Standards-Based Science Institutes: Effective Professional Development that Meets Teacher and District Needs

Alakananda R. Chaudhuri
University of the Incarnate Word
Bonnie D. McCormick
University of the Incarnate Word
Richard Lewis, Jr.
University of Texas at San Antonio

Abstract

Five standards-based science institutes (SI) were conducted between 2005 and 2016 to support improved content knowledge, pedagogy, and pedagogical content knowledge of in-service middle and high school science teachers in the area of biology. The SI were conducted for 90 hours during the summer and academic year. Content covered was related to state science standards taught in the participants' classrooms. Instruction was based on the 5E learning cycle model and emphasized the use of inquiry so that participants experienced the teaching methods specified by the science teaching standards. Pre- and post-test analysis demonstrated significant content gains using this teaching model. Teacher surveys and reflections confirmed that the program had a positive influence on implementation of classroom teaching methods and student learning. Analysis of lesson plans and classroom observations indicated that teachers were able to redesign lesson plans and teaching practices to meet state standards for incorporating inquiry into classroom teaching.

Achieving scientific literacy for all students requires alignment of content standards with curriculum, assessment, pre-service preparation, and professional development (PD) (NGSS Lead States, 2013). Implementation of standards-based teaching requires in-service PD that is based on content knowledge, how science is learned, and best practices of teaching science (NRC, 2001) because teachers who do not have an adequate understanding of STEM content tend to avoid teaching that content or teach it superficially (NRC, 2007). Teachers must also be comfortable with their method of pedagogy to be effective teachers. Student achievement in science is higher when their teachers use reform methods such as collaborative learning groups and group inquiry (MacKinnon, Fowles, Gonzalez, McCormick, &Thomann, 2006; Schroeder, Scott, Tolson, Haung & Lee, 2007), because it enhances students' science process skills, habits of mind, problem-solving skills, understanding of the nature of science, and engages students in the process of scientific discovery (Hofstein & Lunetta, 2004; Nadelson, Seifert, Moll, & Coates, 2012). Supporting the acquisition of the combined knowledge of content and pedagogy, or pedagogical content knowledge (PCK) (Shulman, 1986), is a necessity for improving teaching and student learning. This is because PCK enables a teacher to predict difficulties that may be faced by students and thus prepare themselves with methods and explanations, including useful analogies, representations, and symbols in teaching science topics (Ball, Lubinski, & Mewborn, 2001).

To meet the PD needs of middle and high school science teachers in South Texas, the university offered five, year-long Science Institutes (SI) between 2005 and 2016. The SI were a collaboration with school districts and university science and education faculty. The aim of the program was to strengthen teachers' content knowledge and PCK in the life sciences to meet the challenge of implementing standards-based curriculum. Each institute lasted one year and was structured to reflect the state science teaching standards, the needs of the school districts, the needs of the teachers, and best practices for PD for science teachers. Support for the institutes came from external grants.

Teachers' Perception of Professional Development

Teachers who participate in PD have expectations that these programs will support standards-based teaching. In a study of teachers in a PD program designed to support alignment with state curriculum, Paik et al. (2011) found that teachers expected to learn new

Keywords: biology, middle school, professional development, standards-based, inquiry

instructional strategies, increase science content knowledge, and have the opportunity to design a new unit that matched state standards. Another study found that the most important benefits of PD to teachers were practical applications and resources for translation to their classrooms, opportunities to experience activities and learn concepts in the manner that was similar to their students, experiences relevant to the grade level taught, and establishing relationships with other participants (Rogers, et al 2006).

A study by Johnson (2006) investigated barriers reported by middle school teachers in the second year of a sustained PD program. The findings were that teachers did not buy into reform-based teaching in part because state science assessment did not match reform teaching and standards, there was a lack of administrative support to provide necessary resources, time for collaboration and planning was not available, instructional choices made by teachers were not supported, and participation in PD was difficult. Another group of teachers reported that the PD experiences were not effective because they did not focus on the content taught in the teachers' classrooms, did not provide opportunities to collaborate with colleagues, were not learner-centered, and did not provide assessment or feedback of the experience (Chaval, et al, 2009).

Recommendations for Reform-Based Professional Development

Implementation of reform-based science teaching requires understanding of inquiry and the nature of science (NOS), developing skills in conducting inquiry, PCK to teach inquiry, and the motivation to use inquiry in the classroom (Capps & Crawford, 2013). PD activities should model standards-based instruction methods that match the way science should be taught (Nadelson, 2012). This means that content knowledge be explored in the same inquiry and cooperative environment that the standards recommend for their students. Inquiry-based instruction is consistent with reform because it engages students in the process of scientific discovery (NRC, 2001). However, research indicates that actual implementation of science inquiry in school is problematic, and that teachers may not fully apply inquiry-based science in their classrooms (Haug, 2014). Teachers may not use inquiry in their teaching because they have limited knowledge and experience with inquiry (Capps & Crawford, 2013) and possess naïve and informal conceptions of inquiry-based instruction (Blanchard, Southerland, and Granger, 2009).

