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Science Teaching Reform Through Professional Development: Teachers' Use of a Scientific Classroom Discourse Community Model

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ABSTRACT

This report outlines a 2-year investigation into how secondary science teachers used professional development (PD) to build scientific classroom discourse communities (SCDCs). Observation data, teacher, student, and school demographic information were used to build a hierarchical linear model. The length of time that teachers received PD was the exclusive predictor of change over time, whereas a schools' percentage of low socioeconomic students predicted how PD concepts was initially implemented. Prior to PD teachers expressed a desire to increase opportunities for students to engage in SCDCs, but found some aspects more challenging than others to implement. Generally, there were three categories of the teachers' frequency of use of SCDC strategies: (a) *most observed* that required teachers to change their own communication, classroom management, and direct instruction; (b) *occasionally observed* that provided opportunities for greater oral and written discourse to facilitate students' meaning making of science; and (c) *least observed* that encouraged students' executive control of their learning and teachers' use of formative assessment in response to students' diverse learning needs. Teachers identified administrative support, PD strategies, and teacher collaboration as supports for implementation. However, they rated students' science knowledge, diverse language skills, and discourse abilities as the greatest barriers to implementing a SCDC.

Introduction

Teacher Change Through Professional Development

Since the initial publication of the *National Science Education Standards* (NSES; National Research Council [NRC], 1996) and *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993) in the United States, teacher educators, professional development (PD) providers, and science teachers have grappled with how to improve student learning and incorporate more inquiry-based instruction in science lessons. The *Next Generation Science Standards* (NGSS) (Achieve, 2013) continues to challenge American teachers with its strong emphasis not only on science concepts but also on scientific practices. As states adopt the NGSS, they will be even more reliant upon classroom teachers who can enact curriculum and instruction that aligns with stated learning objectives and the large-scale assessment that will follow.

With a high value placed upon both scientific knowledge and practices, all students need teachers who can provide meaningful, authentic, and rigorous opportunities to learn science. Additionally, Lee, Quinn, and Valdés (2013) highlighted the pressing need for teachers' science lessons to focus on the language-rich aspects of scientific inquiry and communication for all students that are embedded in scientific practices. They also explicated the need for language support for diverse learners, in particular English language learners (ELL). Thus, it is imperative that science teacher PD programs attend to the wide breadth of knowledge and skills teachers need to enact 21st century science instruction (Bellanca & Brandt, 2010) and meet a modern vision of professional practice (Darling-Hammond & Bransford, 2007).

Because teacher PD is a relatively new idea, only taking root in the 1970s (Lieberman, 1992), it is not so surprising that concurrent production of new science curricula (e.g., Biological Sciences Curriculum Study (BSCS)), without a deep understanding of how to affect teacher change and develop teaching expertise over time, has failed to result in science education reform. Yerrick and Roth (2004) also noted key differences between present and past reform recommendations; in the past, teachers' content knowledge and pedagogy were an isolated concern with little attention to student diversity or learning needs (Lee et al., 2013; Oakes & Guiton, 1995). Over time, PD programs have been more broadly used and diversified, creating myriad options through which teachers improve their science content knowledge, methods for engaging students, familiarity with exciting curricula, knowledge of how to conduct scientific research, and so forth. Despite the popularity of PD, historically the community of teacher educators and in-service PD providers has understood little about exactly how teachers apply what they learn during PD to their classroom practice (Hewson, 2007). However, the existing research about PD programs themselves has led to consensus about six aspects of effective and useful PD programs: (a) a clear focus on classroom practice that involves subject matter and pedagogical knowledge; (b) active and inquiry based learning; (c) collaborative learning; (d) duration and sustainability; (e) coherence in its goals and design; and (f) school organizational conditions (van Driel, Meirink, Van Veen, & Zwart, 2012). More recently, there has been a greater focus both on conducting research on teacher PD and on improving the rigor of such investigations to address the past lack of understanding.

A major issue with investigating the effects of teacher PD is that while a particular finding might be critical for one program in one context, it may dissimilarly apply to another. Teachers need time to integrate new ideas as they make sense of their own teaching situations at classroom, school, district and state levels. In essence, researchers need to understand teacher learning and the variation in the ways that teachers use what they have learned. Wilson (2013) identified teacher PD as one of the "grand challenges" in science

education research and called for a more complex view of teacher learning, “one in which professional learning is seen as more dynamic and iterative, connecting teachers’ experiences in their classrooms with formal opportunities for collective reflection and for acquiring new knowledge that targets genuine problems of practice” (p. 311). In the *Second International Handbook of Science Education* (Fraser & Tobin, 2012), there were three chapters devoted to professional knowledge, science teacher learning, and PD. The authors of one of these chapters, Wallace and Loughran (2012), remarked that connecting teacher learning to school reform is a recent phenomenon, but that “teacher learning is a central tenet for educational reform” (p. 303). To respond to this call for more sophisticated and practical insights into the mechanics of teacher learning and application to the classroom setting, educational researchers will need to carefully align measures and analyses of teacher and student performance to determine how teacher learning translates into teacher effectiveness and to ensure the transferability of findings.

In this study, we investigated community of practice-based science teacher learning as a model for instructional change. We report on the implementation of one such research-based, theory-driven PD program called the *Communication in Science Inquiry Project* (CISIP) designed to help teachers create scientific classroom discourse communities (SCDCs; Baker et al., 2009). These communities use the exploration of the natural world along with oral and written discourse to support learning of core scientific concepts. Through a multi-method, quantitative research design (e.g., surveys and classroom observations of science lessons), we examined the factors that acted as barriers and supports to implementation of SCDCs, which aspects of the PD were adopted more readily than others, and teachers’ motivation to change. This information, along with teacher, student, and school demographic information, was then used in the creation of a hierarchical linear model to model change in teachers’ implementation of the PD over time.

The teacher PD that we studied leveraged principles of learning in line with traditional learning theory at multiple levels (e.g., students, teachers). Following in the footsteps of Borko and Putnam (1996), we understand that learning to teach draws on cognitive psychology and certain core learning principles: (a) “the central role of knowledge; (b) learning as an active constructive process; (c) knowledge and learning as situated in physical and cultural contexts; and (d) the importance of prior knowledge and beliefs in learning to teach” (p. 673–674). In our investigation of one instance of teacher PD, we use these same core principles to analyze what these particular teachers learned and how they applied what they knew to enact reformed teaching.

Literature Review

Key Aspects of Teacher Professional Development

In the second edition of their book, Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2003) used aspects of effective teacher PD to offer a design framework for PD. These authors synthesized many general but critical aspects of designing effective teacher PD based on their experiences and knowledge of pitfalls to avoid (e.g., insufficient time, recruiting teachers in equitable ways to ensure diversity); thus their book has become part of the essential cannon of the PD provider, especially with a release of the third edition in 2010. In a recent status report on the current state of the field, Wilson (2013) echoed five key aspects of teacher PD that researchers have identified: (a) “focusing on specific content, (b) engaging teachers in active learning ..., (c) enabling the collective participation of teachers ..., (d) coherence (aligned with other school policy and practice), and (e) sufficient duration (both in intensity and contact hours)” (p. 310). Van Driel et al. (2012) also specifically identified

school organization conditions as an important, yet understudied, aspect of teacher PD. Indeed, much foresight and planning must be employed to both design research-supported teacher PD and concurrently study the effects of those programs. Van Driel et al. (2012) offer a more current review of research on science teacher PD and have documented the increase in the research literature of studies of science teacher PD. They selectively analyzed 44 studies, ultimately placing them into four categories according to Clarke and Hollingsworth's (2002) model of teacher professional growth: (a) the relationship between external domain and the domain of practice; (b) the relationship between the external domain and the personal domain; (c) relationships among the external domain, domain of practice, and the personal domain; or (d) all relationships, including the domain of consequence (i.e., student outcomes). Across these studies, they identified the fact that researchers frequently did not consider the results of teacher PD in the light of school organizational conditions. Indeed, teacher PD can appear to be more effective by ignoring the practical limitations that teachers may face, which could potentially undermine the positive learning experiences that they have had within a professional learning community. As part of this study we deliberately investigated teachers' perceptions of barriers and supports to implementing PD ideas—in particular, how they viewed their administration, students, students' parents, and colleagues.

A national study by Blank, De las Alas, and Smith (2008) that sampled American mathematics and science teacher PD initiatives from 2004 to 2007 failed to find how observed changes due to PD functioned over time, what changed about teachers' practices, or how to evaluate change over time in a way that aligned theory, methodology, analytic method, and findings. The same report indicated that programs that appeared to change teachers' classroom instruction were over 50 hours in length, but it estimated that only about one third of studies reported measurable effects. Banilower, Heck, and Weiss (2007) conducted a study of National Science Foundation-funded Local Systemic Change projects and found that participation in PD was positively related to attitudes toward, and perceptions of, science instruction, including teaching methods and subject matter knowledge. They also found that teachers were more likely to implement specific instructional materials if they received PD on how to use them. Jeanpierre, Oberhauser, and Freeman (2005) reported that PD for the purpose of shifting secondary science teachers to a more inquiry based practice ought to include opportunities for practicing science content and process knowledge with teacher accountability. For example, Penuel, Fishman, Yamaguchi, and Gallager (2007) studied teachers engaged in PD with the GLOBE Program, an international earth science education program, and concluded that the success of the GLOBE program included providing teachers with time to generate implementation plans and materials needed for a more inquiry-based approach to learning. Additionally, Penuel et al. (2007) concluded that when providers adapt PD activities to specific groups, they must balance teachers' own contexts, the PD demands, and negotiating PD goals within schools and classrooms.

By acknowledging the complexity of the educational system, this study highlights the need for administrative support for "meaningful experimentation" in school systems as identified by Donovan (2013) to develop a better understanding of how to reform education. Like Hewson, O'Donnell (2008) reminded us there is insufficient research to guide researchers on "how fidelity of implementation to core curriculum interventions can be measured and related to outcomes, particularly within efficacy and effectiveness studies, where the requirements for fidelity measures differ" (p. 33). When administrative policies and research goals are at odds, or access to schools is prevented, we are unable to investigate how teaching innovations work in real classrooms across multiple contexts with diverse students.

