Abstract Title Page

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Title: Learning Science for Teaching: Effects of Professional Development on Elementary Teachers, Classrooms, and Students

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Abstract Body

Background/context:

Despite considerable evidence regarding the importance of pedagogical content knowledge, little is known about the conditions that foster its growth (Baxter & Lederman, 1999; Loughran, Mulhall, & Berry, 2003; Magnusson, Krajcik, & Borko, 1999; Van Driel, Verloop, & De Vos, 1998). Although some teachers acquire pedagogical content knowledge through years of experience (Geddis, 1993; Gudmundsdottir, 1987a, b; Shulman, 1986), this process is time consuming, and not all teachers benefit from experience in the same way. What is needed are principles to guide the design of teacher courses that reliably develop pedagogical content knowledge in an efficient and timely manner.

Research has yielded consistent evidence that well-designed student curricula, combined with intensive professional development, can result in changed classroom practice and student learning (e.g., Cohen & Hill, 2001; Fennema et al., 1996; Franke et al., 2001; Roberts, 1996; Saxe, Gearhart & Nasir, 2001; Wilson & Sloane, 2000). Such studies have found that an important factor is the degree to which subject content is explored in depth in the professional development and is embedded in student curriculum. However, research has made far less headway in explaining how it is that particular kinds of professional development activities yield results—or not—at the classroom level. Questions thus remain largely unanswered about how to structure teacher education experiences that foster the development of pedagogical content knowledge. In their conclusion of a comprehensive review of research on teaching, Bransford, Brown, & Cocking (2000) recommend that teacher education courses be developed to provide teachers with more effective discipline-specific pedagogical knowledge, and that research address important questions about how to do this. These questions regarding how to combine content and pedagogy to produce the greatest impact on teaching and learning represent the central problem that motivated the research reported here.

Purpose/objective/research question/focus of study:

Few elementary school teachers command a science background sufficient to offer children early and sustained opportunities to develop an understanding of science concepts, and facility with scientific modes of reasoning. This four-year, NSF-funded study was designed to investigate how and to what extent particular combinations of science content and pedagogical learning experiences for teachers in grades 4–5 produce an impact on teachers' knowledge for teaching and on their students' learning. In this paper, we report results from the first phase of this work, which addressed the fundamental questions of whether the professional development courses did, in fact, lead to teacher and student knowledge gains, and what the effects were for the three course models that were tested, in relation to the control group and to one another.

Setting:

This experiment was conducted at eight national research sites, four in the western United States (in Arizona, California, and Washington), and four in the eastern (in Massachusetts, North Carolina, and Alabama). Each research site was either a large school district (three sites) or a collection of geographically close districts (four sites with four or five districts each, and one with 34 districts), for a total of 54 districts in six states. Geographically close districts typically had a history of working together, with the support of a regional entity such as a regional subject area project, university, or county connection.

Potential research sites were identified through recommendations from colleagues in networks of science leaders throughout several states (e.g., lead teachers involved in local NSF- and state-funded Math-Science Partnership Projects). Recruitment criteria included: (a) well-established, stable district or regional science program, so participants would not be teaching science for the first time; (b) strong science leadership (e.g., staff developers, teacher leaders, and district staff/vision), from whom to draw local course facilitators, so as to test the courses' effects when delivered by professionals in the field (not the course developers); (c) academically, culturally, and linguistically diverse student population; (d) standards-based curriculum for teaching science in place, along with necessary supporting resources for teachers and students (and variety in curricula across districts); (e) strong interest in and philosophical alignment with the professional development approaches to be tested; and (f) proven ability to recruit teachers for professional development.

Population/Participants/subjects:

A sample of 268 fourth grade teachers originally met the selection criteria of teaching fourth grade electric circuits in both 2007-08 and 2008-09 school years and agreeing to provide study data, and eventually provided complete data sets including pre- and post-test data from over 5,000 students. Students were not randomly assigned, instead were the students in all participating teachers' classes. The teachers had been randomly assigned to the four treatment conditions, within site, within school, and received a $650 stipend per participant, plus an additional stipend if they participated in an intensive classroom sub-study or in the follow-up data collection. Table 1 shows the number of teachers randomly assigned to each group at each site, and the number who continued into a follow-up year.

[Please insert Table 1 about here.]

Because participants were randomly assigned to groups, teacher backgrounds were similar across the four conditions with respect to years teaching experience, years teaching circuits, hours of professional development in science, and hours of professional development in circuits. The sample included teachers with a wide range of teaching and professional development experience, spanning from novice to veteran.

