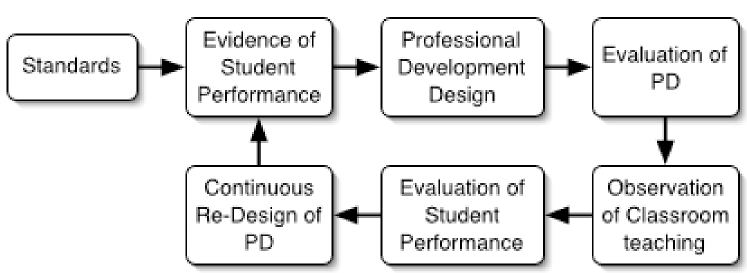

Figure 2: Design research approach for studying professional development.

Prior Work Using Our Design Research Approach

In previous work we examined the content contained in professional development related to the 2002 enactment of the Communicable Disease unit (described below), the strategies used to convey this content and how participation influences teacher learning and the resulting student learning to inform the next iteration of the professional development design. We observed the five workshops aligned with communicable disease, interviewed and observed the teaching of seven of the fifteen teachers enacting the unit during that year and analyzed measures related to student learning from the unit. Our analysis of the professional development identified types of professional development instructional strategies and content of professional development which impacted teachers' instructions and resulted in student learning (Kubitskey et al., 2003). This analysis suggested that our workshops were most effective in terms of impacting teacher practice and student learning when they employed the following strategies:

- model teaching (having the teachers do the pivotal investigations from the unit with the workshop leader acting as teacher),
- peer exchange (having the participants share their ideas), and
- limited direct instruction (workshop leader lecturing to teachers).

We found the content of the workshop should include opportunities for teachers to:

- set up scientific investigations as well as practice conducting them
- incorporate scientific knowledge,
- discuss the impact of various adaptations of the unit on the unit as a whole,
- discuss transitions from one lesson to another.

In the present study, we analyze the content and professional development instructional strategies of the workshops for the 2003 Communicable Disease unit enactment and focus our research on the impact of these workshops on one teacher's practice and the resulting student learning in order to get a finer tuned understanding of the advantages afforded the teacher by her participation in the workshop in order to meet our goals of professional development: teacher "buy-in", participation in community of learners, learning content knowledge which impacts practice and student learning.

Methods

Context and Setting

This study takes place within the larger context of an ongoing research collaboration between the Detroit Public Schools and the University of Michigan called the Center for Learning Technologies in Urban Schools (LeTUS). LeTUS work has included extensive curriculum development (Singer et al., 2000), design and integration of technologies to support student and teacher learning (Marx, Blumenfeld, Krajcik, & Soloway, 1998), broad-based professional development (Fishman, Best, Marx, & Tal, 2001), and collaboration with teachers and school and district administrators (Murray, Fishman, Gomez, Williams, & Marx, 2001). The core of the LeTUS collaboration is the curriculum materials. To date, five different units have been developed for 6th, 7th, and 8th grade science on the topics of air quality, water quality, communicable disease, force and motion, and mechanical advantage. Each unit is constructed according to principles of project-based science (Blumenfeld et al., 1991; Krajcik, Czerniak, &

Berger, 1999), built around a central driving question anchored in a real-world problem, such as "What is the quality of air in my community?" Other features of these units are: investigations and artifact development that provide opportunities for students to learn concepts, apply information, and represent knowledge around the driving question; collaboration among students, teachers, and others in the community; and use of computational technological tools to promote inquiry. Each unit is designed to take between 8 and 12 weeks to enact, or roughly one marking period (Singer et al., 2000). These units are now used by nearly 33% of all middle school science teachers in Detroit, and are one of two district-approved sets of materials for teaching middle-grades science. Throughout the seven-year period where these curricula were developed and adopted for use by teachers in the district, students have improved in their learning of science content as demonstrated both by improved pre-post test gain scores directly aligned with the units (Marx et al., in review). Furthermore, students who participated in at least one LeTUS unit significantly outperformed their peers, both within school and within district on the state standardized science test administered in the 8th grade (Geier et al., in press).

In this study we focus our work on the a 7th grade unit on communicable disease with the driving question, "How Can Good Friends Make You Sick?" This unit teaches microbiology, cells, systems and characteristics of diseases while investigating the spread of disease. Students have an opportunity to conduct their own investigations and use technology in the form of a handheld computer program called "Cooties" that simulates the spread of disease, an online reference tool called "Artemis," designed to support student search and inquiry, and multimedia software designed to describe how disease is spread. Through these multiple means of investigation students have opportunities to create their own understandings of the science.