PD for in-service teachers should 1) focus on content knowledge and student learning in the specific subject area taught, 2) utilize an active learning model of instructions, 3) include designing units of study (e.g., lessons), 4) require peer observation of science lessons, 5) provide adequate time for reflection, and 6) be sustained over at least one school year. In addition, programs should include groups of teachers from the same school, department, or grade level, provide a coherent view of the entire instructional system including local, state and national performance standards, and have the active support of school and district leaders. (Loucks-Horsley & Matsumoto; 1999; NRC, 2012; Desimone and Garet, 2015). For science teachers, it is important that the PD focus be on the content that they teach, that there is coherence with state and national standards, and that there is support for change in teacher practice and student learning (Luft & Hewson, 2014).

Achieving these goals of PD programs can be difficult because changing procedure is easier than improving content knowledge of inquiry-oriented instruction (Desimone & Garet, 2015). There is evidence that programs consistent with the recommendations for reform-based teaching and content standards met teachers' expectations for effective PD (Paik, et al. 2011). Studies confirm the importance of modeling the desired instructional method, collective participation, and longer durations of programs. Surveys of 207 teachers in 37 schools in five states examined the features of PD and the effect on teaching practice at yearly intervals over a three-year period (Desimone, et al. 2002). The findings were that when PD activities emphasized specific instructional practices in a format that provided active learning opportunities, use of those instructional practices increased. In addition, PD is more effective in changing practice when the program is reform-based, and teachers are from the same school, department, or grade. An additional barrier to this type of PD is the cost involved in providing high quality PD that has these characteristics (Garet, Porter, Desimone, Birnman, & Yoon, 2001).

Methodology

The Standards-Based Professional Development Program

The aim of the program was to provide participants with instruction in content knowledge, practical experience in applying inquiry, collaborative learning groups, active learning methods, and resources to implement change in their classrooms. These elements are consistent with recommendations from the literature (Desimone & Garet 2015). Teachers were recruited from two urban districts and many were from the same campuses. The subject matter being taught in the PD matched the teaching assignment of the teachers. Funding for the PD program provided tuition for two graduate courses for each cohort. Biology I was taught in the summer session and Biology II was taught during the academic year (AY). Participants received books, instructional technology, classroom materials, stipends, mileage, and childcare reimbursement. IRB approval was obtained for the collection of data from phone interviews and reflections. All qualitative data collected during the program evaluation were treated appropriately and used in compliance with FERPA regulations and guidelines. Qualitative data were analyzed anonymously and released in aggregate form only.

During the summer, participants met for 45 hours over a three-week period. The AY followed the same pattern with sessions held every other week in the evening. Each session included 30 minutes for the participants to discuss teaching issues, 120 minutes of instructional time, and thirty minutes for revision and presentation of lessons. The instructional model for the PD was the 5E model developed by the Biological Sciences Curriculum Study (BSCS) (Bybee, et al., 2006). By using this learner-centered model for teaching through active learning and inquiry, participants experienced instruction in the SI that is consistent with Texas standards (Bybee, et al., 2006, p. 3). In this model, the teacher actively *engages* students by creating interest, designs activities for students to work together to *explore* concepts and work through problems, guides students to develop *explanations* of phenomenon and justify claims in their own words, extends the lesson so that students *elaborate* and apply concepts to new situations, and *evaluates* students' knowledge and skills based on evidence and behaviors. At least one inquiry activity was included in each PD session.

After experiencing instruction using the 5E model, teachers redesigned and presented lesson plans following the 5E format for standards-based concepts taught in their classrooms. These revisions were done in groups during the summer Biology I course and individually during the academic year Biology II course. Lesson plans were collected and made available to all participants for use in their classrooms. Teachers were observed once during the academic year by the instructors and the mentor teacher. In addition, each teacher participated in peer observations of two other participants.

Beginning with the 2014-2015 cohort, inquiry teaching was emphasized because revised state standards specified that inquiry comprise 40% of instructional time. NGSS defines inquiry as a type of learning that includes asking questions, analyzing data, and drawing conclusions based on evidence (NGSS, 2013). Teachers were required to include at least one inquiry activity in their revised lesson plans. Each activity was identified by type of inquiry specified in the state standards (descriptive, comparative, or experimental) (TEA, 2009), and the level of student inquiry (confirmation, structured, guided, or experimental) (Bell, Smetana, & Binns, 2005).

The specific life science and biology content standards covered in the program were determined by assessing teacher and district needs. The content and instructional methods were consistent with state and national science standards. In 2010, the Texas Essential Knowledge and Skills (TEKS) for science were updated to include an emphasis on inquiry and specified that 40% of instructional time in middle school be devoted to laboratory and field investigations (Charles A. Dana Center, 2011).

