Research in Science & Technological Education

Evaluating the impact of a facilitated learning community approach to professional development on teacher practice and student achievement

Yaron Doppelt [a]; Christian D. Schunn [a]; Eli M. Silk [a]; Matthew M. Mehalik [a]; Birdy Reynolds [a]; Erin Ward [a]
[a] Learning Research and Development Center, University of Pittsburgh, USA

PLEASE SCROLL DOWN FOR ARTICLE

Routledge
Taylor & Francis Group

Evaluating the impact of a facilitated learning community approach to professional development on teacher practice and student achievement

Yaron Doppelt*, Christian D. Schunn, Eli M. Silk, Matthew M. Mehalik, Birdy Reynolds and Erin Ward

Learning Research and Development Center, University of Pittsburgh, USA

The focus of this research was an evaluation of the impact of teacher professional development (PD) on student achievement during implementation of a reform curriculum. The PD consisted of five four-hour workshop sessions distributed over the time teachers were implementing the reform curriculum in their classrooms. The research was conducted in a mid-size, urban school district over the span of two years. Three groups of teachers were contrasted: teachers who continued to use the established curriculum (N = 5), teachers who implemented the reform curriculum without participating in the PD sessions (N = 5), and teachers who implemented the reform curriculum while participating in the PD sessions (N = 13). Teachers who participated in the PD had approximately a one standard deviation advantage in their students' achievement over those who did not. We collected evidence of particular features of the PD that explained the differences in student achievement. The features included: distributing the workshops throughout the implementation; engaging teachers in an active learning process situated in the curriculum; and facilitating a collaborative community of teacher professionals. This study led us to believe that not only are the individual features of the PD important, but the combination of all three together is particularly powerful.

Keywords: science education; design-based learning; professional development; teacher practice; student achievement

Introduction

Professional development (PD) for teachers in the form of in-service training is generally acknowledged to be an important component of improving teacher practice and thereby student learning (Guskey 2000; Kennedy 1998). Given the expense (in time and money) of PD, it is critically important to understand what forms of PD have the greatest impact on teacher practice and student learning. Yet relatively little research has tracked PD all the way to student performance.

Guskey (2000) claims that professional development should plan for what teachers will learn in the workshop and what the workshop will achieve, rather than focusing immediately on what activities will be done in the workshop. In the last 20 years, a number of theoretical papers were published about effective PD (Guskey 2002). However, few papers described field research trying to implement any of the suggested models (Garet et al. 2001). One example of developing successful PD and

*Corresponding author. Email: yarondoppelt@gmail.com

linking it to teacher practice and student learning was described in the study of Fishman et al. (2003). The linkage was performed by analysing data from multiple research tools on teacher practice and student learning. Observation of classroom activities and using a test that is well aligned with the instructional goals of the curriculum are essential components of such research (Fishman et al. 2003).

Our framework

The professional development model that we test in this paper fits most closely with the category of content-based collaborative inquiry (CBCI) (Zech et al. 2000). In this model, teachers work together to create deeper understandings of how their students think about and understand particular subjects. In CBCI, teachers discuss students' understandings, collect and analyse data, share the results with their colleagues, and collaborate to create instructional solutions. Zech et al. argue that in the CBCI process, teachers create shared understandings of content and pedagogy that support students' learning (Zech et al. 2000). In addition, they argue that this process creates a community of teacher-learners.

We extended the teacher collaboration approach to include teacher leaders and curriculum developers who are learning together in extended in-service training associated with the implementation of a reform curriculum. The inclusion of the curriculum developers makes salient the underlying goals of the curriculum and enables more appropriate adaptation to local contexts. The inclusion of teacher leaders creates in-district capacity for continuing PD programmes as the work is implemented within the district. In the second year of the PD programme, for a new cohort of teachers, the model relied heavily on the input of teacher leaders from the first cohort and the central role of the curriculum developers was thus much reduced.

District-wide PD approaches

Little prior research has examined school districts' attempts at professional development, which is where most of the non-volunteer population takes part in professional development (Bobrowsky, Marx, and Fishman, 2001). The absence of empirical research is a critically missing element of our overall understanding of PD (Bobrowsky et al. 2001). Systemic reform of a district cannot be accomplished without scalability of the approach, but the opposite is possible: you can achieve scale (i.e., all teachers) without systemic reform (Blumenfeld et al. 2000). More specifically, PD implemented in conjunction with the district could reach all teachers and yet not involve additional reform. However, it is likely that the approaches to implementing PD taken by most school districts are sub-optimal, and do not take into account all that is known about effective PD. One approach, used in many districts, is to offer the professional development spread over the year in the form of three or four separate in-service days. Each day has little connection to the other in the knowledge of either content or pedagogy, and teachers often report that it does not fit their needs (Hill 2004). Thus, this PD model does not effectively take advantage of the opportunity to support reform throughout the district.

Most professional development is assessed through teacher surveys that ask teachers' opinions of the activity. Professional development using assessments of this type only take into account of how participating teachers react to the activity (Showers, Joyce, and Bennett 1987; Smylie 1989). In addition, the effectiveness of programs is

usually restricted to teachers' self-reported changes in thinking and beliefs (Guskey and Sparks 1991; Supovitz and Turner 2000). As a result, we rarely know what impact the professional development activity ultimately had on student learning. Kennedy's (1998) literature review found that only 10 of the 93 reviewed studies assessed the effects of the professional development activity on students directly. Thus, there is considerable room for improvement in how PD programs are assessed.