As a closing point, the assumption is that student performance is generally correlated with teacher effectiveness and increased teacher effectiveness with more PD. However, because every instance of PD is idiosyncratic, global claims about all PD are difficult to make. Fidelity to PD and its similarities in implementation to other programs is critical to making larger claims about overall traits of PD that are correlated with student learning gains. Nevertheless, we need well-vetted innovations, and to have such innovations, we must have a clearer understanding of how PD is incrementally adopted and implemented or rejected.

Conceptualizing Teacher Change: Learning Theory and Communities of Practice

Kunzman (2003) identified five themes within experienced teachers' learning: (a) a greater awareness of struggling students, (b) more complex understanding of curriculum planning, (c) the importance of collegiality and collaboration, (d) value of feedback and structured reflection, and (e) development of a theoretical framework to inform and guide practice. Such aspects of teachers' learning are often identified as cornerstones to good teaching (Darling-Hammond & Bransford, 2007). The importance of collaboration and collegiality to support community-based situated learning and practice supports sociocultural theories of learning (Lave & Wenger, 1991; Vygotsky, 1986). There are many aspects of learning (e.g., cognitive, affective, motivation) that can be used to understand teacher change. In the past, researchers like Borko and Putnam (1996) framed their synthesis of research findings around teachers' beliefs, subject matter knowledge, and general pedagogical knowledge. The essential quality of a classroom is in the interactions among these categories and other factors; therefore, limiting findings to isolated categories is inevitably an oversimplification. To avoid unwarranted findings, the use of core learning principles must point directly to the particular mechanisms by which learning occurs. In our investigation, we used cognitive learning principles to analyze science teachers' learning by focusing on how they applied new knowledge to enact reformed teaching, thus examining changing instruction in its complexity. Specifically, we employed the following conceptual framework to design a study to better understand how teachers learned how to build scientific classroom discourse communities (SCDC) through PD (Figure 1).

In this view, classrooms are ecosystems, subcultures, communities of practice, places of social reproduction, and microcosms of the communities within which they are situated. Science teachers must navigate their own professional goals, the daily demands of students, parents, colleagues, administrators, and workplace cultures. In the same way, students navigate their own intersecting, complex milieus. There has been a convergence in the research literature on teacher and student learning highlighting their similarities (Loughran, 2007). Teachers may learn new ideas through PD, but may implement them selectively because of their erroneous beliefs about students and how they learn (i.e., intelligence is a fixed quantity, not changeable [Dweck, 2000] and thus only highly motivated honors students can be challenged with inquiry-based science instruction, rather than all students). Similarly, students may learn new scientific ideas and adopt, or not adopt, them based upon their personal beliefs. We used psychological theories of individual cognition to frame both the content of the PD and our study of teachers' learning (Table 1). The three core learning principles are (a) engaging prior understandings, (b) the essential role of factual knowledge and conceptual frameworks in understanding, and (c) the importance of self-monitoring (e.g., metacognition; NRC, 2000, 2005). Our application and research design using these principles will be explained in greater detail in a later section.

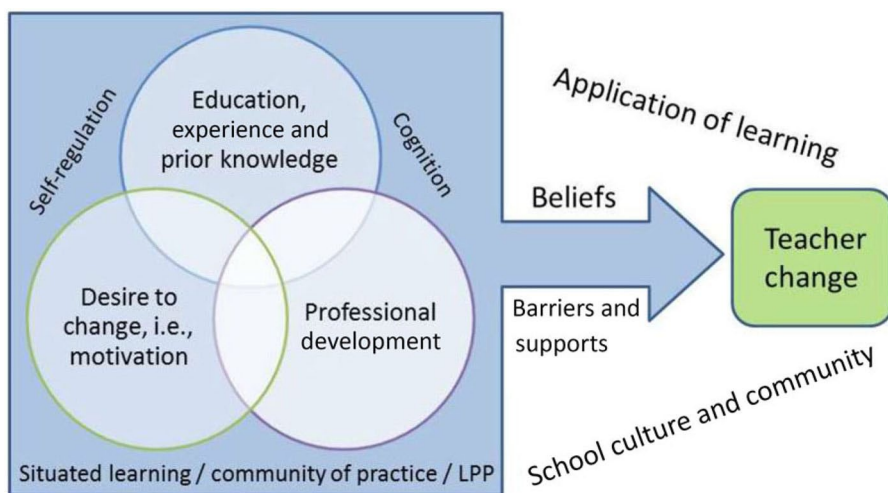


Figure 1. Model conceptual framework of teacher learning and change through cognition, self-regulation, that corresponds with cognitive learning principles and situated learning with respect to individual values and institutional contexts.

Table 1. Matrix of Learning Principles, Teacher's Learning Through PD, and Instrumentation

Learning Principles (NRC, 2005) Student Learning	Teachers' Learning Through PD	Instruments Used To Generate Data
LP 1: Engaging prior understandings	Prior knowledge of instructional strategies, beliefs, science content knowledge, credentials, pedagogical knowledge	<ul style="list-style-type: none"> Teacher education and demographic survey CISIP Teacher Self-Reflection Survey
LP 2: The essential role of factual knowledge and conceptual frameworks in understanding (and assessment of this knowledge)	Facts = individual and observable instructional strategies Conceptual framework = CISIP model of a scientific class discourse community (SCDC) <ul style="list-style-type: none"> inquiry oral discourse written discourse academic language development learning principles 	<ul style="list-style-type: none"> Descriptive statistics individual instructional strategy use within framework of SCDC Observations of teaching (DiISC instrument) = authentic/performance assessment of learning Change in enacted practice (HLM)
LP 3: The importance of self-monitoring	Teachers reflection and identification of what supports and prevents (barriers) their implementation of a model of a SCDC	<ul style="list-style-type: none"> Barriers and Supports Survey

More broadly, Vygotsky's (1986) social development theory of cognition emphasizes the pivotal role of culture, language, and social factors. The concept of a zone of proximal development (ZPD) explains how more capable learners can provide the necessary scaffolding for new or struggling learners. So, in addition to learning theory that focuses on individual cognition, we used the concept of ZPD by having master teachers mentor new teachers within a community of practice (using, as we call it, reciprocal teaching methods). This idea is well outlined by Lave and Wenger (1991) who studied apprenticeship as a mode of learning, developing ideas of situated learning and communities of practice. In particular, their concept of legitimate peripheral participation (LPP) required mentoring of novice members. Student teaching is analogous to apprenticeship in the current model of preservice teacher education, and participating in teacher professional learning communities is the emergent model for in-service teacher PD. Parallels between ZPD and LPP reinforce each theory of learning in social contexts, and many educational researchers have used these theories, thus adopting a situated learning perspective (e.g., Putnam & Borko, 2000). In light of powerful social forces, Lave and Wenger (1991) developed an analytic perspective for educational researchers; situated learning bridges both individual cognitive processes and group social practices, allowing researchers to capture the complexity of the phenomenon of teacher change. From these ideas emerges the concept of a scientific classroom discourse community (Hand et al, 2003; Yerrick & Roth, 2004) to more authentically match the practices of scientists and provide more engaging opportunities to learn science. In this study of teachers' learning and changing practices, we applied Lave and Wenger's analytic viewpoint as others had successfully done (e.g., Franke, Kazemi, Carpenter, Battey, & Deneroff, 2002) to specifically study teachers' participation in PD activities focused on learning how to build their own scientific classroom discourse communities.

Language, Learning Science, and Scientific Classroom Discourse Communities

Science education reform documents (Achieve, 2013; NSES, NRC, 1996) have encouraged science teachers to use authentic learning experiences that reflect the ways in which scientists communicate their own work. Scientists work in teams of researchers, peer-review each other's work, and communicate their findings through a variety of oral and written modes. Thus, to better reflect the practice of doing science, science teachers need to be able to bridge these uses of academic language and practices of scientists with students' everyday language and conceptions of the world around them.

Lemke's (1990) identification of classroom triadic dialogue (initiate-respond-evaluate, otherwise known as "IRE") as a means for knowledge transmission and discourse structure is the antithesis of science education reform. However, Lemke found that it is a favored staple of whole-group discussion pedagogy in science classes. The use of scientific inquiry as a teaching paradigm provides students with more opportunities, not only to engage with scientific questions, make observations, and make meaning from their own experiences, but also to talk with each other and not just their teacher. Gee (2005) stated that students need these peer-to-peer learning experiences to create meaningful discourse and develop conceptual understandings. This follows in the Vygotskian (1986) and Dewian (1938) tradition of social and experiential learning and language. Numerous authors have written about the sociocultural, sociolinguistic, and philosophical elements of scientific classroom discourse communities and the importance of language in learning science (Yerrick & Roth, 2004). For example, in *The New Science Literacy* (Their and Daviss, 2002) and *Crossing Borders in Literacy and Science Instruction* (Saul, 2004) the authors illustrate a combination of science,

language, and learning that are now on the leading edge of science education reform. The CISIP PD program relied heavily upon the use of language and learning theories in developing its model of a scientific classroom discourse community; with this model in hand, one of the main goals of the teacher PD was for teachers to learn how to address the needs of their diverse learners and underrepresented students in science.

As Borko (2004) reported in an analysis of PD research, “we have evidence that PD can lead to improvements in instructional practices and student learning” (p. 3). This conclusion is encouraging and by researching the critical elements of PD that can foster educational reform we can be more effective in providing teachers with opportunities to adopt new practices. In this study, our main objective was to understand how teachers applied a specific PD model as they designed new curriculum and implemented a wider range of instructional practices, focusing specifically on how they constructed scientific classroom discourse communities. We also investigated impediments and supports to teachers’ transformed practices. Within classroom discourse communities, we examined the complex relationships embedded within teaching as a social act and as more than a simple set of behaviors (Erickson, 1986; Lave & Wenger, 1991). We explicitly highlighted and used scientific classroom discourse communities in the PD to model how science and English language arts/ELL teachers could approach teaching and learning with their own students.