Intervention/program/practice:

The study employed three experimental professional development course models, each of which was modeled after a different approach currently supported by districts and teacher educators. Each of the three course designs encompass eight three-hour sessions completed over a series of days—over 8 to 14 weeks during the school year, or a five-day period during the summer. The courses focused on the teaching of electric circuits, a common component of elementary school curricula. All three course designs contained core features of effective science professional development, based on evidence in a growing body of literature (Borko, 2004; Cohen & Hill, 2001; Garet et al., 2001; Weiss et al., 1999).

Each course consisted of two portions—a science content component and a set of strategies intended to develop pedagogical content knowledge. Every course model involved teachers in a common set of science investigations that enabled in-depth, collective exploration of science content. However, the models varied from one another with regard to additional activities designed to support the development of pedagogical content knowledge. In Course A, *Teaching*

Cases, teachers read and discussed written narratives containing student work and dialogue, teacher thinking, and descriptions of instructional materials and activities. Course B, *Looking at Student Work*, involved teachers in analyzing the affordances of specific classroom assessment tasks, and discussing evidence of students' scientific thinking drawn from their own classrooms. Course C, *Content Immersion*, combined the science investigations with a meta-cognitive learning analysis of the teachers' own science learning processes. Teachers in the Teaching Cases and Content Immersion courses taught electric circuits units following completion of the course; teachers in the Looking at Student Work course taught the unit concurrently with the professional development over a two-month period so as to supply samples of their own students' work.

Research Design:

This was a cluster-randomized experimental design with repeated measures over a two-year period. The three professional development courses were delivered 8 times each during the study for a total of 24 times during the study, 12 in Round 1 and 12 in Round 2. Table 2 shows the counterbalanced research design we used to control for order effects and to allow analysis of both facilitator and treatment effects, without confounding the two. Table 3 shows the numbers of courses offered, teachers in each group, and approximate numbers of students from whom we collected content test data.

Teachers at each site were randomly assigned to one of four treatment groups. After these assignments, a sub-sample of 36 teachers was randomly selected to participate in an intensive classroom study—12 from each of three sites (3 per treatment group). These intensive study participants and half of the original sample of treatment teachers were then randomly selected to provide follow-up data one year later. (Teachers in the control group were not included in the follow-up study so they could receive the professional development course in summer 2008.)

[Please insert Tables 2 and 3 about here.]

Data Collection and Analysis:

The data collection measures, samples, and procedures are summarized in Table 4. A teaching background survey provided data on all teachers' professional experience and perspectives on science teaching. Tests of electric circuits content knowledge were administered to all teachers pre- and post-PD, and to their students before and after the electric circuits unit. A randomly selected sub-sample of teachers participated in pre- and post-PD interviews designed to elicit pedagogical content knowledge, and were observed and video-taped twice each while teaching lessons on electric circuits. All professional development activities were video-taped, and survey, content knowledge, and interview data were collected from the professional development facilitators. Data were collected in two rounds of professional development course implementation conducted from August-December 2007 and from January-June 2008. The resulting data set is large, rich, and complex.

Findings / Results:

Teacher outcomes. We fitted hierarchical linear models to analyze the impact of the teacher professional development courses on teacher and student content test scores and found that all three treatments caused large test score gains for both teachers and students. As shown in Table 5, teachers who took any of the courses achieved considerably higher post-test and gain scores than teachers in the control group. On average, teachers in all three treatment groups

showed gains of about 22 percentage points, whereas the control group's gain was less than 3 points. Furthermore, as shown in Table 6, the gains that were maintained an additional year after the professional development were still far greater than the control group gains in Year 1.

[Please place Tables 5 & 6 about here]

As shown in Table 7, hierarchical linear modeling (HLM) confirmed that all three treatments had a significant positive effect. We see here that control teachers' scores increased about 1.6 percentage points from pre- to post-test, and scores of teachers in all three courses increased 19-20 points on top of that. Effect sizes were quite high—1.92, 1.91, and 2.03 for Teaching Cases, Looking at Student Work, and Content Immersion, respectively. (Effect size was computed as the coefficient divided by the pooled standard deviations of the teacher gains.) No differences were found among the three courses in their impact on teacher content knowledge.