Features of PD effective for science reform

Science education reform promises to significantly improve student achievement by transforming the way science has been traditionally taught and focusing on scientific literacy (National Research Council 1996). The success of this reform movement is dependent upon teachers, who often have themselves learned in traditional settings, sometimes with very little education in science, especially in the primary and early secondary grades. It is therefore essential to provide science teachers with opportunities to participate in high quality teacher professional development that is consistent with reform ideas. On the other hand, what constitutes 'high quality' PD has not been well defined, and many of the PD opportunities currently available are not adequate (Borko 2004).

Much of the research concerned with PD has taken place in contexts other than science. As part of a mathematics reform initiative, Cohen and Hill (2000) found that most PD available for teachers had very little or no impact on teacher practice or student achievement. Only PD that closely aligned policy, assessment and curriculum was likely to have an impact. In a review of the research that connected PD with student achievement in mathematics and science, Kennedy (1999) found that the content of PD was of primary importance by comparing effects on student achievement. PD focused on general instructional strategies had very little impact on student achievement, with effect sizes less than 0.20. Content-focused PD that emphasized how students learn particular subjects had a larger impact, with effect sizes of 0.40 and higher (Kennedy 1999). Similar findings regarding the importance of teacher content preparation were obtained by Supovitz and Turner (2000). The available PD opportunities are not equal and the impact that they have on student achievement can vary considerably, depending on the features that are emphasised.

Careful analysis of national sample teacher surveys has articulated the features that have the largest impact on changing teacher practice (Guskey 2000). Those features include engaging teachers in an active learning process, focusing on content knowledge situated in a particular curriculum, and having collective participation among groups of teachers with similar goals, such as those that all teach the same unit (Porter et al. 2003). There are likely to be a number of particular activities that achieve these more general ends. For example, in the currently studied context, teachers from a common grade level implemented much of a new curriculum themselves in small and large groups in the PD just prior to classroom implementation – this particular activity involved the general features of active learning, focused on content knowledge situated in the curriculum, and had collective participation of teacher groups with common goals.

Others have also argued for variations of these general features (Kubitskey and Fishman 2005; Resnick 2005). For example, teacher learning frameworks often include content knowledge, student thinking and learning, pedagogy, improved teacher practice and leadership skills (Darling-Hammond 2000; Loucks-Horsley and

Matsumoto 1999). It is likely that these features relate not only to PD connected to long-standing curricula, but also, especially, to situations of curriculum reform. Sustainable reform curricula are thought to require attention to at least these elements: teachers' content knowledge, how students learn particular content, and active learning (Desimone et al. 2005; Supovitz and Turner 2000).

Taking this research into account, we can begin to understand the impact of PD in the context of a reform. We can then begin to measure the importance of particular approaches to PD in terms of student achievement. The objective of this research is to provide evidence for the necessity of PD when implementing reform science curricula by relating teacher participation directly to student achievement. We will analyse one reform curriculum and its associated PD. Student achievement will be measured by a multiple-choice assessment of conceptual knowledge. We will supplement these quantitative analyses of student achievement with qualitative evidence of prominent features of the PD that led to teachers' enhanced ability to implement the reform curriculum.

The reform context: changing to design-based learning

The intervention that was implemented in this study included two components: curriculum reform involving a change to design-based learning and professional development to support that change. We briefly describe the new curriculum as context here. The professional development sessions are described in the methods section because they are the primary objects of investigation in this paper.

Teachers in the study were asked to change from their existing scripted inquiry curriculum to a design-based learning (DBL) curriculum. DBL can have several advantages. First, since good design involves meeting current and real needs, students are motivated to learn because of the more obvious application of their knowledge to real life situations (Doppelt 2003). Second, DBL is an active process and has all of the advantages of active learning. Active learning is an educational approach that puts the students at the centre of the learning process and recognizes the variation within different learning styles (Dewey 1902; Gardner 1993; Kolb 1985; Perkins 1992; Sternberg 1998). Active learning changes the teacher's role from that of lecturer to the roles of tutor, guide and partner in the learning process (Barth 1972). The knowledge gained through active learning is constructive knowledge and is not knowledge of memorising and doing exercises or homework from books (Gardner 1991). Third, DBL is typically a team activity, and thus has the advantages of collaborative learning. Students that have learned through cooperative methods gain success in academic and non-academic achievements (Lazarowitz, Hertz-Lazarowitz, and Baird 1994). Working in teams generates a greater number and variety of ideas than individual work (Denton 1994). A learning environment that allows teamwork can help students develop their interpersonal communication skills, presentation skills and problem-solving skills (Butcher and Stefani 1995; Doppelt and Schunn 2008). At the same time, DBL may present new difficulties for student learning, especially in the low-performing situations in science education (Doppelt et al. 2008). Many teachers have limited subject expertise in science, but even less in design. Moreover, science teachers face considerable pressure to cover many different science topics during the year. Adding a system design open-ended learning module into the curriculum is therefore difficult for science teachers (Kolodner 2002). These pressures might explain why some teachers only attempt large design projects with their scholars or gifted and talented classes.