Rationale and Research Questions

Our study investigated the issue of science teacher reform through changes in instructional practices. In this case, the PD program focused on learning about a set of instructional strategies from which teachers could choose to design their own scientific classroom discourse communities. This PD design hinged upon salient research findings and the practical needs of science teachers, following a pragmatic perspective which has been espoused and synthesized by Wallace and Loughran (2012). They comment that a pragmatic perspective “would suggest that teachers need the opportunity to engage in authentic activities, participate in rigorous and critical debate within discourse communities, and develop facility with the various tools used in that community” (p. 302). The PD program design and setting in this study encompassed aspects of individual cognition, social interaction, and the learning environment. These variables are dynamic, which complicate studying how teachers learn from specific PD programs, reflect on their teaching practices, and selectively implement what they have learned in their classrooms. Thus, in many ways all research about specific, unique PD experiences will be highly contextualized at two levels: the general level of the PD program design and the more specific level of what will be incorporated into the classroom by different participants.

Throughout our study, we found that fidelity of implementation is a double-edged sword; sometimes it is difficult to balance respect for teachers as experts in their classrooms with outcome-driven PD agendas, but we assumed that effective PD would improve teachers’ knowledge to the extent that it could be observed as a change in their classroom instruction. Table 1 aligns learning principles, teacher learning through PD, and the instruments we used to generate data. We asked the following research questions as part of our overall inquiry into teacher implementation of PD:

1. Which of the instructional strategies from the CISIP did teachers adopt more easily than others to create their own scientific classroom discourse communities?
2. What, if any, student or teacher variables significantly predicted teachers’ implementation of the CISIP model or their initial levels of PD-associated behaviors?

3. To what degree were science teachers motivated to change their instruction to be more aligned with the CISIP model?
4. What were teachers' views of barriers and supports to implementing new ways of teaching science?

Professional Development Research Participants and Context

Teachers were recruited into the PD program in school-based teams with administrator support. Districts were approached initially to determine their interest before recruiting teachers; in fact the administrators were also provided with a 1-day PD session to learn more about the CISIP PD activities so as to better understand the kinds of changes teachers might be making in their classrooms. The teachers were provided with an honorarium to participate during the summer sessions and follow-up Saturday workshops throughout the school year. The majority of the teachers who started the CISIP program stayed with it from beginning to end, but there was approximately a 15–20% attrition rate. During the first year, middle and high school teachers participated in one of two 3-week CISIP summer institutes, followed by 4 day-long workshops to reinforce and elaborate upon the summer PD (Figure 2). The teachers had an opportunity to attend a total of 96 hours of PD programming in the first year. Some teachers had also previously participated in the 2-year development phase, and potentially had accrued an additional 200 hours. During the second year of the study, only high school science and English language arts/ELL teachers from two school districts were observed. Teachers who had participated in the first year acted as mentors and recruited new teachers. These new teams participated in a 4-day introduction to CISIP over the summer and six workshop days throughout the academic year, for an additional 60 contact hours.

The research team was separate from the PD program team, but interfaced regularly with the PD providers to provide feedback from not only the classroom observations between

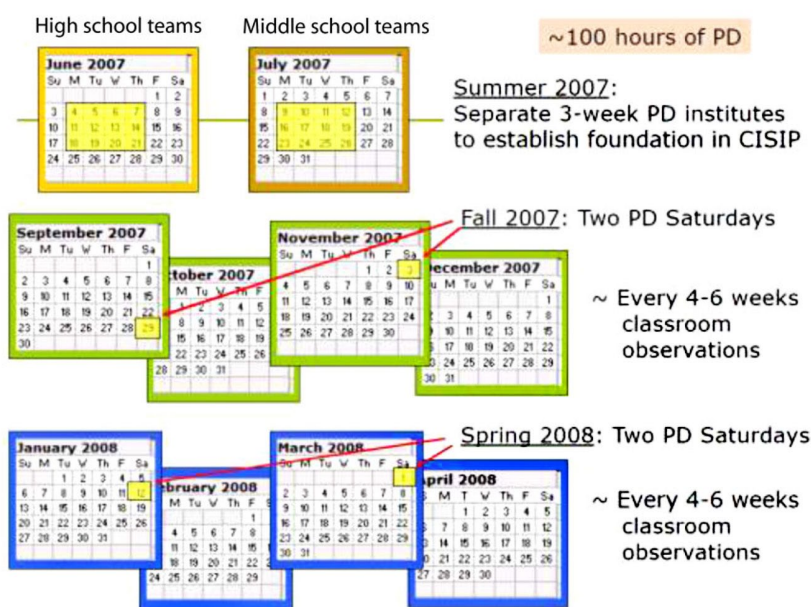


Figure 2. CISIP professional development schedule.

PD sessions but also from the PD workshops. We acted as unobtrusive observers in the classroom when we made observations of the teachers, and we did not provide coaching as there were teacher-leaders already in place to provide support. Our focus was mainly on the teaching behaviors of the teachers themselves and what, if any, aspects of the PD they were trying to use. There was also an external evaluator on the grant who worked independently of the research team but occasionally interacted with the researchers to compare fieldnotes and provide annual reports and feedback to the lead PD providers, principal investigators, and the grant's advisory board.

The Communication and Scientific Inquiry Project Community of Practice

While we, as part of the research team, were interested to see how much of the PD from a specific program was used by teachers, the CISIP program itself rejected the notion of scripted science lessons. While this kept PD context specific to individual teachers' practices, our findings helped guide the development of tools for science education reform. The goal was to teach secondary science teachers how to build SCDCs from a wide range of aligned instructional strategies. Teachers were encouraged to develop their capacity through the development of an "instructional palette," used in turn to design lessons to meet diverse students' learning needs. Teachers had the opportunity to (a) learn more about effective teaching methods, (b) practice designing and teaching science lessons, and (c) confront negative beliefs about teaching science to all students.

At each of the PD sessions, teachers were provided with exemplar activities using specific instructional strategies to model particular aspects of a scientific classroom discourse community. They participated in these activities themselves and then were provided time in groups to brainstorm ways that they could use those same instructional strategies in the context of their own curriculum and students. For example, in the *Mystery Boxes and the Writing of a Scientific Explanation Activity* teachers were provided sealed wooden boxes with objects inside and were asked to generate observations and construct claims using evidence and reasoning. This activity modeled for the teachers the writing process of a scientific explanation with an emphasis on clear performance expectations for writing and the writing of an explanation with claims, evidence, and reasoning. They were also provided feedback on written scientific arguments and revising arguments based upon their teams' writing to model another critical aspect of student learning. This example aligned most strongly with the SCDC aspect of written discourse. Other examples of the four other aspects are presented in Table 2.

The CISIP community of practice included beginning and veteran teachers, in-service teachers, secondary and postsecondary science teachers, and English language arts and ELL faculty. English language arts and ELL teachers were included as part of the school-based teams because of their expertise in oral and written discourse, and it was conceived that they could assist their science colleagues in these areas. The range of teacher knowledge made all teachers simultaneously experts and novices in an interdisciplinary teaching dialogue that drew upon available expertise. The CISIP participants were part of a teacher learning community as defined by Cochran-Smith and Lytle (2003) as "social groupings of new and/or experienced educators who come together over time for the purpose of gaining new information, reconsidering previous knowledge and beliefs, and building on their own and others' ideas and experiences ... intended to improve practice and enhance students' learning" (p. 2462). All teachers in the PD had something to learn from each other because the CISIP model was built upon and integrated critical aspects of multiple disciplines to benefit both nascent and master teachers. Thus, situated cognition and LPP were

Table 2. Selected CISIP Professional Development Activities for Teachers to Learn to Build Scientific Classroom Discourse Communities

SCDC Core Elements	Activity Example
Scientific inquiry	<ul style="list-style-type: none"> • <i>BioLab 1: Human Characteristics</i>: Inquiry investigation about human characteristics with embedded support for academic language development with modeled strategies to use in the classroom. • <i>BioLab 2: Gummy Bear Genetics</i>: Experience and use of academic language development strategies embedded within an CISIP inquiry activity about genetics. • <i>BioLab 3: DNA Extraction</i>: Integration of CISIP components within DNA laboratory.
Oral discourse	<ul style="list-style-type: none"> • <i>Nature of Science (NOS) Communication Card Activity</i>: Definition of NOS and the types of communication that are integral to doing science. Discussion about how scientific writing and talking reflects NOS
Written discourse	<ul style="list-style-type: none"> • <i>Mystery Boxes and the Writing of a Scientific Explanation</i>: Begin writing process of a scientific explanation with an emphasis on clear performance expectations for writing and the writing of an explanation with claims, evidence, and reasoning. Provide feedback on written scientific arguments and revise arguments based upon writing.
Academic language development	<ul style="list-style-type: none"> • <i>Opening Doors</i>: Experience and identification of scaffolding strategies and techniques for teaching academic skills to English language learners (ELL). • <i>BICS/CALP</i>: Explanation of the significance of Basic Interpersonal Communication Skills (BICS) and Cognitive Academic Language Proficiency (CALP) in language acquisition.
Learning principles	<ul style="list-style-type: none"> • <i>Fish is Fish</i>: Introduction to learning principles and the sociocultural influences on ELL as they relate to “Fish is Fish” story. • <i>Graphing Motion with Motion Detectors</i>: Situating of metacognition within an inquiry activity. Development of concepts of graphing of back and forth motion with attention to metacognition.

foundational and the learning community encouraged sharing of subject matter knowledge and instructional approaches from each discipline.