Professional development activities for this unit consist of four Saturday workshops, two during January, and one each during February and March. Until the 2001/2002 school year, the design and implementation of these workshops was primarily the responsibility of the university staff who had developed the unit. In 2002/2003 this responsibility shifted to "lead teachers," teachers who had demonstrated success with the LeTUS inquiry-oriented units (both through observed classroom practice and through their students' performance on pre and posttests). The process of identifying and supporting lead teachers is the focus of ongoing research by our group (Fishman, Fogleman, Kubitskey, Peek-Brown, & Marx, 2003). We mention this transition in professional development leadership here to highlight the fact that the workshops described in this study were led by lead teachers, though informed by the design principles from our prior research (Kubitskey et al., 2003).

Participant

Ms. Konig (a pseudonym) is an African American woman in her early 30s with 7 years of teaching experience ranging from 3rd to 7th grades. Although she participated in LeTUS the previous year (the 6th grade curriculum), this was her first year teaching 7th grade. Nineteen Detroit Public Schools teachers adopted the communicable disease unit in 2003: 10 African American women, 4 white women, 2 African American men, and 3 white men. The teaching experienced ranged between beginning teacher not yet certified teacher to teachers with almost 30 years experience. Ms. Konig is demographically a typical representative of this group, as most were new to communicable disease, African American women experienced in teaching science. Overall, the mean pretest score of 7th grade students of these teachers was 6.89 out of

29, with a range of 4.65-10.81, whereas Ms. Konig's students averaged 7.64, just placing her students in the top quarter of the participating students. Posttests scores ranged 6.30-16.64, with a mean of 11.47. Ms. Konig's students' average score was 14.98, placing them almost in the top 10% of teachers. Her students showed significant gains across the content, with the second highest gain score (7.83) and the second highest effect size (2.77).

Data Collection Activities

We attended each of the four workshops designed to support the 2003 enactment of the communicable disease unit. During these workshops we recorded running records of the activities. As regular attendees at the workshops, our presence was not obtrusive (Emerson, Fretz, & Shaw, 1995) and we participated when called for by the lead teachers, the participants or if the occasion arose where sharing our expertise seemed warranted. We coded each activity with respect to the science content; technology, disease, microbiology, cells and systems as technology use is an integral part of the unit throughout and the unit is designed to teach later four science content and test explicitly for these in the pre and posttests (see Table 1). We specifically identify knowledge for use of technology as it is a central theme of our curriculum and thus identify this separately. Finally we coded for the instructional strategy employed by the lead teacher to teach the participants how to enact the lesson; direct instruction, peer exchange, model teaching, curriculum review, recitation discussion, information exchange, technology set up and planning (see Table 2). We coded for technology as it is integral to the unit. Disease, microbiology, cells and systems are the four main components of the unit, and the subsets for the pre and posttest. Planning is an integral component to curriculum-based workshop support. Finally, as building a community of learners is a goal of our professional development, we coded for specific instances designed explicitly to meet this goal.

Table 1. Codes used to describe topics in Communicable Disease workshops.

Topic	Definition	Example
Technology	The use of computers or handheld computers.	Directions for accessing online support or search engines. Use of software on computers or hand held computers.
Disease	Characteristics of the spread of disease.	Information about transmission of sexually transmitted diseases.
Microbiology	Characteristics of bacteria and viruses.	How bacteria grows. Difference between bacteria and cells.
Cells	Characteristics of cells.	Difference between plant and animal cells.
Systems	Body systems.	What the systems do e.g. the respiratory system helps us breath.
Planning	Information need for the mechanics of enacting the unit.	Information about passing out permission slips, what chemical needs, how to adapt the lessons in shorter time etc.
Community	Designed to create community amongst teachers.	Icebreaker: Pass out 3 playing cards to each teacher and teacher has to select card that best represents him/her and why.

After each workshop we interviewed the focus teacher to get an understanding as to what she felt was salient from the workshop, what was helpful, and if she thought she would use the information in her teaching. We asked further question related to activities from the workshop not mentioned by the teacher as a means of measuring the impact of the workshop as a whole and not merely that which the teacher recalled at that moment. In addition, we listened for markers to expand upon during the interview (Weiss, 1994) which was transcribed into text.

We made classroom observations of Ms. Konig's classroom enactment, selecting three activities to observe which aligned with both the curriculum and the workshop: a spread of disease activity, the bacteria investigation, and a simulation activity on handheld computers, called "Cooties." The spread of disease activity has students exchange water solutions, one or two of which, unbeknownst to the students, have been "spiked" with a base. After the exchange, the teacher places an indicator in each student's water cup to identify those that were contaminated by the base, demonstrating how "interactions" lead to the spread of "germs." The bacteria investigation has students develop scientific questions about bacterial contamination of various areas in the school, form hypotheses and test the hypotheses through experimentation. The "Cooties" activity uses Palm computers to simulate the spread of disease. We observed these lessons, taking running records of the enactment. Because of our past relationship, we often worked as classroom support for the teacher, and this continued during these observations, however any intervention on the part of the observer/classroom support person was noted in the observation notes. During our observations we took jottings we transposed into field notes (Emerson et al., 1995). From our observation field notes we compared the enactment by the teacher to both the instructions in the unit as well as the directions from the workshop. We identified strengths and weaknesses in both the content and pedagogy as a means of evaluating the effectiveness of the professional development designed to support the instruction.