In our DBL, students learned science concepts while trying to design an alarm system for a need in their lives. During the design process, students build their ideas using kits of electronic components primarily from parts from the established scripted-inquiry curriculum kits (e.g., wires, springboards, resistors, LEDs, lamps), but partially supplemented with a few additional electronic components (e.g., buzzers, photocells, thermistors). The addition of supplementary electronic components provided the students with a range of alternative solution strategies for creating their alarm system. Each electronic component could be connected to a specific subsystem of the overall alarm system (e.g., power, detector and indicator subsystems). These subsystems made salient related but distinct conceptual ideas. As students attempt to use the various components available to them in order to embody their design plans in working devices, they need to come to understand how each of the components work individually, how they function within the larger system, and how their performance can be improved. This is a process of discovery and inquiry, and it takes place within the context of creative, design thinking to which students relate because they are creating from their needs and interests. Science content inquiry thinking is thus connected to the design process. Throughout the unit, students deal with basic science concepts such as current, voltage, resistance, parallel and series circuits, and closed loop control (Doppelt et al. 2008).

The alarm system module differed from the established, scripted-inquiry electronics curriculum in a number of significant ways. First, it was much more open-ended, with each student team designing a working alarm system based on their own needs and interests. Second, it was based primarily on a model of formal engineering design rather than on scientific inquiry. Third, the addition of electronic components increased the complexity of the conceptual space. Because of the unique structure of the alarm system module relative to existing practice (as is often the case in reform curriculum implementation), it was thought that a carefully constructed sequence of PD would be necessary to support the implementation of the new curriculum.

Method

Overview

This research was conducted in a mid-size, urban public school district. District leaders identified a need to reform the second half of the existing eighth grade science curriculum focused on electronics. The established curriculum emphasised scripted inquiry and had been in place for five years. In collaboration with district leaders and teachers, university researchers developed the electrical alarm system module in the winter of 2003–2004 (Doppelt, Mehalik, and Schunn 2005). The reform curriculum was designed to supplement and partially replace the first four to six weeks of instruction in the established curriculum with an open-ended design project (Roth 2001; Schunn 2008). Design-based learning (DBL) has been found to be effective for teaching science (Doppelt 2009; Fortus et al. 2004; Puntambekar and Kolodner 2005). In 2004–2005, the district officially adopted the reform curriculum and encouraged all teachers to implement it in their classrooms. This study evaluates the importance of one form of PD that was developed on the basis of current theories of PD: to what extent was this PD critically necessary for the reform to result in improvements in student learning?

Professional development sessions

A series of PD workshops accompanied the reform curriculum, distributed throughout the implementation of the unit. Specifically, teachers participated in five workshop sessions each of four hours duration. Two workshop sessions occurred before teachers implemented the module, and two workshop sessions occurred during the time that the teachers were implementing the curriculum. The final workshop occurred at the end of the implementation as a final reflection on the unit. Distributing the workshops as short workshops spread over the implementation of the unit allowed teachers to receive continued, targeted support for their concerns. Having teachers participate as learners emphasised active learning. After teachers engaged in the same process their students would undergo, they reflected on that experience from an instructional perspective. The workshops also served as a risk-free, collaborative setting for teachers to share ideas with colleagues, including district resource teachers and the university researchers who developed the reform curriculum. Distributing the workshops throughout the implementation, engaging teachers in an active learning process situated in the curriculum, and facilitating a community of teacher professionals were features we viewed as essential features of this PD effort.

In the first year of this two-year study, the developers of the curriculum led the workshops. In the second year, lead teachers from the first cohort gave the workshops (using similar workshop organization and presentation slides), with only minor support from the curriculum developers. In the second year, eight new teachers participated in the workshops.

Participants

The study used a covariate design to evaluate the impact of PD on student achievement, comparing teachers from three groups: established; reform-no-PD; and reform-PD. The established group consisted of teachers who continued to use the established curriculum (N = five teachers, 405 students). The reform-no-PD group consisted of teachers who implemented the reform curriculum without PD (N = five teachers, 274 students). The reform-PD group consisted of teachers who implemented the reform curriculum and participated in PD (N = 13 teachers, 977 students). Additional data regarding each group are presented in Table 1. Teachers from all three groups were distributed approximately equally across the two years of the study.

Although officially encouraged to adopt the reform curriculum and attend the PD, teachers self-selected as to whether they would adopt the curriculum and/or attend the PD, as is typical in many districts. Decisions for or against participating were a complex mixture of positive and negative factors: generally being open to trying new

Table 1.   Percentages of minority students and students qualifying for government subsidized free or reduced price lunch in each teacher group, as well as the mean number of years teaching.

	% Minority ethnic background	% Qualifying for subsidized lunch	Mean number of years teaching
Reform-PD	57	70	10
Reform-no-PD	78	84	5
Established	47	74	12

things; wanting to try something new because they were struggling with the old; being satisfied with current student achievement and therefore not needing to try something new; having other existing PD commitments; and not being permitted to try something new by the principal. As a result, all groups had relatively high proportions of high needs students and moderate experience teachers.

However, to address the potential influence of systematic differences across conditions that might confound the effects of professional development on student performance, we used an ANCOVA approach, including student ethnicity and free/reduced lunch status as covariates, which are the variables that have the strongest impact on student achievement. We also examined teacher variables (certification levels and years of teaching experience), but found no influence of these teacher variables on student achievement.