[Please place Table 7 about here]

Student outcomes. As shown in Table 8, students of teachers in the three treatment groups demonstrated mean gains of approximately 20 percentage points from pre- to post-test on the test of electric circuits content knowledge, whereas students of control group teachers gained an average of 13 percentage points. Furthermore, at every research site, students of treatment teachers achieved mean gain scores that appear higher than the overall mean gain for control teachers' students (see Table 9). HLM results (Table 10) again confirmed these results—effect sizes for impact of the treatments on student test scores were 0.39, 0.52, and 0.52 for Teaching Cases, Looking at Student Work, and Content Immersion, respectively. (Effect sizes were measured as a ratio of treatment effect and the pooled standard deviation of student gain. This latter value is a measure of how much variation in gain we get from students without controlling for any covariates. This is the most conservative measure of effect size.) Although effect sizes were higher for the Looking at Student Work and Content Immersion courses, tests for differences among the three courses were inconclusive.

[Please place Tables 8, 9, and 10 about here]

Accounting for Student Content Knowledge Outcomes. An important question is whether the courses' impact on teacher content knowledge alone accounts for the variance in student outcomes. That is, is it sufficient to bolster teachers' content knowledge in science as a means of producing student learning gains? To determine this, we compared another HLM model, which had *only* teacher content knowledge, to the model that had both teacher content knowledge and the treatment dummy variables. The models were indeed different ($p < 0.01$), and all three treatment effects are significantly positive ($p < 0.05$, $p < 0.005$, $p < 0.005$ for Teaching Cases, Looking at Student Work, and Content Immersion, respectively). The model coefficients indicate expected additional student gains *beyond those gains due to the teachers' content knowledge* of 3.4, 5.4, and 5.3 percentage points (effect sizes 0.26, 0.42, and 0.41, respectively). We conclude that all three teacher treatments do something to improve student test scores beyond that of merely improving teachers' content knowledge. This additional factor accounts for at least as much of the final student impact as does the gained content knowledge of the teachers. Preliminary analyses of our other data indicate that the additional benefits constitute improvements in teachers' pedagogical content knowledge.To further account for student knowledge outcomes, we have also analyzed teacher interviews and classroom observation data to begin identifying differences in pedagogical content knowledge and teaching practices of teachers in the treatment versus control groups, as well as among the three treatment groups.

Preliminary results indicate that teachers who took any of the three courses exceeded control teachers in their explicit attention to developing students' conceptual understanding of science ideas. Treatment teachers more often identified learning goals in terms of conceptual understanding (e.g., stating that they want the students to be able to explain the difference between series and parallel circuits rather than simply naming topics in the unit). In their lessons, treatment teachers used more representations that make patterns in data visible for analysis by the students and support students' scientific reasoning about the data.

Conclusions:

Using a randomized experimental design, we were able to establish that all three professional development models brought about large gains in teachers' and students' science content knowledge, well beyond those of comparable control groups, and that effects of the courses persisted a year later. Clearly, the courses have design features that are highly effective at preparing teachers to support their students' science learning. We also found that it is possible to achieve effect sizes of 2.0 for teachers and .5 for students with high quality professional development experiences and a rigorous research design.

An intriguing finding is that the three courses, which differ considerably in design features, did not differ significantly in their effects on teacher and student content learning. This result suggests that important elements in professional development can be configured in a number of ways and still have beneficial effects. The presence of certain characteristics is essential for high quality professional development, but it is possible for professional development to embody them in a variety of effective ways.

The fact that the courses did not differ in impact on teacher or student content test scores does not preclude the possibility of differences in impact on pedagogical content knowledge—differences that could prove important for intentional design of professional development geared to be effective in varied learning contexts and for student populations with particular characteristics. Since the courses were so different with respect to their pedagogy-related components, in fact, it seems very likely that they affected teachers' knowledge for teaching in different ways. Current analyses are examining these possibilities.

Finally, we found that the large impact of the courses on teacher content knowledge alone does not explain so high a proportion of the variability in student performance as to suggest that teacher content knowledge alone is responsible for the student content gain. There are other factors that we are currently investigating.

Because we found such large effects on teacher and student learning, subsequent analyses of the data set from this study will (a) examine relationships among gains in teacher content and pedagogical content knowledge, changes in classroom practice, and student learning; and (b) work toward specifying processes by which science professional development achieves its effects on teaching and learning. Pursuing these goals can enable us to make a strong empirical and conceptual contribution to the small body of research linking professional development to student outcomes, and to inform both the design of professional development and the preparation of professional developers in science.

Appendices

Not included in page count.

Appendix A. References

References are to be in APA version 6 format.