Table 2. Codes used to describe strategies employed in Communicable Disease workshops.

Code	Description	Example
Direct Instruction	Workshop leader lectures on a certain topic designed to teach a topic.	Lecture on phases of the moon.
Peer Exchange	Teachers share ideas with one another.	Teachers discuss ways in which they uses quizzes to support readers
Model Teaching	Workshop leads activity as if teaching students participating in the curriculum.	Teachers play "chemistry concentration."
Curriculum Review	Going over the printed curriculum.	Teachers look through the explanation part of the curriculum, as it is new, and the group discusses the new approach.
Recitation Discussion	Workshop leaders give presentation with continual interactions with the teachers as a group.	Lead teacher says we need to have the students learn about atoms. Asks "What do we know about atoms?" Teacher responds with characteristics of atoms.
Information Exchange	Workshop leaders share information, not necessarily with the goal to teach the topic.	Review of MEAP scores (Michigan's standardized test) of the district.
Technology Set up	Setting up technology not within the context of model-teaching.	Learning how to access online support.
Planning	Going over ideas for how to implement the curriculum.	Teachers discuss how to cover important content and still complete unit on time.

We interviewed Ms. Konig after she taught the lessons, formally through targeted interviews recorded and transcribed, as well as informally through telephone and in-person conversations over the course of the unit and thereafter. These interviews were used to confirm the interpretation of the observer during the lessons as well as verify the link between the teachers' enactment and the professional development.

Students participating in the unit took a pre and posttest designed specifically to measure student learning in the unit. First we identified questions which aligned with the various activities covered in the workshop and aligned these with Ms. Konig's comments about those activities. Next, we compared the workshop activities as aligned with the four main content areas; microbiology, disease, cells and systems, with the gain scores and effect size on the tests. Finally, we identified questions aligned with the observed classroom lessons and workshop activities to gain a qualitative measure of the student learning as demonstrated on the test through gain scores (difference between the mean post and pretest scores) and effect sizes (the gain score divided by the standard deviation of the pretest).

Findings

We examined the impact of professional development on Ms. Konig's teaching to determine how participation impacted her teaching and student learning, whether the professional development met our goals designed to support inquiry instruction and what we can learn to inform the professional development cycle. We present these findings in terms of the three broad categories we defined for our professional development goals: Social constructs (buy-in and professional community), content (subject matter and pedagogy for inquiry), and impact on practice (practices in classrooms and student learning).

Social Constructs:

By creating a professional development environment that brings together teachers who are teaching a common curriculum in similar conditions, we create an atmosphere conducive to creating a community of learners. Ms. Konig commented on this aspect of the professional development, and in each post-workshop interview she specifically expressed the value of getting together with other teachers and sharing their expertise and experiences. This was often the first thing she mentioned at the onset of the interview when asked what she found useful about the workshop. First she valued the exchange as a means of learning from more experienced teachers: "Actually having a chance… to hear from other teachers who have taught the lesson before…it helped me because it gave me ideas about dealing with things." Second, these communal experiences were also a way to help her deal with the frustration that can sometimes be inherent in attempting a new style of instruction. When asked about the teachers sharing their progress with the unit, Ms. Konig responded, "I'm glad we did that because [another teacher] and I were saying the same thing, 'We must be so behind.'" The discussion helped her realize that others were having the issues with timing. In addition, Ms. Konig contributed to this exchange. During the interview Ms. Konig stated, "I kept thinking about one of those reading strategies…from the [earlier] workshop." She shared the strategy she adopted with her students, providing examples of her students' work. Building this sense of community is building both support from experts to novices, as well as comfort from a shared experience (Grossman, Wineburg, & Woolworth, 2001).

LeTUS teachers have a range of motivations for participating in professional development. Not all LeTUS teachers are volunteers, as some are "volunteered" by administrators and others in position of authority, as was the case for Ms. Konig. Teacher "buy-in" thus becomes an essential component for the sustainability of the instructional reform initiative. Although each of the goals lends itself to teacher buy-in, teachers' continued participation with LeTUS and its continued growth over its lifetime suggests teachers are buying in to adopting project-based science and the LeTUS curricula. In 7th grade alone, teacher participation has grown over the past six years from 10 to 30 teachers enacting the units during the 2003-2004 school year (note that this tally includes years after the year described in this case study). During her first year with LeTUS (2001-2002), Ms. Konig taught 6th grade. In fact, Ms. Konig initially was not satisfied with the 6th grade curriculum but continues to participate because, as she stated, she is a "team player" and she liked the opportunities that workshops gave her to interact with other teachers. She also attributed her early discomfort to being new to project based science. She was much more satisfied with the 7th grade curriculum and continues to participate to this day, possibly due to being experienced in project-based science and the content itself. In Ms. Konig's case, the buy-in did not happen immediately, however her induction into the community of learners helped facilitate her later buy-in.