Measures

In this study, we used three main research tools: pre-post knowledge test (KT); qualitative analyses of video from the teacher workshops; and informal observations of class activities. In order to measure student achievement in the first year of implementation, we created a six-question knowledge assessment that was designed around core concepts in electricity, such as resistance, current, voltage and series versus parallel circuits. The assessment was deliberately short in order to encourage as many teachers as possible to agree to implement the assessment. Indeed, the completion rate in the reform groups was 75% and in the established curriculum groups 52%. On the other hand, the internal reliability of a six-item assessment was relatively low (Cronbach Alpha = 0.36), reflecting a diversity of individual concepts that must be learned about resistance, current and voltage. In the second year, taking into account what the literature says about common misconceptions about electrical circuits, and what we had learned from our observations and workshops in the first year, we enhanced the knowledge assessment to reflect all the core concepts that are taught in the learning module. The enhanced version of the knowledge assessment included 20 items. The internal reliability of the enhanced test was much higher (Cronbach Alpha = 0.80). We analyze the results of the six-item test collapsed across both years for maximum statistical power, and then the 20-item test just for the second year data for maximum instrument validity. Appendix A includes examples from the test items.

The analyses of video from the teacher workshops provide some insights into how the workshops supported teachers learning to use the new curriculum in their classes. Teacher workshops can vary from pure administrative details to purely content focused presentations and to 'gripe' sessions. Our goal was to use workshops to support teacher learning about the content knowledge, the pedagogical content knowledge and build a community of learners among the teachers. The video data were coded to see whether the workshop was in fact generally spent in productive ways, but also in a variety of modes to produce a rich learning environment for teachers. The coding of video was done according to six categories: (1) administrative issues (e.g., scheduling of workshops, distribution of materials); (2) content, including both pedagogical content knowledge (e.g., information on how to teach particular elements in the module) and basic content knowledge (e.g., information on the underlying electricity concepts, why certain phenomena occurred); (3) discussion (e.g., teachers engaging in 'whole class' discussions); (4) teacher reflections on classroom experiences (e.g., how this teaching compared with prior teaching experiences); (5) teamwork (e.g., teachers working in

small groups to enact the curriculum themselves); and (6) presentations (e.g., teachers presenting their own group work to the other teachers or their own adjustments to the module to the other teachers). This coding was done on four of the workshops, and it was implemented by a research assistant trained on a subset of the video data.

Observation of in-class activities is an essential tool for educational field research. We used these classroom observations to triangulate and interpret what teachers said in the workshops. In addition, the observations were used to verify how teachers implemented the developed learning module (i.e., that their self-reports during the workshops matched their classroom behaviours). Observations were scheduled to occur randomly without advance notice with the following constraints: each teacher was visited on at least two different days; typically only one class period was observed on a given day; teachers were sampled at different densities varying from two visits to over 20 visits, in part to show that visits did not change student performance, and in part to support case studies reported elsewhere (Doppelt et al., 2008). During the classroom visit, the researchers would observe classroom activities, minimizing interaction with the students. The researchers wrote observation notes in a logbook.

Results

The possible range of scores in the knowledge test is 0 to 1 (proportion correct). The experiment group started at an overall lower mean science knowledge pre-test score (0.29) than the contrast group (0.38). The differences in initial test scores are likely to be explained by the differences in the socioeconomic status between the experiment and contrast group schools and the teacher selection process. The gap in overall performance decreased, from the initial difference of nine test percentage points to essentially parity in performance, with less than one test percentage point difference, with the experiment group having a final overall mean test score of 0.45 and the contrast group with a final overall mean score of 0.46.

What impact did participating in the PD have on student achievement?

We first used an analysis of covariance on student achievement data to calculate the corrected mean student score for each teacher taking into account percentage of students from a minority ethnic background and the percentage qualifying for free or reduced lunch. With the corrected means, teachers in the reform-PD group (M = 0.49) outperformed teachers in the reform-no-PD group (M = 0.40). Teachers in the established group had a mean student achievement of M = 0.44, which was higher than the reform-no-PD teachers, but less than the reform-PD teachers. Figure 1 presents the means and effect sizes. The effect size of participating in PD versus not participating is greater than one standard deviation, which is a substantial effect size (Kennedy 1999). A t-test analysis shows there exists a significant difference between mean student scores from the reform-PD group in comparison to mean student scores from the reform-no-PD group (t(16) = 2.09, p < 0.05). The other group contrasts were not statistically significant.