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Appendix B. Tables and Figures

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Table 1

Number of Teachers in Each Treatment Group in Each Round as of June 2009

Site	Round	Teaching Cases	Looking at Student Work	Content Immersion	Control	Total
1	1	9	-	8	10	27
	2	-	4	3	-	7
	Follow-up	4	4	5	n/a	13
2	1	-	7	6	12	25
	2	7	-	6	-	13
	Follow-up	4	5	8	n/a	17
3	1	11	-	-	8	19
	2	12	11	-	-	23
	Follow-up	6	6	-	n/a	12
4	1	5	-	-	6	11
	2	-	7	-	-	7
	Follow-up	4	5	-	n/a	9
5	1	-	-	9	5	14
	2	-	-	-	-	-
	Follow-up	-	-	-	n/a	-
6	1	17	-	-	12	29
	2	-	9	9	-	18
	Follow-up	9	4	6	n/a	19
7	1	-	9	-	9	18
	2	-	-	6	-	6
	Follow-up	-	5	5	n/a	10
8	1	-	10	7	17	34
	2	9	8	-	-	17
	Follow-up	-	12	3	n/a	15
Total	*1 and 2*	*70*	*65*	*56*	*79*	*268*
Total	*Follow-up*	*27*	*41*	*27*	*n/a*	*95*

Table 2

Counterbalanced Research Design with Three Treatment Models (A, B, and C) and a Control Group†

Site	Facilitator Pair	Round 1		Round 2		Total no. of teachers at site*
		Summer 07	Fall 07	Winter 07/08	Summer 08	
Site 1	1		C	B		24
	2		A		C	
Site 2	3		B	C		39
	4		C	A		
Site 3	5		A	B	A	42
Site 4	6		A	B		19
Site 5	7		C			17
Site 6	8	A		C		46
	9	A		B		
Site 7	10		B	C		26
Site 8	11		B		A	55
	12		C	B		
Totals						268

Note. A – Cases; B – Looking at Student Work; C – Content Immersion

† Time distinctions are not relevant for the control group, so no D's shown in columns, but control teachers and students are included in row totals.

* Figures include only individuals with both pre- and post-instruction quiz data.

Table 3

Numbers of PD Courses Taught, Teacher Participants, and Students for Three Experimental Interventions and a Control Group in 2007-08

Treatment	No. times offered in Round 1	No. times offered in Round 2	Total no. times offered	No. teachers	No. students
A. Teaching Cases	5	3	8	70	1,218
B. Looking at Student Work	3	5	8	65	1,134
C. Content Immersion	4	4	8	54	1,190
D. Control	-	-	-	79	1,738
Total	12	12	24	268	5,280

Table 4

Instruments, Samples, and Data Collection Procedures

Instrument	Sample	Procedure
Written and online surveys	All facilitators and teachers; follow-up random sample of half the teachers per treatment group	Packet sent to facilitators; all treatment teachers take pre- and post-course, during first and last course sessions and online. Control teachers complete in project meetings at each site and online.
Science content tests	All facilitators and teachers; follow-up random sample of half the teachers per group	Packet sent to facilitators; all treatment teachers take pre- and post-course, during first and last course sessions. Control teachers complete in project meetings at each site
Student content tests	Students of all teachers.	Teacher administers within two weeks before and two weeks after electric circuits unit.*
Teacher pedagogical content knowledge interview	Random sub-sample of nine per group.	Researcher administers pre and post interviews within two weeks before course, and after teacher has taught classroom unit.
Classroom videotaping and observation protocol	Two lessons in classrooms of random sub-sample of nine per group.	Videographer and observer collect data during two lessons in electric circuits unit—first & one in middle of unit.
Course session videotaping and observation	All course sessions at all sites. Judith add detail here.	Videographer and observer collect data during 3 sessions... Judith add detail here.

*Sealed packets of student tests with standardized administration instructions and script sent to teachers. Teachers sign affidavit that they did not provide help to students other than reading test questions aloud.