Content Knowledge

In a previous study (Kubitskey et al., 2003), we concluded that strategies of professional development consistent with facilitating desired changes in practice include model-teaching and peer exchange, as direct instruction did not seem to significantly nor consistently impact teachers' practice. Our analysis of the workshop revealed that the lead teachers had abandoned direct instruction as an professional development instructional strategy and, in this case, primarily adopted a model teaching strategy for the workshops with approximately 45% of the workshop time allotted to model teaching, with multiple opportunities for teachers to participate either through peer exchange or recitation discussions (approximately 30% of the time), (Figure 3), which aligns with the suggestions from our previous work.

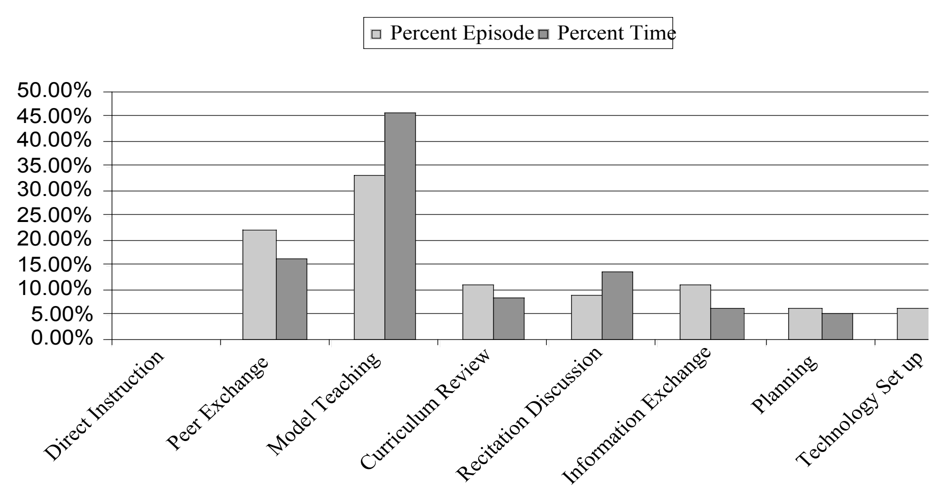

Figure 3. Instructional strategies used in Communicable Disease workshops.

In addition, we suggested the content of the workshop needed to include opportunities for the teachers to actively try out activities they were to teach, as well as set up the apparatuses necessary for the activities, science and technology subject-matter knowledge, and hold discussions about the impact of changing the activities on the surrounding lessons as well as the unit as a whole. These workshops met this first requirement by having teachers enact the three main laboratory inquiry activities and set up two of three. In addition, the teachers set up and enacted the three major technology related inquiry activities over the course of the workshops, thus informing the teachers' pedagogical knowledge. Ms Konig credited the workshop with informing her pedagogical knowledge as she expressed appreciating the multiple opportunities to run through lessons and set them up as reminding her or helping her prepare for the activities. We also suggested that workshops should include more content knowledge, in this case both science and technology. The teachers had ample opportunity for learning the content they needed to teach the children, including discussions about disease, microbiology, cells and systems. However the depth of the science content knowledge did not extend beyond middle school level science. From the analysis of the workshop, we identified the frequency and duration of coverage of science content. Over 30% of the time was spent teaching about disease, approximately 15% microbiology, less than 10% on cells, and approximately 5% on systems (See Figure 4). Yet during the interviews Ms. Konig did not mention science content knowledge of the workshop explicitly.