Participants in the PD Program

Seventy-seven teachers from five cohorts participated in the SI. These cohorts attended SI during the summer and AY of 2005-2006, 2007-2008, 2009-2010, 2014-2015, and 2015-2016. Twelve of the participants in the 2014-2015 continued in 2015-2016 cohort. Teachers were chosen from two urban high-need independent school districts (ISD) that impact large numbers of minority students coming from families with income below the poverty line as documented by the U.S. Census Bureau's data. Teachers in these school districts who were not certified to teach science or were teaching out-of-field were actively recruited and given preference in the selection process. The participant's self-reported data indicate that the gender, racial, and ethnic composition of the participants was consistent in the five SI. The average composition of the cohorts in the entire PD period from 2005-2016 was 78% female and 22% male. The ethnic distribution of the participants was 48% Hispanic, 41% White, 3% African American, 7% Asian/Pacific Islander, and 2% reported the category "Other". The student ethnicity report of these two districts presented 68-91% Hispanic, 6% African American, 2-19% White, and 0-3% Asian or American Indian. In these districts, 8-17% of students were enrolled in bilingual and English language learning programs, 7-19% were designated as having limited English proficiency (LEP), and 10-12% were enrolled in Special Education programs. The percent of students who qualified for the federal free lunch program were 93% from one district and 52% from the other. (TEA, 2016a).

Research Questions

Evidence was obtained to answer the following questions:

- Were there significant gains in participants' content knowledge?
- Did the participants' perceptions of teaching methods change?
- Were participants able to adapt lesson plans to the 5E model in their classroom?
- Were participants able to develop and implement inquiry-based activities in the classroom?

Data Collection and Analysis

Content knowledge gains were evaluated through pre- and post-tests of each SI. At the beginning of each course, teachers were given a pre-test of the biology concepts taught in the SI. The post-test was given at the conclusion of each course in the SI. The pre-post test instruments were based on the content standards outlined in the TExES (Texas Examinations of Educator Standards) competencies as well as the TEKS Objectives, Grades 6-12, and the content needs of teachers. The pre-post-tests assessed both the teachers' ability to use and analyze in-depth concepts in biological sciences and their ability to apply their knowledge in critical thinking and problem-solving.

The tests were designed to look for the logical sequence of concept knowledge, not isolated facts. Questions were multiple-choice items and scored by machine to facilitate item analysis of the scores. Each test contained approximately 50 items. The multiple-choice questions are designed to measure various cognitive levels including knowledge, comprehension, application, analysis, and evaluation. The instrument also contained questions with reading passages that required analysis of data or problem solving to answer the question. Common misconceptions were used as distractors where applicable. For example, a reading passage on the development of antibiotic resistance in bacteria tested the understanding of natural selection with distractors of development of resistance by the patient or acquisition of resistance by the bacterium through exposure to the antibiotic. Means and standard deviations as well as comparison of differences between paired pre-test and post-test scores were used to evaluate content gains in each institute. Test score analysis utilized independent group, paired t-testing, and correlation coefficients for longitudinal comparison.

Participant assessment of their experience was an important aspect of the evaluation. Teachers completed questionnaires about the effect of the SI on their performance in the classroom and their perception of the impact on student performance. Comparisons of participant perceptions were analyzed using frequency distributions. Qualitative data were collected from reflections submitted after each session and phone interviews of the 2015-2016 cohort, which were conducted by an external evaluator.

Redesigned lesson plans were analyzed to evaluate the development of inquiry activities related to content standards. Inquiry activities were classified by the type of inquiry and by the level of student directed inquiry found in the activities. Classroom observations by a mentor teacher provided evidence of implementation of inquiry activities in the science classroom. Participants in Cohort 4 and 5 were observed by the mentor teacher. The lessons observed was determined by the availability of the participants and the mentor teacher. The topic was determined by the curriculum plan of the participant's school.

Results

The findings affirmed that teachers needed content support (Table 1). For each cohort, participant pre-test scores were low. The average scores were less than 60 with one exception; in Cohort 1 Biology I Summer 2005, the mean was 69. The highest pre- and post-test difference (+35.80) was found for Cohort 5 Biology I Summer 2015 course. The lowest test difference (+17.55) was identified for the Cohort 2 Biology II 2007-2008 course. The differentials between the pre-test and post-test were statistically significant for each of the following courses: Cohort 1 Biology I Summer 2005 and Biology II 2005-2006 ($t(20)=14.1$, $p=.01$), Cohort 2 Biology I Summer 2007 ($t(21)=9.69$, $p=.01$), Cohort 2 Biology II 2007-2008 ($t(19)=19.66$, $p=.01$), Cohort 3 Biology I Summer 2009 ($t(17)=5.31$, $p=.01$), Cohort 3 Biology II 2009-2010 ($t(17)=17.87$, $p=.01$), Cohort 4 Biology I Summer 2014 ($t(15)=8.43$, $p=.01$), Cohort 5 Biology I Summer 2015 ($t(14)=8.91$, $p=.01$), and Cohort 5 Biology II 2015-2016 ($t(13)=5.65$, $p=.01$), all of which are statistically significant at $p < .01$. The correlation coefficients (*r* values) ranging from 0.56 at p < '.05, and 0.67-0.82 at $p < .01$ (Cohorts 1-4, 2005-2014) indicate that each participant tended to show improvement in test scores. The correlation coefficients for the Cohort 5 Biology I Summer 2015, and Biology II 2015-2016 courses were not statistically significant with r values of 0.48 ($p = .17$) and 0.38 ($p = .28$), respectively.