Based upon critical research findings, the CISIP model included five essential curricular aspects to design effective science instruction: (a) scientific inquiry, (b) oral discourse, (c) written discourse, (d) academic language development, and (e) learning principles (e.g., accessing student’s prior knowledge (NRC, 2000, 2005)). As a learning platform, scientific inquiry that relied upon a constructivist learning approach provided teachers with opportunities to engage with scientific questions, make observations, and interpret data to generate their own conclusions in the same ways as their students. While the instructional strategies

promoted in CISIP were carefully selected from relevant research literature, the types of lessons teachers designed for students ultimately determined what, if any, benefits students gained as a result of their teachers' PD. Teachers were regularly provided time to cogenerate lessons with colleagues. Over time, the PD providers collected and shared teacher-generated examples of transformed lessons using the CISIP model.

In summary, CISIP provided school-based teams of teachers with year-round PD that regularly focused on (a) ELLs' needs and the challenges of academic language acquisition for mainstream students, (b) opportunities for teachers to redesign lessons using SCDC instructional strategies, (c) activities for teachers to exchange ideas, (d) opportunities for teachers to reflect upon their own learning during activities, and (e) regular and explicit instructional examples and connections to the SCDC model. The CISIP PD model also included rigorous use of student science notebooks with embedded academic language learning support. The PD program carefully wove the aforementioned five core elements throughout the activities for the teachers (see Table 2 for selected examples). Over time the PD providers collected and showed teacher-generated examples of lessons that had been transformed using the SCDC model. Teachers were also provided time during the PD to develop their own lessons for their own students.

Methodology

Participants

Of the teachers participating in the CISIP PD, there were a total of 16 high school and 13 middle school teachers, mostly female (69%), with an average of 11.3 years ($SD = 8.9$ years) of teaching experience, who consented to allow classroom observations. Their demographic information is given in Table 3. Included in our entry survey of teaching demographics, we also asked teachers to provide us with some indicators of their prior knowledge, e.g., how to teach ELLs, science methods coursework, course(s) on the history and nature of science (NOS; e.g., 48% of teachers without), thus providing some indicators of what teachers might know about the CISIP core ideas prior to starting the program.

Data Collection and Researcher Stance

There were three levels of our investigation: (a) *Level 1*: surveys of 11 middle and 14 high school science teachers who participated in first year of CISIP, (b) *Level 2*: 15 middle and high school science teachers who consented to regular classroom observations, and (c) *Level 3*: the classroom instruction and perceptions of PD of two high school biology teachers. The data collection timeline was as follows: (a) Upon their entry into the PD program, teachers were asked to fill out a demographic questionnaire and a beliefs survey; (b) as they engaged with the PD, we scheduled four to six observations throughout the school year; and (c) at the end of the PD program, we had them take the belief survey again (postprogram) and complete a survey of what they viewed as supports or barriers to implementing the PD in their own classroom.

When we conducted observations, we generated fieldnotes that described the focus and science content of the lesson that were covered, the classroom activities that occurred, the kinds of instructional strategies that were being used by the teachers, and the kinds of discourse that were occurring (e.g., small group, whole group). We did not transcribe the lessons, as we did not intend to engage in linguistic discourse analysis, but rather classified the types of discourse instructional strategies that occurred (e.g., peer to peer). We also collected copies of any handouts that the teachers provided their students. These fieldnotes allowed

Table 3. Teacher Education and Demographic Information

Teacher Demographic Information	
Middle school	13
High school	16
Female	20 (69%)
Male	9 (31%)
Average years teaching	11.3 (SD = 8.9)
Average number of degrees	1.76 (SD = 0.64)
Bachelor's degree	9 (31%)
Post-Baccalaureate course work	4 (13.8%)
Master's degree	15 (51.7%)
Medical Doctorate degree	1 (3.4%)
Certification	
No teacher preparation	1 (3.4%)
Undergraduate teacher certification program	12 (41.4%)
Postbaccalaureate teacher certification program	16 (55.2%)
In-field	27 (93%)
Out-of-field (elementary)	2 (6.9%)
PD-relevant coursework	
Mean number of science courses	17.3 (SD = 10.49)
Mean number of science methods courses	1.7 (SD = 2.00)
Teachers without a class in history and philosophy of science	14 (48%)
Teachers without an English content course	7 (24%)
Teachers who had—one to two English classes	8 (27.5%)
Teachers without an English or language arts teaching methods class	17 (58.6%)
Teachers without an ESL class	5 (17.2%)

us to use the *Discourse in Inquiry Science Classrooms* (DiISC) instrument to determine the degree of alignment with the CISIP model of a scientific classroom discourse community.

Over 2 years, the research team conducted 297 observations of teachers' science lessons; the distribution and participants in these observations are as follows: In the fall of 2007, the lead author observed 14 Level 2 teachers one to four times each for a total of 31 observations; she conducted most of these observations with another researcher and engaged in interrater consensus discussions after each observation. Other members of the research team also made other observations in pairs. In the spring 2008, the lead author, who was also primarily responsible for the training of other observers, observed six teachers one to ten times each for a total of 24 solo observations; other members of the research team also made solo observations. Thus, during the 2007–2008 academic year, 106 classroom observations of CISIP science teachers (Level 2) were conducted. We then used the observation scores to build an exploratory, 1-year longitudinal model using hierarchical linear modeling (HLM) to determine what, if any, significant relationship existed between various teacher attributes and teachers' fidelity to the CISIP model (Lewis, 2009).

Because the results of the 1-year HLM were tentative, we generated another year of observation data to build a better-powered model; these results are presented below. Over

the course of the 2008–2009 academic year, we made an additional 163 observations (first in pairs, and once reliability was reconfirmed, as independent observers) of 10 original participants and 16 of their newly recruited teaching colleagues for a total of 30 teachers (16 science and 14 English language arts/ELL teachers). Seven of the 10 original teacher participants had previously participated in the PD but not in the research study. Additionally, we made 28 observations of 13 comparison (i.e., non-CISIP) science teachers. The lead author also constructed case studies of two high school biology teachers (Level 3) that are presented elsewhere due to space constraints (Lewis, 2011).

The research team was also part of the instrument development team that engaged in extensive field-testing and constant comparison with the CISIP program sessions. We developed this instrument because there were few available classroom observation instruments at the time and none that were aligned with the content of the PD. For over a year, the research team conducted observations in pairs and generated consensus scores and refined the items to be unidimensional. After determining that interrater reliability had been achieved, the observers conducted observations independently.

Instruments

Each of the 323 teachers' lessons was scored with the DiISC instrument. The DiISC was developed over 3 years and was aligned with the SCDC model; its development is chronicled in greater detail elsewhere (Ozdemir, Lewis, & Baker, 2007). Of note is the fact that we have not, as of yet, established a holistic validity and reliability argument for using this instrument. Initially, the items were developed in reference to previous research on the role of writing, oral discourse, scientific inquiry (NRC, 1996), learning principles in science teaching and learning (NRC, 2000, 2005), and academic language development strategies. A manual for use with the DiISC was developed and outlines the theoretical underpinnings of the development of the instrument as well as the psychometric properties (Baker et al., 2008). The five scales on the DiISC match the five aspects of CISIP. We used the 36-item DiISC as proxy for teacher fidelity to the CISIP model, to better understand which instructional strategies were used more often than others, and model teacher change over time. Each item used a 0–3 point scale with a unique rubric. To reiterate, based on an insufficiently developed validity argument (due to time and sample size limitations), we used proportional scores (total teacher score/total possible score) within the five scales, rather than a more complex composite score (e.g., principle components analysis). In fact, attempts to simplify the response patterns (using principle components analysis) or examine underlying factor structure (using exploratory factor analysis) yielded results that were uninterpretable. Other work is being done to improve this measurement device and generate proper, holistic validity and reliability arguments, but until that work is completed, we are unable to make the case that results similar to those we found would be possible without using the DiISC in the same way as it was used in this study.

Two exploratory surveys were implemented, the *CISIP Teacher Self-Reflection Survey* (comparing teachers' current and desired use of CISIP), and a survey of barriers and supports to implementing PD. We also used an educational history and teacher demographics questionnaire to complement the classroom observations as a means to investigate teachers' motivation to change, their learning from the PD and how they used instructional strategies to build their own SCDC, and what factors appeared to support or confound teachers' efforts to change their practice. The *CISIP Teacher Self-Reflection Survey* was written in an effort to determine teachers' desire to change their instructional practices and included 19 Likert-type items aligned with the five CISIP aspects and one item on lecturing, which was a teaching method that the PD sought to decrease in its frequency.

The 30 science teachers in the study took this survey before they started the summer institute. Teachers rated the frequency of occurrences of different teaching methods within their classrooms from two perspectives: “the way it is,” and “the way I’d like it to be.” The survey had a repeated-measures design, and data were nonparametric; we conducted sign tests to identify significant differences between the medians of the sampled teachers’ current and desired teaching practices on any of the 20 items. We used Kendall’s *tau-b* to measure the degree of correspondence between each pair of teachers’ ratings and to assess the significance of this correspondence in an effort to determine whether there was a statistical relationship between each pair of variables for teachers’ current and desired frequency of a specific instructional strategy.

Science teachers responded to a second survey designed to assess their perceptions of various categories of barriers and supports to PD implementation. We designed the survey based on teacher comments as well as a systematic list of variables that could potentially affect teachers’ views toward implementation. The survey categories were (a) administrative actions, (b) collaborative teacher relationships, (c) curriculum, (d) instruction, (e) parents, and (f) students. This 46-item survey used a five-point Likert scale, rating major to minor supports for implementing PD. The items were tallied by subgroups, and the means were calculated. We set ranges between 1.0 and 5.0 to classify the groups’ mean response to each item as a barrier (1.00–1.50 = major barrier; 1.51–2.49 = minor barrier) or a support (4.50–5.00 = major support; 3.50–4.49 = minor support) to obtain a rough approximation of teachers’ perceptions as a group within each category.