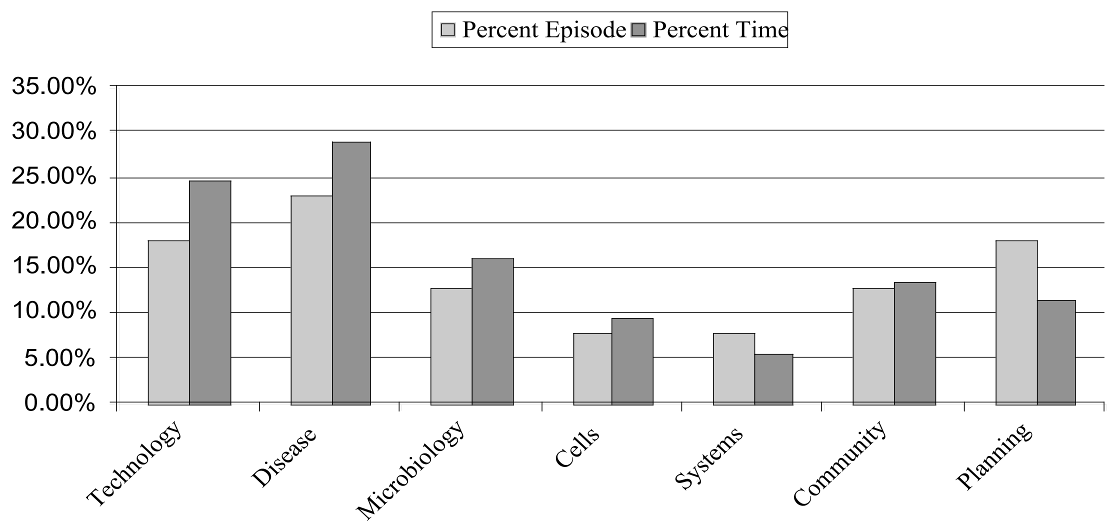

Figure 4. Content covered in Communicable Disease workshops.
(Note: These do not add to 100% as some episodes covered multiple types of content.)

Teachers also learned content knowledge of technology beyond the middle school level by learning how to set up the handheld computers and navigate various online environments. Ms. Konig stated in the first post-workshop interview that she hoped the workshops would cover technology issues. In the remaining three post-workshop interviews she attributed using the technology in the workshop informed her content knowledge of technology, e.g. how to set up the handheld computers. In addition she attributed the workshop with informing her pedagogical knowledge of technology. An example of a typical response is when discussing technology instruction, when reflecting on instruction from the workshop about the online search engine tool, Artemis, she responded,

> That was useful because I was trying to think of ways to keep [the students'] interest and I think that [worksheet for Artemis] will help guide me with the reading….I saw how [the lead teachers] did theirs, what kind of questions to put in. [The lead teacher] didn't make it too difficult but [the students] actually have to read through the articles to find it.

Ms. Konig valued the opportunity to learn the content of technology, both that which the students need to know as well as that which she needs to use the tools. She also valued the pedagogical knowledge shared at the workshop addressing the application of the technology in the classroom.

However Ms. Konig was not completely satisfied with the technology preparation. She specifically stated in the interview that she did not feel adequately prepared to teach using a software program designed to create models of relationships (Model-it). Despite the fact nearly an hour was spent having the teachers create models, much of the time for her was spent troubleshooting the program (content knowledge of technology) and her model and she never felt adequately prepared to teach using the program (content knowledge of the science taught by the program and pedagogical content knowledge of technology). She substituted for this virtual activity a non-technical version, however, the only question on the post test for which her students did not demonstrate a significant gain was a question directly aligned with this activity.

Thus Ms. Konig valued the information from the workshop as influencing her instruction, or pedagogy. She did not explicitly mention science content knowledge, however this may have been due to the nature of the interview or the social norms of discussion. Science teachers are expected to know science and may not automatically discuss new science knowledge. Ms. Konig also valued both the content knowledge of technology as well as the pedagogical knowledge of technology; however more time needs to be spent on technology allowing teachers to fully grasp both the content knowledge of the technology as well as the content knowledge of that which the technology is designed to address.

From the workshop notes and the information from the interview we create a general description of Ms. Konig's "know that" from the workshop. Although general inferences could be drawn with respect to the student learning, we required classroom observation to make more reliable claims about practice. Through interviews conducted after the lessons and discussions we identified that to which Ms. Konig attributed her learning of the approach she used in the workshop.

Impact on Practice

Interviews and observation of the workshops allowed us to examine the content and the teachers' self-reported learning. However, to examine the impact on practice required both classroom observation and interviews with the teacher to determine how the "know that" from the workshop transformed into the "know how" in the classroom (Ryle, 1949). From the interviews we concluded that Ms. Konig valued the opportunity to do the activities as well as set them up as it either showed her how to do an activity anew or refreshed her memory. The observations of her classroom practice supported this assertion. First, the workshops directly influenced the Ms. Konig's pedagogy for management of materials and set up of the lesson.

During the bacteria investigation, Ms. Konig set up the activity as modeled in the workshop and stressed components of the investigation deemed important by the lead teachers. In particular, she had the students take time to develop a “good, meaningful question” that was testable and met the criteria for scientific investigation. She stressed the importance of control, dependent and independent variables, creating a hypothesis and testing a hypothesis. She allowed the children ample opportunity to develop their own question, while guiding them carefully towards creating testable scientifically sound investigations. Analysis of the questions on the pre and posttest which align with the bacteria investigation show significant gains by the students ($p<0.001$) (see Table 3). The overall performance of Ms. Konig’s students on all questions dealing with microbiology also showed significant gains and showed her students’ strongest performance as compared to disease, cells, and body systems (see Table 5 below).

Table 3. Ms. Konig’s students’ performance on pre-posttest questions related to the bacteria investigation, n=121.