Surveys indicated that the SI had positive effects on student-teacher rapport and classroom participation. By combining the *effective* and *very effective* responses, 75% or more in each SI stated that the program was effective for improving rapport and student participation in the classroom (Table 2). There was fluctuation between these two categories but little increase in the *not effective* category. Generally, the perception of program effectiveness on students was consistent over the assessment time period.

Participants perceived that SI was very effective in enhancing teacher instruction. Four items were used to gauge participant perceptions of their science instruction in the classroom (Table 3). In Cohort 1 Biology I Summer 2005 course, 71.4% of the participants said the program had a *major influence* on their overall teaching. By 2014, perceptions of the program influencing overall teaching remained relatively unchanged at 70%. Regarding improvement in science instruction, all participants stated that the program positively influenced their instruction. In cohort 2 Biology I Summer 2007 course, 80.0% of the teachers said that the program had a *major influence* on their science instruction in the classroom which was 81.3% for the same cohort in 2007-2008 Biology II course. In Cohort 3 Biology II 2009-2010 and Cohort 4 Biology I Summer 2014 courses, the participants who indicated that the program had a *major influence* on their science instruction ranged from 76.5%-80.0%. (Table 3).

The program received mixed results from participants when asked about how it changed perceptions regarding student learning abilities. Between 30% and 52% of the participants felt that the program had a *positive influence* on their perceptions of student learning abilities (Table 3). For those who said the program had a *major influence,* the percentages over time were consistently lower. Exceptions were in two cohorts. In Cohort 2 Biology II 2007-2008, 52.9% indicated that the program had a *major influence*. In Cohort 4 Biology I Summer 2014, 60.0% felt it had a *major influence*. Participants generally perceived that the program changed their instructional methods in the classroom. In Cohort 2 Biology II 2005-2006, 61.9% of the participants indicated that the program had a major influence on their instructional methods. This increased to 76.5% for the Biology II 2007-2008 Cohort 5. The participants who stated that the program had at least *some influence* on their instructional methods ranged from 90.0%-100% in all the cohorts (Table 3).

In AY 2014-2015 (Cohort 4) and AY 2015-2016 (Cohort 5) Biology II courses, the participants developed lesson plans that were based on the 5E learning cycle model. Individual lesson plans were submitted by 13 of the teachers in Cohort 4 and by 14 participants in Cohort 5. Ten teachers submitted lesson plans both years. Four teachers in Cohort 4 left the program at the end of AY 2014-2015 and were replaced with four teachers that taught on the same campus or district as another teacher who was continuing in the program.

During the summers, teachers collaborated in groups of three to develop a lesson plan based on the 5E model. Teachers developed individual lesson plans during the AY. All the lesson plans contained examples of active and collaborative

Table 1. Pre and Post-Test of Content Knowledge

Cohort	Cohort 1	Cohort 1	Cohort 2	Cohort 2	Cohort 3	Cohort 3	Cohort 4	Cohort 5	Cohort 5
Course Year	Biology I Summer 2005	Biology II 2005-2006	Biology I Summer 2007	Biology II 2007-2008	Biology I Summer 2009	Biology II 2009-2010	Biology I Summer 2014	Biology I Summer 2015	Biology II 2015-2016
Pre-test Mean	51.14	53.10	53.64	69.15	54.0	41.9	57.88	50.80	46.79
Pre-test S.D.	12.09	12.61	12.06	7.61	19.05	9.52	17.20	16.71	11.27
Post-test Mean	76.19	77.81	72.45	86.70	74.30	71.40	85.75	86.60	75.93
Post-test S.D.	11.61	8.71	11.61	5.3	14.69	12.12	8.27	13.08	21.23
Test Difference	25.05	24.71	18.82	17.55	20.33	29.50	27.88	35.80	30.14
T-test	14.1*	14.1*	9.69*	19.66*	5.31*	17.87*	8.43*	8.91*	5.65*
Rho (r)	.77*	.77*	.71*	.87*	.56**	.82*	.67*	.48***	.38***
Number	21	21	22	20	18	18	16	15	14

*$p < .01$, **$p < .05$, ***$p > .05$

learning. The activities included concept maps, active note taking, simulations, games, share pairs, cooperative groups, and inquiry.