These surveys were meant only to provide exploratory, descriptive results. There has been no development of a validity and reliability argument associated with these surveys, as they are not related to inferences we make here. The reliability and validity arguments of the DiISC were not adequately developed for our purposes to generalize findings, and the surveys were meant only to be descriptive. Our goal was to build credible findings not generalizable inferences, and thus we: (a) provide descriptive information for other researchers, (b) establish research questions that can be investigated with greater rigor in other studies, and (c) characterize the specific results of this study.

Modeling Teacher Change Over Time

We used HLM to explore relationships between PD, teachers’ practice, and systemic variables (Raudenbush & Bryk, 2002; Shadish, Cook, & Campbell, 2002). We chose to use a Hierarchical Linear Model (HLM) for several reasons. Primarily, because we were unable to meet the assumptions of analysis of variance (ANOVA) or other, related general linear model techniques. Conversely, we did not have the sample size to conduct a multilevel Structural Equation Model (SEM) without making the assumptions that would transform the SEM into an HLM. Because HLM is technically a type of SEM, and the assumptions of our analysis reduced the SEM to an HLM, we will refer to our modeling process as using only HLM. We also used HLM because our sample had missing data over time (unequal sample sizes at each time point).

We used several variables to account for initial differences between student groups and treatment over time. We chose these variables by creating an exhaustive list based on available information. As such, the analysis was exploratory. With this technique, individuals can be clustered within time points, so that the number of individuals at any time point could change (Raudenbush & Bryk, 2002); this was needed as teachers joined and exited the study at different times with more or less PD. Our sample size also required that we use a linear rather than nonlinear model. In the construction of the model, we used available teacher demographic information on professional experiences (e.g. length of time teaching).

Table 4. Summary of 1 Year of DiISC Observations ($n = 106$) of All Science Teachers ($n = 16$)

Scale	Number of Items	Maximum Score	Median	<i>M</i>	<i>SD</i>	<i>z</i> -Scaled Mean	<i>z</i> -Scaled <i>SD</i>
Scientific inquiry	6	18	3.0	3.36	3.24	0.19	0.18
Oral discourse	5	15	5.0	5.37	3.11	0.36	0.21
Written discourse	6	18	4.0	4.50	2.44	0.25	0.14
Academic language development (ALD)	8	24	7.0	7.51	3.22	0.31	0.13
Learning principles	11	33	7.0	7.72	4.10	0.23	0.12

We selected eight additional variables for their potential correlation with teachers' implementation of PD (Cuban, 1992), including, but not limited to school district size, per pupil spending on classrooms, total spending costs, socioeconomic variables, and average teacher salaries for each teachers' district (data source: [State blinded for anonymity] Department of Education, 2008). We used the DiISC scores as our outcome measure.

For the longitudinal model, our sample size allowed a two-level model (we attempted a third level, but the model was underpowered). The first level included the total raw observation scores on the DiISC for all five areas. The second level included a dummy code for group participation (PD or non-PD comparison group) with demographic information. Ultimately, only the two models described below allowed us to make inferences with statistical evidence. With a small, contextualized sample size, our investigation was exploratory and limited our capacity to generalize to other groups of teachers in the larger population or definitively decide between the two final models.

Results

Below, we present the results of which CISIP instructional strategies teachers used over the course of the first year of PD, as well as the results of a 2-year HLM to show how teachers' instruction changed. Finally, to explore the possible reasons behind these changes we conclude with summaries of results from the *CISIP Teacher Self-Reflection Survey* and *Barriers and Supports Survey*.

Research Question #1: Teachers' Adoption of SCDC Instructional Strategies

During the first year of PD, we found that teachers' use of the CISIP scientific classroom discourse community model varied in implementation (see Table 4). On each scale, the science teachers, based on a comparison of their *z*-scaled means, scored from highest to lowest in their use of groups of strategies: (a) oral discourse, (b) academic language development, (c) written discourse, (d) learning principles, and (e) scientific inquiry. The means were used to rank order all teachers' ($n = 16$) use of the CISIP instructional strategies to see which elements of CISIP were used most and least (Table 5). Generally, the teachers'

Table 5. Rank Order by Mean of Most to Least Used CISIP Instructional for All Science Teachers

Scale	Item	Description	Mean	SD
ALD	20	Clear instruction	2.11	0.83
Writing	18	Use of notebooks	1.50	0.93
ALD	19	Vocabulary acquisition	1.43	0.78
Oral	11	Model science discourse vocabulary	1.38	0.80
ALD	21	Visual aids gestures	1.38	0.79
Oral	9	Small group discussion	1.35	0.95
LP	42	Feedback	1.32	0.79
LP	38	Community norms	1.24	0.83
LP	39	Teacher expectations	1.17	0.72
LP	32	Review concepts	1.11	0.87
Oral	10	Bridge everyday with academic	1.06	0.91
Writing	14	Prewriting	1.05	0.87
Sci. Inq.	1	Inquiry environment	1.04	0.94
Oral	8	Whole-group divergent questions	1.04	0.82
Writing	16	Practice scientific writing	1.03	0.79
LP	31	Facts and conceptual framework (NRC, 2005)	1.03	0.79
ALD	25	Organize groups structure roles	0.85	0.85
LP	34	Metacognition (NRC, 2005)	0.76	0.86
Sci. Inq.	4	Observe/data collection	0.73	0.97
ALD	22	Bridge language and culture with science	0.63	0.77
Sci. Inq.	5	Claims-evidence	0.59	0.92
Oral	12	NOS discussion	0.55	0.87
ALD	24	Direct instruction learning strategies	0.55	0.74
Sci. Inq.	2	Students ask questions for investigation	0.46	0.78
Writing	13	Formal scientific writing	0.46	0.78
Writing	17	Writing instruction	0.41	0.67
LP	28	Assessing prior knowledge (NRC, 2005)	0.32	0.68
Sci. Inq.	3	Design exploration	0.28	0.64
ALD	23	Differential instruction language	0.28	0.53
ALD	26	Available supplementary resources	0.27	0.67
LP	35	Self-monitoring	0.27	0.61
Sci. Inq.	6	Data interpretation / sources of error	0.25	0.69
LP	37	Executive control	0.25	0.66
LP	36	Self-awareness	0.18	0.45
LP	29	Modifies instruction	0.07	0.29
Writing	15	Rubrics for revision of writing	0.06	0.23

Abbreviations: ALD, Academic language development; LP, learning principals; NOS, nature of science; Sci. Inq., scientific inquiry.

frequency of use of these strategies within lessons fit into three categories: (a) *most-observed* (often- and sometimes-used) strategies that required teachers to change their own communication, classroom management, and direct instructional behaviors; (b) *occasionally observed* strategies that provided opportunities for greater oral and written discourse to facilitate students' meaning making of science; and (c) *least observed* strategies that encouraged students' executive control of their own learning and teachers' use of formative assessment to be more responsive to students' diverse learning needs (Table 6). These groups are described in more detail as follows.

Table 6. Frequency of Use of Instructional Strategies through First Year of PD

Scale	Often Used (M = 1.51 +)	Sometimes (M = 1.01–1.50)	Occasionally (M = 0.51–1.00)	Rarely Used (M < 0.50)
Scientific inquiry (SI)		SI 1 inquiry environment	SI 4 observe/data collection SI 5 claims-evidence	SI 2 students ask questions for investigation SI 3 design exploration SI 6 data interpretation/ sources of error
Oral discourse (OD)		OD 8 whole group divergent questions OD 9 small group discussion OD 10 bridge everyday with academic OD 11 model science discourse vocabulary	OD 12 Nature of science discussions	
Written discourse (WD)		WD 14 prewriting WD 16 practice scientific writing WD 18 use of notebooks		WD 13 formal scientific writing WD 15 rubrics for revision of writing
Academic language development (ALD)	ALD 20 clear instruction	ALD 19 vocabulary acquisition ALD 21 visual aids gestures	ALD 22 bridge language and culture with science ALD 24 direct instruction learning strategies ALD 25 organize groups' structure roles	ALD 23 differential instruction language ALD 26 available supplementary resources
Learning principles (LP)		LP 42 feedback LP 38 community norms LP 39 teacher expectations LP 32 review concepts LP 31 facts and conceptual framework	LP 34 metacognition	LP 28 assessing prior knowledge LP 35 self-monitoring LP 37 executive control LP 36 self-awareness LP 29 modifies instruction

Most-Observed PD Strategies

The subcategory of *often-used* instructional strategies was solely occupied by an underlying stance of clear instruction by modeling expectations in the set of academic language development strategies (ALD, #20), which topped the list by far with a mean of 2.11 ($SD = 0.83$); nearly in a category of its own. A “2” score on this item indicated that the “teacher provided clear objectives and directions” to the students. To score a “3,” teachers would have to have been observed monitoring students for their understanding of objectives and directions. In practice, we observed that teachers provided students with clear objectives and directions in their lessons and that some teachers used monitoring more consistently than others.

Included in the subcategory of *sometimes-used* PD strategies (item means ranged from 1.03 to 1.50) were 15 items from all five scales. These strategies included two ALD (vocabulary acquisition and the use of visual aids and gestures to support scientific language), one inquiry (establishing an inquiry environment), four oral discourse (modeling scientific discourse and vocabulary, small group discussion, bridging everyday with academic language, and asking more divergent questions of the whole group), three written discourse (use of science notebooks, prewriting, and practicing scientific writing), and five learning principle items. For example, as they engaged in the CISIP program teachers began to use science notebooks more often, which provided students with a place to record their ideas and engage in prewriting. Teachers also employed small-group discussion more frequently and used more divergent questions when they conducted whole-group discussions. Such instructional moves were also a step toward using more inquiry-based instruction.

Occasionally Used Strategies

We less frequently observed seven other strategies that were at the crossroads of scientific inquiry, discourse and NOS (item means ranged from 0.55 to 0.85). We occasionally observed students collecting data and making claims supported with evidence, discussing NOS, and using metacognition to reflect upon their learning. Teachers occasionally used some critical academic language development strategies, such as assigning students roles within small groups, providing direct instruction about learning strategies, and bridging students’ language and culture with the academic register of science. Because these were science teachers with little formal education in the use of language arts, they may have lacked the awareness and confidence to employ such strategies on a more regular basis without further mentoring.