Question (each 1 point)	**Pre-test (SD)**	**Post-test (SD)**	**Gain (SD)**	**Effect Size p< .001**
You can see bacteria on agar plates after incubation because the bacteria A. increased size and strength. B. divided and increased in number. C. stopped moving and died. D. changed color and shrank.	.27 (0.45)	.93 (0.26)	.75 (0.46)	1.47
Something you do before you start an investigation is: A. Collect data. B. Write procedures that address the hypothesis. C. Carry out the experiment with multiple trials. D. Draw conclusions from data.	.45 (0.50)	.75 (0.44)	.30 (0.56)	0.60
David decided to investigate how the growth of bacteria was affected by temperature. The hypothesis that he tested was: "As temperature increases, bacteria will reproduce faster." In his hypothesis, temperature is the A. constant variable. B. control variable. D. dependent variable. E. independent variable.	.25 (0.43)	.53 (0.50)	.29 (0.70)	.67

Second, Ms. Konig demonstrated her own of learning of both content knowledge of technology and well as pedagogical content knowledge of technology during the Cooties activity. Although she needed to adapt the lesson due to time constraints, Ms. Konig set up the Cooties activity as modeled at the workshop. Ms. Konig was under the impression the handheld computers were already programmed, but when she got them out the day before the activity she discovered the program was not up to date. She prepared each of the handheld computers from the information at the workshop and stated she would not have done the activity had she not been at the workshop because she would not have been able to reload the programs on the handheld computers. Students were required to trace the initial carrier of a disease and predict why one person did not get sick on the pre/posttest, mimicking the analysis of the cooties activities. Here, too, Ms. Konig's students showed significant gains, however the mean posttest score on the question predicting the initial carrier of .34 was the lowest of the 20 multiple choice questions which we address below (see Table 4).

Table 4. Ms. Konig's students' performance on pre-posttest questions related to the "spread of disease" and "Cooties" activities, n=121.

Question (each 1 pt)	**Pre-test (SD)**	**Post-test (SD)**	**Gain (SD)**	**Effect Size p< .001**
Description of spread of disease asking to predict initial carrier.	0.07 (0.26)	0.34 (0.48)	0.27 (0.53)	1.04
Question about why a certain person probably didn't get sick – immunity.	0.36 (0.48)	0.64 (0.48)	0.28 (0.62)	0.58

Our analysis of the workshop suggested science content beyond that of what students needed to learn was rarely discussed, with the exception of content knowledge of technology. However, based on classroom observation, this caused a significant challenge for the enactment as Ms. Konig did not have access to some content knowledge that was needed to help her set up the anchoring activity. The anchoring event, designed to pique student interest at the onset of the unit, has students simulate the spread of disease by exchanging a fluid with one another in the form of water in cups, one or two of which is spiked with a base. At the end of the activity, the teacher places an indicator solution in the cups to show the students how the base had spread throughout the room. Ms. Konig enacted the lesson as demonstrated in the workshop, using the pedagogical techniques shared during the workshop. However, when she placed the indicator in the cup it failed to react, leaving the students with no visual cue that they had been contaminated. From classroom observation and discussion with Ms. Konig during class we determined that the base she had used was too dilute. At the workshop Ms. Konig was given the base for the activity in the concentration needed for the classroom. The curriculum guide directed the teacher to dissolve pure base in water to create the proper concentration. Since the teacher was not instructed about the concept of molarity (beyond the scope of typical middle school curriculum), she proceeded to mix the sample by diluting to 1/250 the recommended concentration. With the exchange during the enactment, the sample became even more diluted in the student glasses so the indicator did not work. This represents a situation where the science content from neither the workshop nor the curriculum was sufficient for proper enactment of the lesson. Since the primary purpose of this activity was an anchoring event, measuring student performance directly is problematic. However, it seems plausible that the impact of the activity on the students was diminished because the students did not have the surprise of the contaminated solution instantaneously turning bright pink.

In addition, more time at the workshop must be spent assisting teachers in how to manage the time and activities of the unit, as a common problem of the units is that they take longer than anticipated and the content at the end of the unit gets short changed, which coincides with our earlier findings. This was evidenced by Ms. Konig's enactment of a virtual spread of disease activity, Cooties, towards the end of the unit, designed to revisit the aforementioned spread of disease activity virtually through the use of handheld computers. The activity as written in the unit, would take at least four days, which Ms. Konig did not have. Thus, with the first author's assistance, she combined two activities into a single activity that would only take one day. However, in hindsight, this truncation limited the chance the students had to learn about how to trace the initial carrier of disease, merely reinforcing what should have been apparent in the first spread of disease activity. The students did not have multiple opportunities to trace the initial carrier of the disease, and this was evidenced in their posttest performance (see Table 4), where only 34% of the students were able to trace the initial carrier. This represented a significant gain from the 9% on the pretest ($p<0.001$); however this represented the lowest score on the multiple choice questions on the test. Possibly more time should have been spent allowing student to have the opportunity to trace initial carriers of disease as the adaptation of the Cooties activity impacted the learning of the unit as a whole by significantly reducing opportunities for students to learn and practice tracing initial carriers of disease.