These results suggest that PD is a large and necessary factor in having reform curriculum positively impact student achievement, especially relative to the effect of the curriculum alone. Although not statistically significant, the effect of the reform without PD appeared slightly negative. This result is perhaps not surprising given that
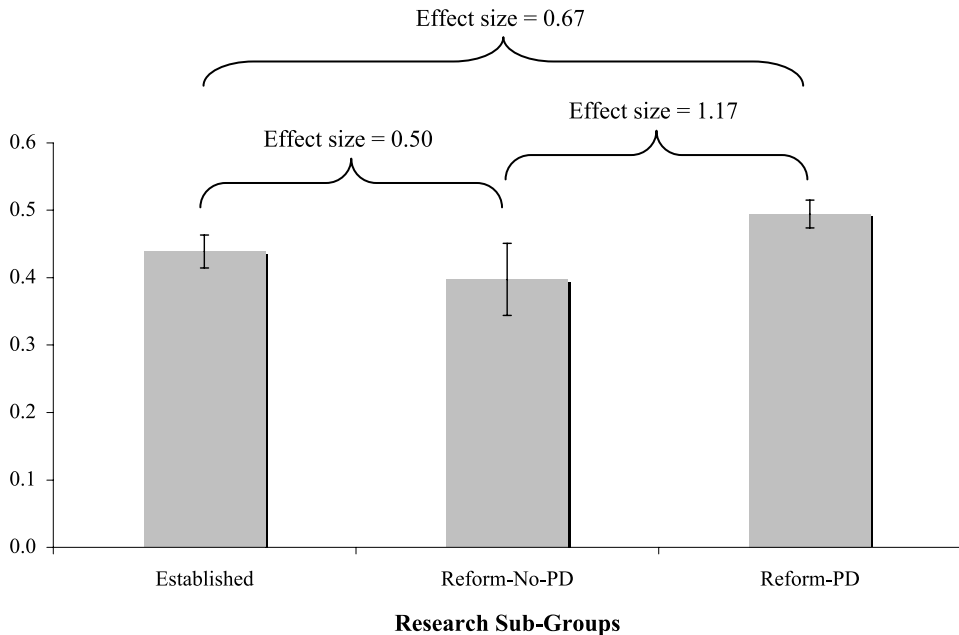
Figure 1.   Students' mean scores with standard error bars and effect sizes (pooled SD=0.08).

teachers from the established group had been using the established curriculum for five years and were very familiar with it.

The basic results in Figure 1 hold for the short test items used across both years and for the enhanced test used in the second year alone. That the results hold in the second year suggests that the central role of the curriculum developers in leading the workshops was not so critical; rather it was the nature of the workshops themselves that was important.

What did teachers gain from participating in the PD?

Consistent with the past literature, our approach to PD contained theoretically-critical elements and was thus successful. However, can we achieve some insights into what specifically was gained in the PD?

After the initial workshop that involved presenting an overall perspective on design-based learning, the interested teachers attended four workshops that focused on implementation of the module. The participating teachers shared their experiences during the workshops. This sharing was a basis for further discussion and reflection.

During the four workshops a significant amount of time was devoted to teacher reflections on classroom experiences. Teachers brought and shared example materials from student portfolios, from student team presentations and from instructional materials that the teachers developed themselves. We identified five modes of teachers' participation during the workshops that mirror activities that could happen in the classroom. If the amount of time involved in the PD sessions matters (Supovitz and Turner 2000) and if active learning is important, then one would hope that relatively little time is wasted on management or simple lecturing. Similarly, if we are encouraging teachers

Table 2.   Workshop length and percentages of time devoted to different modes in the teacher PD workshops.

Workshop	Time (min)	Admin.	Content	Discussion	Reflection	Teamwork	Presentations
1	187	45%	14%	7%	4%	22%	9%
2	177	9%	38%	5%	16%	27%	6%
3	189	3%	58%	2%	16%	21%	0%
4	164	4%	45%	13%	15%	7%	16%
Total	716	16%	39%	6%	12%	19%	7%

to change their teaching practice towards more active forms of learning as is found in DBL, then PD that is heavily focused on lecturing is not providing a good model of instruction. The five categories are: administration, which included such things as explanations about the logistics of how to implement the module; content, during which the developers lectured about the module with teachers listening; discussion, which involved teacher questions, comments and suggestions; reflection, which involved teachers reporting on their implementation in classes; teamwork, for which teachers worked in groups to experience the module's tasks; and presentations, during which teachers presented what their teams created. Table 2 presents an analysis of these different modes of teacher engagement during workshops. The table was created from an analysis of workshop video and audio recordings. This analysis shows that 16% of the workshop time was devoted to administration, 38% to content lecture and 46% to discussion, reflection on teachers' experiences in class, teamwork and presentations. Thus, a substantial portion of the time spent in professional development was devoted to collaborative learning and reflection activities for the teacher based on their own learning and teaching experiences.

During our observations of 440 lessons across 15 different middle schools, we noticed that teachers devote time to different teaching modes, in a way that reflects what happened during the workshops. Teachers changed their role in the classroom, moving away from traditional lecturing, and moving to a number of reform instructional activities: devoting more attention to guiding teamwork, leading class discussion around team presentations, and promoting creative solution by encouraging students to try their ideas and test them by constructing models of their alarm systems.

The following two qualitative examples from the PD workshops illustrate the features of facilitating a collaborative learning community, engaging teachers as learners, and distributing the PD workshops during the implementation of the reform curriculum. They are representative of the types of interactions that teachers have with the reform curriculum, the electronics content, and the community of teachers. These types of interactions were commonly observed in our PD workshops.