Least Used PD Strategies

Despite regular PD sessions, teachers still struggled with using strategies that placed more choice (e.g., executive control) and self-regulation (e.g., self-monitoring and self-awareness of learning) in students’ hands (item means ranged from 0.06 to 0.46). For instance, a student-designed open inquiry-based investigation in which students generated their own research questions and procedures was a rare occurrence in these teachers’ curriculum. Students were rarely encouraged to find sources of error in their investigations and engage in formal scientific writing with rubrics for revision of their own writing. Finally, teachers were rarely observed to use formative assessment to revise their instruction.

However, while teachers used more guided than open inquiry instructional methods in their classrooms, they began to noticeably change their instruction. While this overall, 1-year use of CISIP strategies provides an inventory of which specific strategies were most easily adopted and which were used least, the longitudinal analysis that follows provides a more sophisticated overall analysis of teachers' use of the CISIP model over not just one, but 2 years of PD.

Research Question #2: Predictors of Teachers' PD Implementation

To refine our analysis, we designed two two-level HLMs. Both models were compared against a null model, i.e., a model with no predictors at either level of the analysis. This was to ensure there was variance to model at each level by the predictors we would ultimately include. It would also provide a baseline fit statistic with which to compare more complicated models. We used the total raw DiISC measures to describe teacher characteristics that might predict teachers' levels of implementation of a scientific classroom discourse community in their own classrooms. Of note is the fact that while no individual student-level information was available, we used the percentage of each teacher's school's students who qualified for a free and reduced lunch program. Also, we used the variables to describe potential factors that may account for change over time in the amount of PD strategies the teachers used. The two models, Model A and Model B, are described in the following equations:

Model A	Level 1 :	$PD\ Use = \Pi_0 + \Pi_1 * (time) + e$
	Level 2 :	$\Pi_0 = \beta_{00} + \beta_{01} * (SES) + r_0$
		$\Pi_1 = \beta_{10} + \beta_{11} * (experimental\ condition) + r_1$
Model B	Level 1 :	$PD\ Use = \Pi_0 + \Pi_1 * (time) + e$
	Level 2 :	$\Pi_0 = \beta_{00} + \beta_{01} * (SES) + r_0$
		$\Pi_1 = \beta_{10} + \beta_{11} * (total\ PD\ participation) + r_1$

We systematically tried every available predictor. The two resulting models were the only combinations of predictors that predicted with statistical significance. Both models fit similarly well,¹ having, statistically significant predictors for intercept and slope. However, the actual predictors of slope differed; that is, they were different conceptualizations of treatment. In Model A, treatment was a simple 1 or 0 grouping value. In Model B, that group membership was reflected by the actual amount of PD that any one teacher received. The HLM approach allowed for participants to enter or leave the PD and have different total amounts of participation in the program at any point in time. Because we were unable to analytically choose Model A or B (i.e., there was no statistically significant difference in fit), and both models indicated the same treatment effect (i.e., there was no qualitative differences in inferring an effect of treatment), we defer to discussing both models in making inferences about that treatment effect (see Tables 7 and 8 for the estimated parameters).

1. Of note is that, unlike with traditional modeling techniques, we were unable to provide effect sizes. HLM requires that we consider model fit and only produces pseudoeffect sizes.

Table 7. Model A

	Effect (Variable)	B	Se	t Ratio	df	p Value
Intercept, Π_0	Intercept, β_{00}	38.22	4.70	8.13	58	< 0.01
	Poverty	-19.48	7.96	-2.45	58	0.018
Slope, Π_1	Intercept, β_{10}	-0.012635	0.011984	-1.05	58	0.297
	Condition, β_{11}	0.023016	0.009537	2.41	58	0.019

Table 8. Model B

	Effect (Variable)	B	Se	t Ratio	df	p Value
Intercept, Π_0	Intercept, β_{00}	36.790893	5.046069	7.291	58	< 0.01
	Poverty	-18.719641	8.550526	-2.189	58	0.032
Slope, Π_1	Intercept, β_{10}	0.002363	0.009015	0.262	58	0.794
	Condition, β_{11}	0.000481	0.000198	2.431	58	0.018

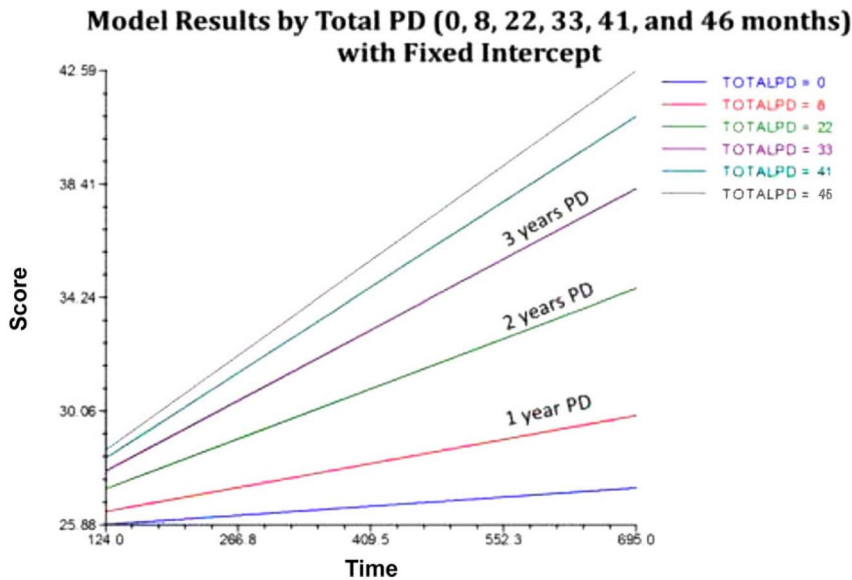


Figure 3. Slopes of teacher change due to amount of PD, holding intercept constant at zero. The lowest regression line represents the comparison group with no PD with an additional year of PD for each higher line.

In either Model A or B, the amount of PD, was the only statistically significant predictor of teachers’ changing instructional strategies over time. Specifically, the more PD a teacher received, the more they used PD-corresponding instructional strategies. To illustrate, in Figure 3 the slopes of the lines represent the rate of change by different groups of teachers according to the amount of PD teachers received. In Figure 4, we hold the intercept constant and consider treatment as only a 0 (no PD) or 1 (PD) condition, simplified in the graph as follows: In either model, socioeconomic status (SES) was the only predictor of teachers’ beginning use of PD-related strategies. Holding the slopes constant, we obtained the graph in Figure 5 to demonstrate differences in initial levels of PD. For the sake of completeness,

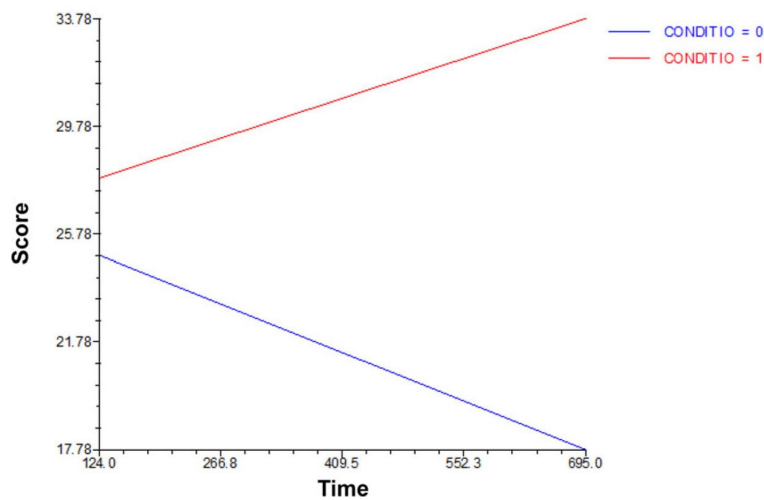


Figure 4. Teacher change slopes over time with and without PD.

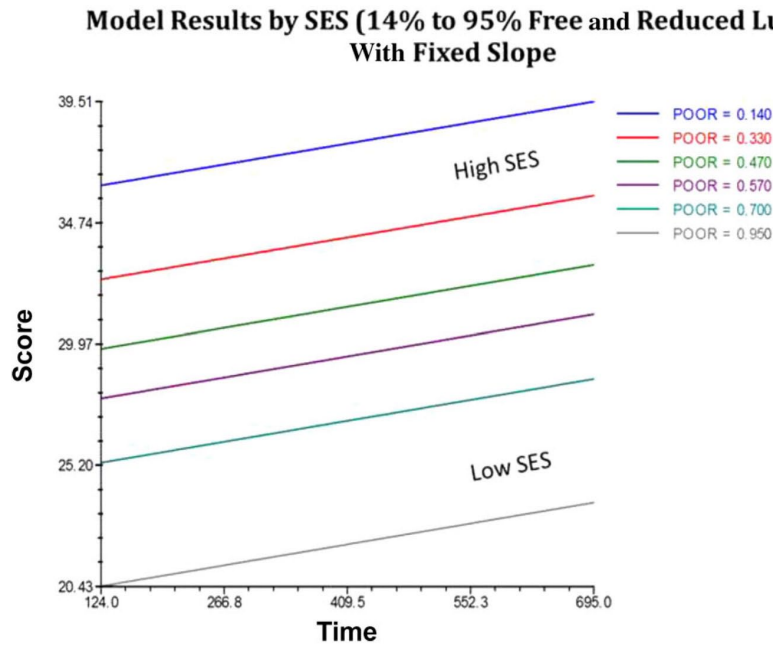


Figure 5. PD-related change over time holding slope constant. The percentage of students qualifying for free and reduced lunch decreases from 95% on the lowest regression line to 14% at the highest.

we include Figure 6, which allows both slope and initial SES to vary simultaneously, but it is complicated and thus we present further analysis of what the models mean in terms of teacher change.