To meet state standards of teaching 40% of the lesson using inquiry, lesson plans developed in AY 2014-2015 (Cohort 4) and AY 2015-2016 (Cohort 5) Biology II courses required at least one inquiry activity related to the state science standards. Inquiry is defined by Bell et al. (2005) as answering a research question using data analysis. The individual lesson plans were analysed to identify the type of inquiry specified in the state standards (Table 4). In AY 2014-2015, 5 of the 13 (38.4%) lesson plans included at least one inquiry activity while in AY 2015-2016, 10 of the 14 (71.4%) revised plans included inquiry activities. During the second academic year the lesson plans contained more variety in the type of inquiry. For AY 2014-2015, 3 of the 5 (60.0%) inquiry activities were descriptive inquiry. In the second year, 3 of the10 (30.0%) activities were descriptive, while five of the 10 (50.0%) were comparative. Experimental inquiry was utilized in the lesson plans once in AY 2014-2015 and twice in AY 2015-2016.

Lesson plans were also rated by the level of student involvement in inquiry using categories from Bell, et al. (2005), (Table 4). Confirmatory or illustrative inquiry is teacher-directed and the results are known. In structured inquiry, the teacher choses the question and procedures. Guided inquiry is conducted with a question generated by the teacher and students design or select the procedures. In open inquiry students choose the question and design the experiment. During AY 2014-2015 and AY 2015-2016 confirmation was selected most for inclusion in the lesson plans. In AY 2015-2016 participants also included structured inquiry. The number of guided inquiry activities were the same in both AYs. There were no instances of open inquiry in the lesson plans.

During AY 2015-2016, classroom observations were conducted of Cohort 5 participants by a mentor teacher in order to document the use of inquiry

Table 2. Perception of SI Impact on Students

Course Year		Not Effective %	Somewhat Effective %	Effective %	Very Effective %
Cohort 1 Biology I (2005)	Improved student-teacher rapport.	0.0	14.3	42.9	42.9
	Increased participation in class.	0.0	9.5	52.4	38.1
Cohort 1 Biology II (2005-2006)	Improved student-teacher rapport.	0.0	14.3	23.8	61.9
	Increased participation in class.	0.0	14.3	38.1	47.6
Cohort 2 Biology I (2007)	Improved student-teacher rapport.	4.8	9.5	42.9	42.9
	Increased participation in class.	4.8	9.5	38.1	47.6
Cohort 2 Biology II (2007-2008)	Improved student-teacher rapport.	0.0	25.0	56.3	18.7
	Increased participation in class.	0.0	18.7	75.0	6.3
Cohort 3 Biology II (2009-2010)	Improved student-teacher rapport.	0.0	0.0	35.3	64.7
	Increased participation in class.	0.0	5.9	17.6	76.5
Cohort 4 Biology I (2014)	Improved student-teacher rapport.	0.0	20.0	30.0	50.0
	Increased participation in class.	0.0	10.0	40.0	50.0
Cohort 4 Biology II (2014-2015)	Improved student-teacher rapport.	6.2	25.0	43.8	25.0
	Increased participation in class.	0.0	37.5	50.0	12.5
Cohort 5 Biology I (2015)	Improved student-teacher rapport.	0.0	0.0	71.4	28.6
	Increased participation in class.	0.0	0.0	71.4	28.6
Cohort 5 Biology II (2015-2016)	Improved student-teacher rapport.	8.4	25.0	33.3	33.3
	Increased participation in class.	0.0	16.7	58.3	25.0

Table 3. Perception of SI on Science Instruction

Course Year		No Influence	Some Influence	Major Influence
Cohort 1 Biology I 2005	Improved my overall teaching effectiveness.	4.8	23.8	71.4
	Improved science instruction.	0.0	28.6	71.4
	Changed perceptions of students' learning	19.0	47.6	33.3
	Changed my instructional methods.	9.5	42.9	47.6
Cohort 1 Biology II (2005-2006)	Improved my overall teaching effectiveness.	0.0	38.1	61.9
	Improved my science instruction.	0.0	40.0	60.0
	Changed perceptions of students' learning	4.8	52.4	42.9
	Changed my instructional methods.	0.0	38.1	61.9
Cohort 2 Biology I (2007)	Improved my overall teaching effectiveness.	0.0	33.3	66.7
	Improved my science instruction.	0.0	20.0	80.0
	Changed my perceptions students' learning.	26.3	47.4	26.3
	Changed my instructional methods.	5.0	40.0	55.0
Cohort 2 Biology II (2007-2008)	Improved my overall teaching effectiveness.	0.0	41.2	58.8
	Improved my science instruction.	0.0	18.8	81.3
	Changed perceptions of students' learning.	5.9	41.2	52.9
	Changed my instructional methods.	0.0	23.5	76.5
Cohort 3 Biology II (2009-2010)	Improved my teaching effectiveness.	0.0	41.2	58.8
	Improved my science instruction.	0.0	23.5	76.5
	Changed perceptions of students' learning.	17.6	41.2	41.2
	Changed my instructional methods.	5.3	52.6	42.1
Cohort 4 Biology I (2014)	Improved my overall teaching effectiveness.	0.0	30.0	70.0
	Improved my science instruction.	0.0	20.0	80.0
	Changed perceptions of students' learning.	10.0	30.0	60.0
	Changed my instructional methods.	0.0	40.0	60.0
Cohort 4 Biology II (2014-2015)	Improved my overall teaching effectiveness.	6.3	43.8	50.0
	Improved my science instruction.	6.3	50.0	43.8
	Changed perceptions of students' learning.	12.4	43.8	43.8
	Changed my instructional methods.	6.3	43.8	50.0
Cohort 5 Biology I (2015)	Improved my overall teaching effectiveness.	0.0	57.0	43.0
	Improved my science instruction.	0.0	57.0	43.0
	Changed perceptions of students' learning.	0.0	71.4	28.6
	Changed my instructional methods.	0.0	43.0	57.0
Cohort 5 Biology II (2015-2016)	Improved my overall teaching effectiveness.	0.0	60.0	40.0
	Improved my science instruction.	0.0	40.0	60.0
	Changed perceptions of students' learning.	8.3	50.0	41.7
	Changed my instructional methods.	10.0	50.0	40.0