Example 1: learning to teach and teaching to learn a complex new evaluation task

During one of the workshops, one teacher indicated she and her students were confused about a complex evaluation task that uses a decision matrix. This task requires students to rank three solutions in terms of how well that solution satisfies a set of student-generated requirements. It was proving challenging for teachers as well as students:

Going back to the matrix. …some of the students are still a little confused on it and after a while I started to get confused myself… How do you rank the solutions with each of the requirements? …I feel like I still need more clarification on that part. (Teacher 1)

In response, one of the workshop teacher leaders explained at length how she resolved the issue of the decision matrix in her class:

Remember the last [workshop] I said the same thing. I was having the same problem [in my class] and the only way we could decide was how we had decided the first [workshop] when you [referring to a district resource teacher who actively participated in all the workshops] were presenting… In our group [during the PD session], we talked about cost and size. And when we factored those things in, only then they [her students] could come up with a solution. (Teacher 2)

This prompted an extended discussion between several teachers and the workshop teacher leaders. When the discussion concluded, one of the curriculum developers (CD 1) reflected on it by explaining that the purpose of the task is to elicit various modes of thinking (e.g., comparative and evaluative) from the students, a cognitive demand that is not often made of students. In this example, multiple players were actively involved in drawing on their experiences as learners while doing the task in the PD and as teachers implementing this task in their classrooms.

The teachers reported that as a result of this type of learning in a collaborative community of their peers around their specific needs, they could immediately put into practice what they had experienced in PD to assist the performance of their students. Teachers cited this as a primary reason for consistently attending the PD sessions throughout the implementation of the reform curriculum.

Example 2: adapting pedagogy to higher cognitive demand with electronics content

Several of the teachers reported that they do not know a lot about electronics and that they attend the PD sessions to learn this content. As an added difficulty, the reform curriculum has open-ended tasks that require a deep understanding of the content and a flexible use of alternative instructional strategies in order for teachers to scaffold the tasks effectively. In the following segment, one teacher shared a student's complex circuit design and written description that was generated during his class's open exploration with the electronics components. Everyone in the PD session gathered around to view the circuit and help this teacher understand what his students had done:

Teacher 3:   This student here… I'm sort of not sure what he did… He did this yesterday… Well, for some reason, he hooked just this one battery… He said when he presses the left [switch], the light bulb comes on, and when he presses the right [switch], it doesn't. And together [both switches], it doesn't. So, I didn't have an answer for him. It was at the end of the period.
Teacher 4:   Thank goodness for the bell. [Everyone laughs.]
Teacher 3:   My student tried to explain what was going on here but I don't really understand this. …I told my students, I'll take this to my workshop tomorrow.

Many teachers offered possible explanations. However, as a whole they were still uncertain about how the circuit functioned. Recognizing the confusion among the teachers, one of the curriculum developers modelled an appropriate instructional

intervention and suggested the following: 'So, if the student was here, I would ask him or her, to try to show the, ah, track of current, via, ah, the wires' (CD 2). At that point, several teachers successfully tracked the current through the circuit and came to a consensus about how the student's circuit functioned. 'So we're getting at it. I'm learning with them. This is my first time so I'm paying attention to this' (Teacher 3).

After the workshop, during our observations, we noticed how teachers implemented this idea 'tracking the current via the wires' in their classrooms. In several cases students succeeded in understanding the functioning of their own circuit only after the teacher guided them to try to track the current.

Having the workshop distributed during the implementation of the reform curriculum gave teachers the opportunity to bring challenging examples from their classrooms. Teachers received help with electronics content, alternative instructional strategies and decisions about when and where each strategy is appropriate. In this community, the teachers felt safe to admit their limited content knowledge, open to learning pedagogical interventions and enabled to address their students' questions with confidence. As a result of these experiences, the teachers changed their practice in ways that were more consistent with the reform curriculum.

General discussion

Many districts do not require teachers to participate in PD when implementing a reform curriculum (Briars and Resnick 2000), including the district in the current study. When comparing the reform-PD group and the reform-no-PD group, one can see that participating in PD has a large impact on student achievement. These findings lead us to suggest that districts should not implement a reform curriculum without strongly advocating or perhaps even requiring teacher participation in appropriately supporting PD.

In addition, the particular features of the PD are likely to impact upon its effectiveness. As mentioned earlier, it cannot be assumed that PD has an impact upon teacher practice or student achievement (Cohen and Hill 2000). In particular, we argue that distributing the workshops throughout the implementation, engaging teachers in an active learning process situated in the curriculum, and facilitating a collaborative community of teacher professionals are effective for successful science reform curriculum implementation. Our observations of class activities documented teacher practice and team activities. This study strengthens past research regarding the impact of a high quality PD on teacher practice and student learning (Kubitskey and Fishman 2006). Creating a community of teacher professionals who share student materials and classroom practice in a series of workshops that are distributed during the implementation of a reform curriculum impacts upon both teacher practice and student learning.

This study further leads us to believe that not only are the individual features of the PD important, but the combination of all three is powerful. For example, the collaborative community builds around the active learning activities, and then the distributed workshops allow lessons from the classroom to be shared within the community. Active learning activities make salient the challenging features of the curriculum, which later workshops can then build upon by connecting pedagogical content knowledge questions that arise in the classroom with experiences from prior workshops. Lee et al. (2004) recommended a similar approach when working toward a broadly-implemented and sustainable curriculum reform.

In addition, further analyses need to be done regarding the observation of class activities and students' portfolios. In this study, we have only begun to explore how observations of class activities validate our findings from the workshop video, as recommended elsewhere (Borko et al. 1997).