We also examined student learning across the four main science content areas of the unit; microbiology, cells, disease and systems. Students scored significantly higher on the posttest which included questions surrounding microbiology, cells, disease and systems (Table 5). Ms. Konig's students scored higher gain scores than the mean of all teachers, and greater effect sized with the exception of the disease content, which included a question requiring students to trace the initial carrier of disease (see Table 6).

Table 5. Scores on multiple-choice portion of Communicable Disease test for all teachers, 2003, n=1213 students.

All Teachers	Microbiology (6)	Cells (3)	Disease (9)	Systems (4)
Pretest (SD)	1.31 (1.07)	0.97 (0.80)	1.77 (1.41)	1.42 (1.02)
Posttest (SD)	2.98 (1.42)	1.27 (0.95)	3.45 (2.02)	2.01 (1.14)
Gain (Effect Size)	1.68 (1.57)***	0.29 (0.36)***	1.68 (1.91)***	0.59 (0.58)***

***p<.001

Table 6. Scores on multiple-choice portion of the Communicable Disease test for Ms. Konig, 2003, n=122 students.

Teacher	Microbiology (6)	Cells (3)	Disease (9)	Systems (4)
Pretest (SD)	1.17 (1.08)	1.48 (0.80)	1.61 (1.18)	1.96 (0.93)
Posttest (SD)	4.05 (1.00)	2.22 (0.86)	3.75 (1.68)	2.63 (1.17)
Gain (Effect Size)	2.88 (2.67)***	0.74 (0.93)***	2.15 (1.82)***	0.67 (0.72)***

***p<.001

Over all, Ms. Konig's students showed exceptional gain scores between the pre and post test of on average 7.83 points out of a possible 29 points, with an effect size of 2.77 ($p<0.001$) as compared to the group as a whole with a gain score of 5.01 with an effect size of 1.34 ($p<0.001$). When we examine the questions which align with that covered in the workshop we observe significant improvement on the students' tests scores with the exception of the question aligned with that which Ms. Konig reported needing more help. The classroom observations also reinforce the impact of the workshops on quality inquiry instruction and use of technology, but also brought to fore considerations for future workshops.

Discussion

This study allows us to illustrate critical linkages between professional development, teacher learning, classroom enactment, and student learning. We believe that the data in this case demonstrates the relationship between each of these key elements in our reform-oriented professional development. Through our analysis we demonstrate that our workshops, designed to support teacher enactment of an inquiry-based, technology-rich curriculum, met the six goals we set out for quality professional development, with varying degrees of success. Our data suggests (1) teacher "buy-in" and (2) the development of a community of learners. Our analysis of the workshops themselves determined that (3) science content knowledge and (4) pedagogical knowledge for inquiry were integral components of the workshop. Our classroom observations recorded the impact of (5) professional development on practice. Finally, (6) the students' pre and posttest scores as aligned with activities (and overall) demonstrate student learning from the teacher's enactment of the unit. But what do these findings say about characteristics of quality professional development that result in improved student learning?

The 2003 Communicable Disease unit professional development workshops employed model-teaching, peer exchange and recitation as the primary means of instruction, following the professional development strategies we recommended based on prior research (Kubitskey et al., 2003). Garet, Porter, Desimone, Birman, & Yoon (2001) suggest professional development which incorporates "opportunities for active learning" result in improved teacher learning from professional development. They distinguish between more "traditional" modes of professional development, such as single-day workshops, and reform-oriented professional development using active learning, such as coaching, video analysis of practice, and examination of student work. But of course workshops are only a medium for professional development, and there are many different ways to constitute them. The emphasis on model-teaching and peer exchange also allows LeTUS teachers an opportunity to participate in active learning. Our observations of the workshops allow us to conclude that teachers are actively engaged during the majority of the workshop. In addition, the content covered during the workshop included science content knowledge and pedagogical knowledge related to teaching particular lessons within the unit. Science content knowledge is an essential component of quality professional development (Garet et al., 2001; Loucks-Horsley & Matsumoto, 1999). Our findings in this and previous work suggest teachers do not credit learning science content knowledge from the workshop despite its inclusion in the professional development, although they do attribute learning related to content knowledge of technology (Kubitskey et al., 2003). Analysis of the classroom observations in this case study suggests that a deeper treatment of science content knowledge beyond the middle school level is needed, both as it applies to scientific subject matter content as well as scientific process modeled through technology. Problems related to a lack of science content knowledge arose in relation to the set-up of the physical spread of disease simulation (using water spiked with a base), when the teacher wasn't given sufficient information to detect a discrepancy between the directions in the teachers' guide and the materials on hand. In addition, the teacher expressed a lack of technological know-how related to the use of one software application, instead substituting a chalkboard variation for the activity. Other classroom observations and teacher interviews suggested content knowledge learning with respect to technology (she was able to set-up activities successfully). Classroom observation suggested teacher learning of science process (demonstrated through adoption of inquiry lesson) and science content (demonstrated in classroom observation). Garet et al. (2001) also suggest that high-quality professional development is coherent, long term, and includes multiple teachers from the same schools in a common teaching experience. Our workshops meet all these criteria in that the workshops coincided with the teachers' enactment of the curriculum, take place monthly, and include teachers in the same urban school district teaching a common curriculum.