instruction in the classroom. The mentor teacher held a doctorate in education and was also a certified high school science teacher with four years of classroom experience. Fourteen teachers were observed, and nine of the teachers began or completed an inquiry activity during the class period observed. Of the inquiry activities observed, 60% were descriptive and 40% were comparative. The level of inquiry was 70% confirmation or illustration, and 30% structured, which indicates that the activities were teacher directed.

Discussion

Because creating effective PD programs for science teachers is resource intensive and requires adequate funding in order to meet both the recommendations from national organizations and the expectations of teachers, it is critical to demonstrate that the program accomplishes the goals of improving standards-based instruction in science classrooms. To accomplish this, we sought to improve content knowledge, to increase pedagogical content knowledge, to provide a model of active-learning that could be incorporated into the participants' classrooms, and to increase the use of inquiry in participants' classrooms. In our study we found evidence that the participants in the SI demonstrated gains in these three areas.

One of the goals of the program was to strengthen the content knowledge of the participants in the area of the biological sciences. Analysis of pre-test scores of five cohorts confirmed that the teachers needed content support. The post-test analysis demonstrated the teachers made significant gains in content knowledge. Students commented on their content acquisition in both phone interviews and reflections that were gathered as part of the grant evaluation. Teachers expressed that they liked that the content was taught in more depth than in an undergraduate survey course and that they felt confident going back to their schools to teach it to their students. They felt a sense of confidence. Many of the teachers did not major in science or did not have a strong background in Biology. They felt they had a better grasp of the content and were more confident teaching the material and answering student questions at a deeper

Table 4. Inquiry Activities Observed in Participants' Classrooms

Type of Inquiry	AY 2014-2015 Cohort 4 Percent	AY 2014-2015 Cohort 4 Number Observed	AY 2015-2016 Cohort 5 Percent	AY 2015-2016 Cohort 5 Number Observed
Descriptive	23%	3	21%	3
Comparative	8%	1	36%	5
Experimental	8%	1	14%	2
Incomplete/None*	62%	8	29%	4
Level of Inquiry				
Illustration/Confirmation	23%	3	29%	4
Structured Inquiry	8%	1	21%	3
Guided Inquiry	15%	2	14%	2
Student Directed	0%	0	7%	1
Incomplete/None*	62%	7	29%	4
Total Lesson Plans		13		14

* None/incomplete - only made observation and did no analysis or connection to scientific meaning

level. One participant wrote that "going to the classes at the university helps to light the fire again and make me feel that passion and excitement about being a teacher."

Participants in the program were expected to apply appropriate PCK in redesigning their lesson plans. Many of the participants taught in schools where the curriculum was prescribed at the district level. By modeling how to use the 5E instructional model with an emphasis on inquiry, the teachers were able to modify their teaching within the constraints of the prescribed curriculum. Survey results showed that at least 90% of the teachers in each of the five cohorts thought that the PD program had at least some influence on improving overall teaching, improving science teaching, and changing instructional methods. Many teachers shared in their reflections and interviews that the program transformed what was done in the classrooms. One teacher commented, "I will take all of these activities that we did this summer and try to incorporate them into my class." Learning new techniques, labs that could be used in their classrooms, inquiry-based learning, cooperative learning groups, and activities that gave students a common frame of reference were mentioned by many of the participants. One teacher wrote "I found the kids were definitely more engaged than they were. They are grasping the material a lot easier." Another teacher said that she was more open to allowing the students ask questions and guide their own learning.