Although the current study provides important contributions to literature by linking professional development to student learning, it is important to note a number of caveats and possible directions for future research. First, we did not randomly assign teachers to condition. It is possible that characteristics correlated with student learning influenced whether teachers adopted the curriculum or attended the PD. By working closely with district officials, we were able to include a broad cross-section of teachers in the PD, and our correlational analyses suggest that teacher characteristics could not explain our results. However, it is possible that more in-depth measures of prior teacher performance could find some relationship. Note that it is very difficult to implement studies using random assignment of teachers to professional development settings because of the political and pragmatic difficulties of mandating attendance to extended PD to only a subset of teachers. Thus, it is likely that variations of quasi-experimental designs will remain the method of choice for studies examining the impact of PD on teaching.

Second, we focused on reform from scripted hands-on to design-based learning. This kind of reform is, perhaps, different from other science curriculum changes (e.g., from one textbook to another, from one textbook to a scripted hands-on curriculum, or from one textbook to design-based learning). We see the transition that we examined as being of moderate complexity. The teachers were going to a very complex kind of situation, but were starting in a curriculum that was already part of the way along the continuum from textbook to design-based learning.

Third, we examined only short-term student performance. It is possible that reform curricula without PD would eventually receive the same student performance levels, although it is an open question as to whether that would be a common result or a result found in only the stronger teachers and as to whether the narrowing would occur after a year or two or after a decade of experimentation alone.

Acknowledgments

References

Barth, R.S. 1972. *Open education and the American school.* New York: Agathon Press.

Blumenfeld, P., B.J. Fishman, J. Krajcik, R.W. Marx, and E. Soloway. 2000. Creating usable innovations in systemic reform: Scaling up technology-embedded project-based science in urban schools. *Educational Psychologist* 35, no. 3: 149–64.

Bobrowsky, W., R. Marx, and B. Fishman. 2001. The empirical base for professional development in science education: Moving beyond volunteers, Annual Meeting of the National Association of Research in Science Teaching (NARST), St Louis, MO.

Borko, H. 2004. Professional development and teacher learning: Mapping the terrain. *Educational Researcher* 33, no. 8: 3–15.

Borko, H., V. Mayfield, S. Marion, R. Flexer, and K. Cumbo. 1997. Teachers' developing ideas and practices about mathematics performance assessment: Successes, stumbling blocks, and implications for professional development. *Teaching and Teacher Education* 13, no. 3: 259–78.

Briars, D.J., and L.B. Resnick. 2000. *Standards, assessments – and what else? The essential elements of standards-based school improvement.* Los Angeles, CA: Center for the

Study of Evaluation, National Center for Research on Evaluation, Standards, and Student Testing.

Butcher, A.C., and L.A.J. Stefani. 1995. Analysis of peer-, self- and staff-assessment in group project work. *Assessment in Education: Principles, Policy and Practice* 2, no. 2: 165–85.

Cohen, D.K., and H.C. Hill. 2000. Instructional policy and classroom performance: The mathematics reform in California. *Teachers College Record* 102, no. 2: 294.

Darling-Hammond, L. 2000. Teacher quality and student achievement: A review of state policy evidence. *Education Policy Analysis Archives* 8, no. 1.

Denton, H. 1994. The role of group/team work in design and technology: Some possibilities and problems. In *Teaching technology,* ed. F. Banks, 144–51. London: Routledge.

Desimone, L., A.C. Porter, B.F. Birman, M.S. Garet, and K.S. Yoon. 2005. Keying in to high quality professional development: District strategies and professional development features that contribute to quality programs. *The Newsletter of the Comprehensive Center—Region VI* 8, no. 1: 3–7.

Dewey, J. 1902. *The child & the curriculum.* Chicago: University of Chicago Press.

Doppelt, Y. 2003. Implementation and assessment of project-based learning in a flexible environment. *International Journal of Technology and Design Education* 13, no. 3:   255–72.

Doppelt, Y. 2009. Assessing creative thinking in design-based learning. *International Journal of Technology and Design Education* 19, no. 1: 55–65.

Doppelt, Y., M.M. Mehalik, and C.D. Schunn. 2005. A close-knit collaboration between researchers and teachers for developing and implementing a design-based science module. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching (NARST), Dallas, TX.

Doppelt, Y., M.M. Mehalik, C.D. Schunn, E. Silk, and D. Krysinski. 2008. Engagement and achievements: A case study of design-based learning in a science context. *Journal of Technology Education* 19, no. 2: 21–38.

Doppelt, Y. and C.D. Schunn. 2008. Identifying students' perceptions of the important classroom features affecting learning aspects of a design-based learning environment. *Learning Environment Research* 9, no. 2: 163–78.

Fishman, B., R. Marx, S. Best, and R. Tal. 2003. Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education* 19, no. 6: 643–58.

Fortus, D., R.C. Dershimer, R.W. Marx, J. Krajcik, and R. Mamlok-Naaman. 2004. Design-based science (DBS) and student learning. *Journal of Research in Science Teaching* 41, no. 10: 1081–110.

Gardner, H.E. 1991. *The unschooled mind: How children think and how schools should teach.* New York: Basic Books.

Gardner, H. 1993. *Multiple intelligences/the theory to practice.* New York: Basic Books.

Garet, M.S., A.C. Porter, L. Desimone, B.F. Birman, and K.S. Yoon. 2001. What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal* 38, no. 4: 915–45.