However, the workshops did not include any extended discussion about the impact of altering or omitting lessons on the unit as a whole, which was suggested from our previous work (Kubitskey et al., 2003). Classroom observation brought to the fore the disconnect between curriculum enactment as intended and curriculum enactment in practice. The spontaneous nature of the classroom itself (Jackson, 1990; Lortie, 1975) inevitably leads to adaptation of the lessons. Curriculum designers are particularly concerned with maintaining the integrity of the lessons as intended whereas teachers are often concerned with getting through the content with optimum student learning within the context of instructional disruptions and time constraints (Fishman & Krajcik, 2003; Squire, MaKinster, Barnett, Leuhmann, & Barab, 2003). Curriculum-aligned workshops offer a place to assist in the teachers in these adaptations. Failure to address this issue posed a problem in Ms. Konig's teaching when she had to shorten a two-lesson, four-day activity on the virtual spread of disease (the Palm-based "Cooties" activity) to a single class period. As a result, students did not have multiple opportunities to trace the initial carrier of a disease, and this translated into their weakest area of performance on the posttest. Research suggests one characteristic of successful professional development is that it is aligned with reform-based curriculum adoption (Garet et al., 2001; Loucks-Horsley & Matsumoto, 1999). Our study suggests, in addition to supporting the *adoption* of curriculum itself, the professional development need also include information that guides teachers with respect to any *adaptation of* the established curriculum.

By using information from previous iterations of our professional development design model to create professional development intended to meet our six goals for professional development as identified through the literature: (1) Teacher "buy-in" combined with (2) creating a community of learners, (3) informing both science content knowledge as well as (4) pedagogy of inquiry in order to influence (5) teacher practice and (6) student learning. We were thus able to create, together with the lead teachers, professional development activities which met the needs of both the teacher and students. By evaluating this professional development using our design model we are able to identify the strengths and weaknesses of the activities to inform the next iteration, while testing the assertions from our previous application of the design approach. By making a close examination of both teacher learning and the resulting student learning, we both inform and are informed about our professional development design.

Conclusion

Participation in an inquiry-oriented, technology-rich curriculum reform effort has a positive effect on student learning, but what is the role of professional development in this learning outcome? Our previous work suggested that participation in the professional development supported teachers' implementation of inquiry-based instruction. This case study supports this assertion as the teacher reported and demonstrated learning teacher's pedagogy of science teaching and pedagogy of use of technology, as well as the content knowledge of technology that informed her application of the technology. The key role of professional development in shaping teachers' enactment practices is demonstrated clearly in this case study. The high-level goals of the professional development program in this study – creating a community of learners who "buy-in" to the effort, supporting learning of a range of content and pedagogical knowledge, and influencing student learning outcomes – contribute centrally to the overall success and sustainability of the LeTUS curriculum reform initiative. Our iterative approach to professional development design allows the professional development to adapt to the needs of the community at hand, allowing for continual reevaluation and adaptation to meet the needs of the teachers and students.

This case demonstrates the value of our design approach to creating and evaluating professional development, enabling us to identify both strengths and weaknesses that may easily have eluded our observation had we relied on any single point of evidence for teacher learning from professional development. We place particular value on observations of classroom practice that can be linked directly to professional development. In addition, the fine grained analyses of student learning in relation to specific activities in the classroom creates a rich database of insights that can be applied directly to future professional development re-designs. Thus our design approach both allows us to identify characteristics of quality professional development, as well as inform ongoing improvements.

Acknowledgements

We gratefully acknowledge the collaboration and support of the administration and faculty of the Detroit Public Schools and the entire hi-ce research team, especially Bob Geier, Phyllis Blumenfeld, Joe Krajcik, and Elliot Soloway. We also wish to thank the other members of the Teacher Knowledge and Technology research group, Stein Brunvand, Jay Fogleman, Hsien-Ta Lin, and Jon Margerum-Leys. This research was funded with support from the National Science Foundation under the following programs: CAREER (REC-9876150), REPP (REC-9725927), CRLT (REC-9720383), and USI (ESR-9453665), and by the W.K. Kellogg Foundation and the Spencer Foundation. All opinions expressed in this work are the authors' and do not necessarily represent either the funding agencies or the University of Michigan.

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