During the AY 2014-2015 and 2015-2016, we added an emphasis on inquiry activities to meet the new state standards that specified using inquiry at least 40% of the time. Our experience with the teachers was that they believed all forms of active learning to be inquiry. This is a common problem among in-service teachers. Another study also reported that in spite of the fact that most of the teachers believed that they were using inquiry to teach science, only four of 26 teachers could be considered to be using inquiry instruction at the desired level (Capps & Crawford, 2013).

Participants successfully presented redesigned lesson plans that were required to include at least one inquiry activity during the academic year component of the SI. Classroom observations provided evidence of use of inquiry activities in the participants' classroom at the end of AY 2015-2016. It is clear from the analysis that implementation of inquiry continued to be an area that was problematic for the participants. However, during the AY 2015-2016, the teachers were better able to design inquiry activities. Although four of the teachers in AY 2015-2016 were new to the program, three of them were able to include inquiry activities in their lesson plans. This suggests that teachers working in groups with more experienced participants were able to accomplish the goals of the program.

Lesson plan analysis indicated that most of the inquiry lessons were teacher directed. Lesson plans did not include any examples of open inquiry. This is probably because middle school teachers are less comfortable managing experimental designs with their student populations or are not yet confident in their inquiry skills. All of the experimental activities were developed by high school teachers. Classroom observations confirmed that the participants were implementing inquiry in their classrooms. In two-third of the classrooms observed, students either began or completed an inquiry activity.

Participants were enthusiastic about the inquiry experience. They felt that it was important that the PD experience was based on inquiry activities and that those activities could be taken back to the teachers' classrooms. "I was more apt to or more able to turn that into an inquiry-based lesson because of what I did" in the PD program. The lesson plan presentations also helped the teachers "bring back engaging and inquiry-based lessons and activities" to their classrooms. Many teachers expressed that they were able to modify their lesson plans and "took it to a higher level of understanding by making them more open-ended with more data collection and data analysis." Learning how to take a teacher-centered lesson plan and making it more student-centered was valued by the teachers.

The participants frequently commented that the PD program was important because they learned from each other. These teachers also shared what they learned with the other teachers on their campus, including sharing classroom activities. They felt empowered by their success in a graduate class and used their knowledge to help their peers. "Being able to share dialogue and practices with other science teachers both at the K-12 and collegiate level has expanded my practice." When asked what has most influenced their teaching, many commented that it was the variety of strategies shared in class, especially the lesson plans that other teachers presented. "It was a great experience, not only to learn a lot from our professors, but also to learn a lot from each other".

Conclusion

These results are consistent with the recommendations for professional development programs. The program was designed to incorporate the recommendations from the literature on best practices including focusing on a specific content area, needs of the learner, school-based support, designing units of study peer observation of science lessons, providing time for reflection, and continuing over several years. The assessment results provide strong indications that the SI goals of enhancing content knowledge, instructional practice, and developing communities of practice among the participants were achieved.

The pre- and post-assessment scores indicated that teacher's knowledge of science improved as a result of the program. Throughout the nine assessment periods, participants consistently agreed that the program helped them develop professionally and enhanced their teaching skills. The overwhelming majority of participants agreed that the program either had some influence or a major influence on improving their biology instruction, changing their instructional methods, and improving or changing their overall teaching effectiveness. Additionally, the majority of participants stated that their expectations of student performance increased based on their involvement in the PD program. The analysis of results supports that the 5E instructional model provided the teachers with the tools to alter their traditional teaching practices and to include the inquiry-based teaching practices specified by NSES and the state standards. In addition, the instructional design was effective in fostering group interaction among these teachers so that they could learn from each other and support each other by sharing instructional strategies.

References

Bell, R., Smetana, L. & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher* 72(7): 30–34. https://www.mun.ca/educ/undergrad/scied/files/bell_simplifying-inquiry_2005..pdf. Accessed 10 April 2016.

Birman, B. F., Desimone, L., Porter, A. C., & Garet, M. S. (2000). Designing professional development that works. *Educational Leadership*, 58(8), 28-33. http://www.ascd.org/ASCD/pdf/journals/ed_lead/el200005_birman.pdf. Accessed 10 April 2016.

Blanchard, M.R., Southerland, S.A., & Granger, E.M. (2009). No silver bullet for inquiry: Making sense of teacher change following an inquiry-based research experience for teachers. Science Education, 93, 322-360.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landers, L. (2006). *The BSCS 5E instructional model: Origins, and effectiveness.* Colorado Springs, CO: Biological Sciences Curriculum Study.

Capps, D. K. & Crawford, B. A. (2013). Inquiry-based instruction and teaching about nature of science: Are they happening? *Journal of Science Teacher Education,* 24, 497-526, doi: 10.1007/s10972-012-9314-z.

Chaval, K., Abell, S., Pareja, E. Musikul, K., & Rizka, G. (2009). Science and mathematics teachers' experiences, needs, and expectations regarding professional development. *Eurasian Journal of Mathematics, Science, & Technology Education*, 4910, 31-43. http://ejmste.com/v4n1/Eurasia_v4n1.pdf#page=35. Accessed 10 April 2015.