Guskey, T.R. 2000. *Evaluating professional development.* Thousand Oaks, CA: Corwin Press.

Guskey, T.R. 2002. Does it make a difference? Evaluating professional development. *Educational Leadership* 59, no. 6: 45–51.

Guskey, T.R., and D. Sparks. 1991. What to consider when evaluating staff development. *Educational Leadership* 49, no. 3: 73–6.

Hill, H.C. 2004. Professional development standards and practices in elementary school mathematics. *The Elementary School Journal* 104, no. 3: 215–31.

Kennedy, M.M. 1998. *Form and substance in in-service teacher education* (Research Monograph No. 13). Arlington, VA: National Science Foundation.

Kennedy, M.M. 1999. *Form and substance in mathematics and science professional development, NISE Brief* (Vol. 3). Madison, WI: National Center for Improving Science Education.

Kolb, D.A. 1985. *Learning styles inventory.* Boston: McBer and Company.

Kolodner, J.L. 2002. Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education* 39, no. 3: 9–40.

Kubitskey, B., and B.J. Fishman. 2005. Untangling the relationship(s) between professional development, enactment, student learning and teacher learning through multiple case

studies. Paper presented at the Annual Meeting of the American Educational Research Association (AERA), Montreal, Canada.

Kubitskey, B., and B.J. Fishman. 2006. Professional development design for systemic curriculum. Paper presented at the Annual Meeting of the American Educational Research Association (AERA), Montreal, Canada.

Lazarowitz, R., R. Hertz-Lazarowitz, and J.H. Baird. 1994. Learning science in a cooperative setting: Academic achievement and affective outcomes. *Journal of Research in Science Teaching* 31, no. 10: 1121–31.

Lee, O., J.E. Hart, P. Cuevas, and C. Enders. 2004. Professional development in inquiry-based science for elementary teachers of diverse student groups. *Journal of Research in Science Teaching* 41, no. 10: 1021–43.

Loucks-Horsley, S., and C. Matsumoto. 1999. Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics* 99, no. 5: 258–71.

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

Perkins, N.D. 1992. Technology meets constructivism: Do they make a marriage? In *Constructivism and Technology of Instruction: A conversation,* ed. T.M. Duffy & H.D. Jonassen, 45–55. Hillsdale, NJ: Lawrence Erlbaum Associates.

Porter, A.C., M.S. Garet, L.M. Desimone, and B.F. Birman. 2003. Providing effective professional development: Lessons from the Eisenhower Program. *Science Educator* 12, no. 1: 23–40.

Puntambekar, S., and J.L. Kolodner. 2005. Toward implementing distributed scaffolding: Helping students learn science from design. *Research in Science Teaching* 42, no. 2: 185–217.

Resnick, L.B. 2005. Teaching teachers: Professional development to improve student achievement. *AERA Research Points* 3, no. 1: 1–4.

Roth, W-M. 2001. Designing as distributed process. *Learning and Instruction* 11: 211–39.

Schunn, C.D. 2008. Engineering educational design. *Educational Designer* 1, no. 1: 1–21.

Showers, B., B. Joyce, and B. Bennett. 1987. Synthesis of research on staff development: A framework for future study and a state-of-the-art analysis. *Educational Leadership* 45, no. 3: 77–87.

Smylie, M.A. 1989. Teachers' views of the effectiveness of sources of learning to teach. *The Elementary School Journal* 89, no. 5: 543–58.

Sternberg, J.R. 1998. Teaching and assessing for successful intelligence. *The School Administrator* 55, no. 1: 26–31.

Supovitz, J.A., and H.M. Turner. 2000. The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching* 37, no. 9: 963–80.

Zech, L.K., C.L. Gause-Vega, M.H. Bray, T. Secules, and S.R. Goldman. 2000. Content-based collaborative inquiry: A professional development model for sustaining educational reform. *Educational Psychologist* 35, no. 3: 207–17.

Appendix.   Example of knowledge test's items

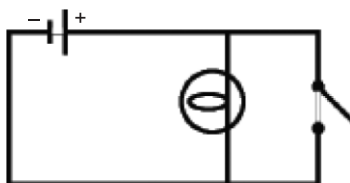(1) Which bulb(s) are lit in this circuit when the switch is open?
a. A
b. B
c. C
d. A and B, but not C
e. None of the bulbs are lit
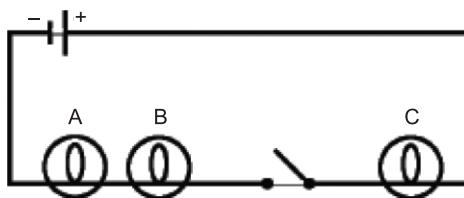
(2) Refer to Figures A and B, and explain the following:
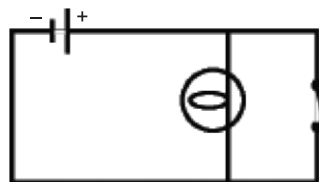a. If the switch is open, as in Figure A, is the bulb glowing?
Yes   ☐
No   ☐

Explain your reasoning: _____
b. If the switch is closed, as in Figure B, is the bulb glowing?
Yes   ☐
No   ☐

Explain your reasoning: _____

(3) Some students set up the circuits represented below.
Mark a √ in the box next to each bulb that is glowing.

Mark a X in the box next to each bulb that is NOT glowing.