We claim an effect on teachers’ instructional practices, presumably due to the PD, as this effect was supported by both models’ results and corresponding interpretations. This can

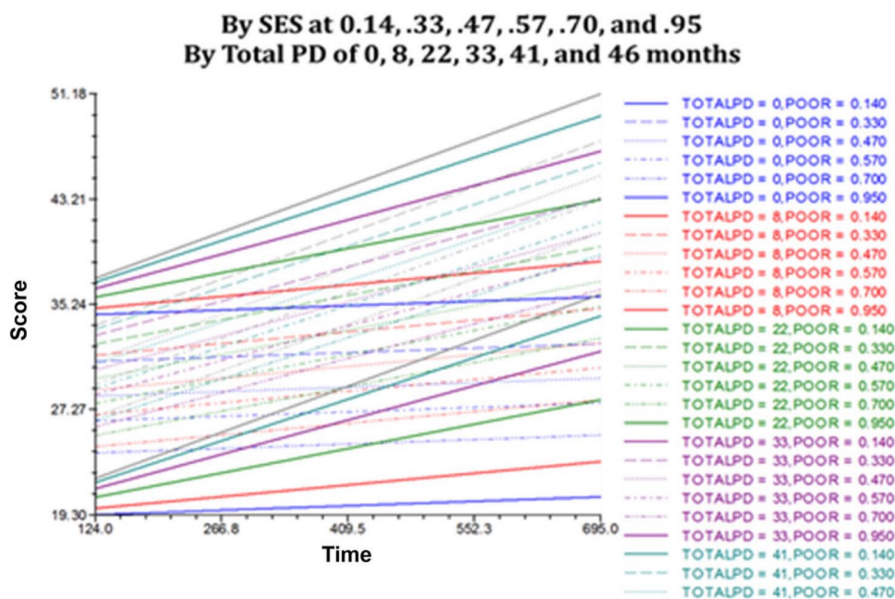


Figure 6. Complex full model that allows both slope and initial intercept (SES) to vary within subgroups.

be seen in Figure 3, where the intercepts, the teachers' starting points, were constrained to demonstrate how the slopes varied across levels of treatment, and in Figure 4, where only the group membership (with or without PD) was allowed to vary. While teachers increased in their use of CISIP instructional strategies, they began at a range of scores reflecting the average SES of their students. Figure 5 is a simplified graph of Model A where slopes were constrained according to specific levels of SES and treatment condition to demonstrate how the starting points of teachers varied across levels of SES. Figure 6 allows both SES and total amount of PD to vary simultaneously. In every graph, the effect of SES is uniformly related to the amount of initial, CISIP-related instructional practices that teachers used and the amount of PD (or whether they received it at all or not) determined use of PD-related strategies over time.

Research Question #3: Teachers' Prior Knowledge and Motivation to Change Instruction

Teachers' Experience, Certifications, and Subject Matter Knowledge. Our demographic survey results of science teachers' prior knowledge (i.e., educational background, preparation programs, and coursework) are presented in Table 3. Overall, there was a balance of new, mid-career, and veteran teachers with a variety of perspectives and experiences. Teachers were mainly in-field, secondary certified through either undergraduate or post-baccalaureate pathways. Nearly half of the teachers lacked a history and philosophy of science course. This lack of formal education in NOS, along with the observation data of science lessons in which teachers only occasionally engaged their students in discussions about NOS in conjunction with the science concepts they were studying, suggested that these teachers would benefit from learning more about NOS throughout the PD. Additionally, science teachers lacked expertise in English language arts content and associated teaching methods coursework in the use of written discourse and academic language development. With a statewide requirement that

teachers carry ELL endorsements, it was not surprising that most had had at least one ELL methods class. However, when we observed the science teachers such language-based instructional strategies were not often used. This suggests that all teachers needed even more opportunities to discuss and practice ALD and discourse, particularly written strategies. Despite our efforts to determine a pattern of which prior knowledge variables might predispose teachers to more readily adopt the PD model, none of these variables proved to be significant in our modeling process, nor in our general inspection of the data.

Teachers' Desire and Motivation to Change Instruction. To better understand teachers' level of motivation to change their teaching practices through the PD, we administered the *CI-SIP Teacher Self-Reflection Survey*. Based upon the sign tests, all differences between teachers' current and desired median teaching practices were significant at the $p < .001$ level, except for item #19, "How often during the week do students get information through lectures?," which was significantly different, but at the $p < .05$ level (Table 9). Six survey items (#7, 10, 14, 15, 17, and 20) required teachers to self-assess how often students engaged in inquiry-based instruction and activities; on average, the teachers rated their desired practice to more frequently include these inquiry-based instructional strategies than their current use. For instance, teachers wanted their students to develop and recognize alternative explanations for data, construct their own understanding of scientific concepts, defend their ideas with scientific evidence, and engage in hands-on activities more often. However, while teachers expressed the desire to change, based on our classroom observations of their teaching they still struggled with more frequent implementation.

Four survey items (#2, 3, 5, and 8) concerned oral discourse strategies and opportunities for students to talk with each other. Teachers wanted to include more student presentations, peer-to-peer discussions of their data, and whole-class discussions about NOS. Two items on the survey (#1 and 9) asked teachers to determine how often students engaged in writing related activities. Results indicated that teachers desired to increase how often they had their students write about scientific investigations and revise their scientific writing ($z = -5.10$, $p < .001$). Again, while teachers reported that they wanted to use more oral discourse, the classroom results were mixed; some oral discourse strategies appear to be more easily integrated into teachers' instruction, whereas more formal aspects of scientific writing were less frequently used.

Two items (#6 and 11) inquired about specific strategies to increase students' academic language comprehension, having "students relate subject matter to their own experiences in other subjects or their own personal lives," and "acquiring scientific vocabulary through alternative means such as visual and/or kinesthetic activities." Teachers reported that they also wanted to increase how often they used these strategies. In practice, when we observed lessons, we sometimes saw the more easily adopted ALD strategies having to do with vocabulary acquisition and visual aids, but rarely saw differentiated instruction based on students' language capabilities or teachers explicitly bridging students' language and culture with the academic language and culture of science.

Teachers also indicated that they wanted to use learning principles more consistently in their classrooms. Five items (#4, 12, 13, 16, and 18) concerned opportunities for students to engage in various activities such as accessing prior knowledge, constructing conceptual frameworks, and engaging in metacognitive practices. Providing students with feedback on their written work is also in this category (item #18). Item #12 ($z = -4.903$, $p < .001$), addressing students' abilities to plan and organize their learning as an aspect of executive control and metacognition, and #13 ($z = -4.903$, $p < .001$), addressing students' writing and/or

Table 9. Results of Sign Tests on Science Teachers' Responses to the "CISJP Teacher Self-Reflection" Survey Items

Item Pair (Current-Desired Use)	Negative Difference	Positive Difference	Number of Ties	Z	Significance
<i>How often do students . . . ?</i>					
1. write about science investigations	0	21	9		.000 ^a
2. share findings through presentations	0	24	6		.000 ^a
3. discuss data and understanding of meaning with peers	0	27	3	-5.004	.000
4. write and/or discuss ideas about concepts to be studied	0	25	5		.000 ^a
5. engage in whole class discussions about the NOS	0	22	8		.000 ^a
6. relate subject matter to their own experiences or lives	0	23	7		.000 ^a
7. develop and recognize alternative explanations for data*	0	26	3	-4.903	.000
8. engage in discussion to acquire language structure and vocabulary appropriate for science communication	0	26	4	-4.903	.000
9. revise their writing about science	0	28	2	-5.103	.000
10. construct their own understanding of scientific concepts through observation and writing their own definitions	0	25	5		.000 ^a
11. acquire scientific vocabulary through alternative means (visual and/or kinesthetic activities)	0	23	7		.000 ^a
12. plan and organize their learning*	0	26	3	-4.903	.000
13. write/discuss before, during, and after a unit of study to identify their changing ideas and how they arrived at them	0	26	3	-4.903	.000
14. defend their ideas with scientific evidence/data through discussion and writing	0	23	7		.000 ^a
15. write and discuss their imaginative ideas as a means of exploring science phenomenon	0	26	4	-4.903	.000
16. discuss or write what they have learned after a science lesson	0	24	6		.000 ^a
17. discuss how theories have the explanatory power to generate many testable hypotheses	0	25	5	.000 ^a	.000 ^a
18. receive feedback from you on their written work	0	20	9		.000 ^a
19. get information through lectures	6	0	24		.031 ^a
20. engage in hands-on inquiry activities	0	18	12		.000 ^a

Significance indicates a difference between the medians of the paired measures.
a = Binomial distribution used.

discussing “before, during, and after a unit of study to identify their changing ideas and how they arrived at these ideas about science” (i.e., metacognition) were also significantly different than the teachers’ self-assessment of their pre-PD instruction. From our analysis of the most and least frequently used strategies, teachers more easily adopted CISIP strategies such as (a) establishing community norms in the classroom, (b) providing clear feedback and teacher expectations, and (c) metacognitive opportunities (although less often). Throughout the first year of the PD, teachers struggled to change their instruction to become more reliant on assessing students’ prior knowledge, helping students to become more self-aware and self-monitoring of their learning, and providing opportunities for students to have executive control of their learning.

Summary: Greatest Desired Areas of Change. The top five (25%) strategies that the teachers identified as their most desired changes were to have (a) #13, “Students write and/or discuss before, during and after a unit of study to identify their changing ideas and how they arrived at these new ideas about science” (+1.90); (b) #12, “Students plan and organize their learning” (+1.77); (c) #15, “Students write and discuss their imaginative ideas as a means of exploring science phenomenon” (+1.63); (d) #17, “Students discuss how theories have the explanatory power to generate many testable hypotheses” (+1.60); and (e) #9, “Students revise their writing about science and in particular, their own investigations” (+1.53). Thus, in theory these five instructional strategies could be targeted as ones that teachers would be initially most receptive to learning and implementing in their classrooms. In our observations, we saw that teachers made changes within one year of engaging with PD by providing more opportunities for peer-to-peer oral discourse and pre- and informal writing within the context of guided inquiry activities. They demonstrated less change in providing opportunities for student-designed inquiry investigations and executive control of learning. Teachers also appeared to need more encouragement and practice to integrate opportunities for students to learn about NOS, which could have addressed their desire for students to better understand hypotheses and theories within science.