Table 5

Teachers' Mean Percent Correct and Gain Scores (with SDs) on Content Test by Treatment

Treatment	*n* Pre	Pre	*n* Post	Post	*n* Gain	Gain
A. Teaching Cases	68	60.9% (11.2)	69	82.2% (10.8)	67	21.9% (10.3)
B. Looking at Student Work	69	56.3% (11.4)	63	79.3% (8.2)	63	21.5% (10.2)
C. Content Immersion	64	57.8% (14.6)	57	80.7% (11.8)	56	22.0% (13.0)
D. Control	86	56.6% (12.7)	73	59.1% (12.0)	70	2.6% (10.5)

Table 6

Teachers' Mean Gain Scores on Year 1 Content Pre-tests and Post-tests and Gains Maintained through the Follow-Up Year, by Site

	A. Teaching Cases		B. Looking at Student Work		C. Content Immersion		Across-Treatments	
Site	Y1 Gains	Maintained Gains	Y1 Gains	Maintained Gains	Y1 Gains	Maintained Gains	Y1 Gains	Maintained Gains
1	17.4%	8.9%	31.3%	34.7%	21.1%	27.5%	23.3%	23.7%
2	18.0%	9.4%	28.1%	20.5%	24.7%	19.7%	23.6%	16.5%
3	25.5%	15.9%	13.6%	12.4%	-	-	19.6%	14.2%
4	21.3%	26.7%	31.4%	22.7%	-	-	26.4%	24.7%
5	-	-	-	-	21.1%	13.0%	21.1%	13.0%
6	17.5%	17.8%	23.8%	27.3%	23.0%	33.0%	21.4%	26.0%
7	-	-	19.9%	22.3%	23.8%	25.5%	21.8%	23.9%
8	22.6%	-	20.4%	14.5%	22.1%	12.5%	21.7%	13.5%
Total	20.4%	15.7%	24.1%	22.0%	22.6%	21.9%	22.4%	19.4%

Table 7

HLM Results for Teacher Tests–Regressions on Teacher Gains

	Model T1	
Variable	Coefficient	*SE*
A. Teaching Cases	19.5	2.3
B. Looking at Student Work	19.3	2.4
C. Content Immersion	20.5	2.5
Veteran	1.0	1.5
Novice	5.2	2.6
Round2	-0.3	2.0
Site1	-3.9	3.5
Site2	2.5	2.8
Site3	0.0	2.8
Site4	2.7	3.4
Site5	-3.4	3.8
Site7	-2.3	3.1
Site8	0.4	2.5
(Intercept)	1.6	2.4
SD(CourseID)	2.5	1.5
SD(Residual)	10.1	0.5

Table 8
Students' Mean Percent Correct and Gain Scores (with SDs) on Content Test by Treatment

Treatment	*n*	Pre-test *mean* (*SD*)	Post-test *mean* (*SD*)	*Mean* gain (*SD*)
A. Teaching Cases	1347	48 (11)	68 (13)	20 (15)
B. Looking at Student Work	1392	48 (11)	69 (14)	22 (15)
C. Content Immersion	1013	48 (10)	68 (14)	20 (14)
D. Control	1494	49 (11)	62 (13)	13 (14)

Table 9
Treatment Teachers' Students' Mean Percent Correct and Gain Scores (with SDs) on Content Test by Site

Site	*n*	Pre	Post	Gain
S1	367	48.1 (11.0)	63.5 (13.5)	15.4 (15.6)
S2	759	48.6 (10.3)	66.0 (13.2)	17.4 (14.2)
S3	1,037	48.4 (19.2)	69.3 (12.0)	21.0 (13.9)
S4	313	48.0 (11.9)	68.5 (14.9)	20.5 (15.8)
S5	366	47.2 (8.8)	61.9 (14.2)	14.7 (14.2)
S6	967	48.7 (11.0)	66.7 (14.6)	17.9 (15.5)
S7	555	48.4 (10.6)	67.3 (13.7)	18.9 (14.7)
S8	916	47.0 (11)	65.6 (13.3)	18.6 (15.0)

Table 10

HLM Results for Student Tests–Regressions on Student Gains[2]

Variable	Coefficient	*SE*
A. Teaching Cases	5.7	1.4
B. Looking at Student Work	7.5	1.4
C. Content Immersion	7.5	1.5
Round2	1.6	1.2
Site1	-3.1	1.9
Site2	-0.3	1.6
Site3	2.9	1.6
Site4	2.4	2.1
Site5	-3.1	2.3
Site7	1.4	1.9
Site8	0.6	1.6
Veteran	1.9	0.9
Novice	1.0	1.4
(Intercept)	11.6	1.4
SD(CourseID)	1.1	1.1
SD(Teacher)	5.9	0.4
SD(Residual)	13.1	0.1

[2] First columns are coefficients; second column standard errors. (Intercept) is the grand mean, or overall intercept. The last three rows correspond to the standard deviations of the random intercepts due to PD course, the random intercept for the teachers, and the error term capturing individual student variation..