Charles A. Dana Center. (2011). *K-12 science TEKS*. Austin, TX: Charles A. Dana Center at The University of Texas at Austin. http://www.utdanacenter.org/sciencetoolkit/downloads/teks/science-teks-staar.pdf. Accessed 15 May 2016.

Desimone, L. M., & Garet, M. S. (2015). Best practices in teachers' professional development in the United States. *Psychology, Society and Education, 7*(3), 252-263.

Desimone, L. M., Porter, A. C., Garet, M. S Yoon, K. S., & Birman B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis,* 24, 81-112. http://www.jstor.org/stable/3594138. Accessed 10 April 2016.

Garet, M. S., Porter, A. C., Desimone, L., Birnman, B. F., & Yoon, K. D. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal,* 38, 915-945, doi: 10.3102/00028312038004915.

Haug, B. S. (2014). Inquiry-based science: Turning teachable moments into learnable moments. *Journal of Science Teacher Education, 25*(1), 79-96. doi:http://dx.doi.org.uiwtx.idm.oclc.org/10.1007/s10972-013-9375-7.

Hofstein, A., & Lunetta, V.N. (2004). The laboratory in science education: Foundations for the twenty-fi rst century. Science Education, 88, 28-54.

Johnson, C. (2006). Effective professional development and change in practice: Barriers science teachers encounter and implications for reform. *School Science and Mathematics,* 106, 150-161, doi: 10.1111/j.1949-8594.2006.tb18172.x.

Loucks-Horsley, S. & Matsumoto, C. (1999). Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics,* 99, 258-271, doi: 10.1111/j.1949-8594.1999.tb17484.x.

Luft, J. &Hewson, P. W. (2014). Research on teacher professional development in science. In Lederman, N. G. & Abell. S.K,Eds,Handbook*ofResearchonScience Education Vol. II,* (889-910), New York: Routledge *doi*:*10.4324/9780203097267*.

Mackinnon, C., Fowles, J., Gonzalez, E., McCormick, B., and Thomann, W. (2006). The impact of state standards on teacher professional development and student performance in middle school science: A Texas case study. In D. W. Sunal & E. L. Wright (Eds.), *The Impact of State and National Standards on K-12 Science Teaching,* (361-390), Greenwich, CT: Information Age Publishing.

Nadelson, L. S., Seifert, A., Moll, A. J., & Coats, B. (2012). i-STEM summer institute: An integrated approach to teacher professional development in STEM. *Journal of STEM Education,* 13(2), 69-83. http://uiwtx.idm.oclc.org/login?url=http://search.proquest.com/docview/1009901964?accountid=7139. 10 Accessed April 2017.

National Research Council (2001). *Educating teachers of science, mathematics, and technology.* Washington, D.C.: National Academy Press.

National Research Council. (2007). *Taking science to school: Learning and teaching* *science in grades K-8.* Richard A. Duschl, Heidi A. Schweingruber, and Andrew W. Shouse, (Eds.). Board on Science Education, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press, doi: 10.17226/11625.

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

Paik, S., Zang, M., Lundeberg, M. A., Eberhardt, J., Shin, T. S., & Zhang, T. (2011). Supporting development: Teachers' preparedness, expectations and their fulfillment. *Journal of Science Education and Technology.* 20, 422-434, doi: 10.1007/s10956-9308-1.

Rogers, M. P., Abell, S., Lannin, J., Wang, C., Msuikul, D. B., & Dingman, S. (2006). Effective professional development in science and mathematics education: Teachers' and facilitators' views. *International Journal of Science and Mathematics Education*, 5(3), 507-532. doi: 10.1007/s10763-006-9053-8.

Schroeder, C. M., Scott, T. P., Tolson, H., Huang, T., & Lee, Y. (2007). A meta-analysis of national research: Effects of teaching strategies on student achievement in science in the United States. *Journal of Research in Science Teaching*, 44, 1436-1460, doi: 10.1002/tea.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Texas Education Agency (TEA). (2009). Chapter 112. Texas essential knowledge and skills for science subchapter B. middle school. *Texas Education Agency*. http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112b.html. Accessed May, 2017.

Author Note Alakananda R. Chaudhuri, Department of Chemistry, University of the Incarnate Word. Bonnie D. McCormick, Department of Biology, University of the Incarnate Word. Richard Lewis, Jr. Department of Sociology, University of Texas at San Antonio

This research was supported by the Teacher Quality Grant Program at the Texas Higher Education Coordinating Board. The Teacher Quality Grant Program is supported through federal funds under NCLB Title II, Part A.

Correspondence concerning this article should be addressed to Bonnie McCormick, Department of Biology, University of the Incarnate Word, 4301 Broadway, San Antonio, TX 78209. Contact mccormic@uiwtx.edu