Research Question #4: Teachers’ Views of Barriers and Supports to PD Implementation

Using our survey items, teachers assessed perceived barriers and supports for implementing what they learned during the CISIP program. Teachers identified more sources of support than barriers; however, we did not ask them to weight each factor and we acknowledge that even one negative factor may be sufficient to prevent teachers from implementing what they learn through PD. Table 10 summarizes the percentage of items in each area that middle and high school teachers identified as barriers to, and supports for, PD implementation. Overall, comparable percentages of barriers and supports were identified by middle and high school science teachers. On average, the high school science teachers rated 23 items (51%) on the survey as a minor or major support, 18 items (40%) as neither a support nor a barrier, and only four items (9%) as barriers, but all barrier items identified by these teachers concerned parents and students. Middle school science teachers rated 21 survey items (47%) as supports, 16 items (36%) as neither, and eight items (18%) as barriers. Five of the eight barriers (63%) identified by these teachers concerned parents and students, whereas the other three included standardized testing, class size, and teacher team meeting and planning time. Overall, more items were considered supports (3.5 or greater) than barriers (2.5 or less) (Figure 7). Owing to space limitations only those factors that were considered to be barriers to implementing the CISIP model are discussed.

Table 10. Summary of Supports, Barriers to PD Implementation (or Neutral) for Middle and High School Teachers

Area	Middle School			High School		
	Supports (%)	Neutral (%)	Barriers (%)	Supports (%)	Neutral (%)	Barriers (%)
All areas (n = 45 items)	47	36	18	51	40	9
Administration (n = 4)	100	0	0	100	0	0
Collaboration (n = 9)	44	44	11	66	34	0
Curriculum (n = 5)	40	60	0	20	80	0
Instruction (n = 17)	59	29	12	65	35	0
Students (n = 8)	13	37	50	13	50	3
Parents (n = 2)	0	50	50	0	50	1

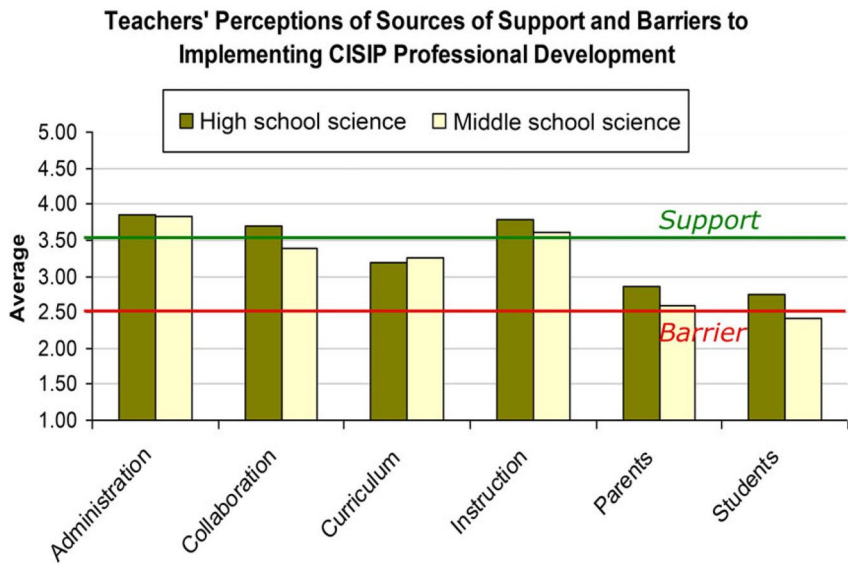


Figure 7. Graph of average responses by barriers and supports survey item categories.

Parents. Middle and high school science teachers perceived parents’ attitudes toward the CISIP curriculum as neutral ($M = 3.18\text{--}3.29$). However, both the high school ($M = 2.43$) and middle school ($M = 2.00$) science teachers saw parents’ ability to help their students with writing and discourse as a minor barrier to implementing the SCDC model. Whether or not these perceptions were accurate, teachers’ beliefs could affect the amount and level of homework assignments that teachers gave to their students. If parents were viewed as being able to help their children at home, teachers might assign more challenging tasks, but if home support was perceived as absent, little or no homework might be assigned. Even the types of assignments that would be started in class and then need to be finished at home might be limited in scope.

Students. Middle school science teachers viewed students somewhat more negatively than high school teachers, on average identifying four items as minor barriers to implementation, as opposed to three items. Both high school ($M = 2.43$) and middle school ($M = 1.91$) science teachers perceived students' diverse language skills as minor barriers to CISIP implementation. Both also identified their students' grade-level background knowledge and writing and discussion skills as a minor barrier. Finally, middle school science teachers ($M = 2.18$) identified their students' attendance as a minor barrier to implementing CISIP.

Discussion

We sought to document and investigate the following aspects of teachers' learning through the CISIP program: (a) prior education, teacher certification, and length of teaching experiences; (b) desire to change current teaching practices to be more aligned with the CISIP model; (c) use of specific PD strategies initially used within 1 year of PD and the overall change in their teaching practice over 2 years; and (d) identification of those factors that were supports or barriers to implementing the PD. When we synthesize the results in light of the PD, we see several trends: (a) teachers who are better able to engage their students with the nature of scientific communication, (b) the benefits of iterative PD with a complex task such as teaching science, and (c) the challenges of changing teachers' beliefs about how people learn and enacted instructional practices to match their desire for reform in the classroom. We discuss the relevance of these findings here in a broader context.

Teachers' Professional Development Concerning the Nature of Scientific Communication

The CISIP community of practice included a range of teachers that provided a balanced distribution of new, midcareer, and veteran teachers with a variety of perspectives and experiences. When we observed teachers' science lessons, we noticed that they only occasionally engaged their students in discussions about NOS. That nearly half of the teachers lacked a course in the history and philosophy of science suggested that most, even experienced, teachers would benefit by learning more about NOS as they developed and implemented science lessons. Since the 1990s, science education reform documents (NSES, NRC, 1996; Achieve, 2013) have encouraged the use of authentic learning experiences that reflect the ways in which scientists undertake and communicate their own work. Scientists work in teams of researchers, peer-review each other's work, and communicate their findings through a variety of oral and written modes. Thus, to better reflect the practice of doing science in authentic ways, all science teachers need to be able to bridge academic language and practices of scientists with students' everyday language and conceptions of the world around them.

The CISIP program was designed to help science teachers develop greater expertise and skills to implement instructional strategies in writing and academic language development to support students' learning of science. With less formal education in language arts and literacy strategies, the science teachers were less likely to integrate written discourse into their science lessons. In this study, we found that teachers, even with explicit PD activities on how to integrate writing into their science lessons, rarely engaged students in formal scientific writing or provided rubrics for their students to revise their writing. Science teachers also rarely provided differentiation in instruction or found ways to bridge language and culture with science. These sorts of communication and critical thinking skills are vital to a well-rounded education and have been carefully delineated in the new national science

education standards (Achieve, 2013). The NGSS also include cross-references to the Common Core English language arts standards that further emphasize the critical role of language in learning science and developing scientific literacy.

Throughout the CISIP program, teachers did improve in their use of small-group discussion even though they still relied upon whole-group classroom instruction. This improvement reflects a move toward adopting more aspects of a scientific classroom discourse community while still retaining teacher control, but it was a noticeable shift in teachers' practices. Lemke's (1990) identification of classroom triadic dialogue (IRE) as a means for knowledge transmission and discourse structure is the antithesis of science education reform as it prevents students from sharing control of the classroom discourse. However, Lemke found that it is a favored staple of whole-group discussion pedagogy in science classes. The CISIP program provided examples of how to shift the discourse in the classroom to establish more equitable and interesting learning opportunities for students. The use of social constructivist scientific inquiry as a teaching paradigm provides students with more opportunities, not only to engage with scientific questions, make observations, and make meaning from their own experiences, but also to talk with each other and not just their teacher. Gee (2004) argued that students need such peer-to-peer learning experiences to create meaningful discourse and develop conceptual understandings. Kelly (2014) identified discourse as one of the emerging research directions in science education in his review of discourse practices.

As shown in our model of instructional change, by trying to engaging students in SCDCs, CISIP teachers made some progress in changing their instruction to be more aligned with Vygotsky's sociocultural theory of learning (1986) and constructivist tenants of inquiry based teaching. The inclusion of both oral and written discourse also aligns with the second core NRC (2005) learning principle, the essential role of factual knowledge and conceptual understandings. However, the fact that these science teachers lacked prior knowledge of how to use these types of instructional strategies before the PD seminars indicates that teacher education programs themselves should consider how to prepare teachers to be able to better meet state and national science education standards. Sadler (2006) addressed this issue specifically in a science methods course in which there was a focus on argumentation, but found that preservice teachers rarely had an opportunity to try this in their student teaching placements. Thus, we have a self-perpetuating problem of a lack of oral and written discourse in science classrooms and a lack of modeling these scientific practices for future science teachers.

Legitimate Peripheral Participation: The Benefits of Iterative Professional Development

There was no significant difference between the middle and high school science teachers' use of new strategies learned at the CISIP seminar activities. This indicated that although the teachers participated in separate 3-week summer institutes, it did not measurably affect their implementation of the CISIP instructional strategies as new participants. However, there was a significant difference between previous and new participant groups in their use of the CISIP strategies. The previous participants had higher implementation scores. This suggests that a second iteration of the same PD program supported greater implementation by those who elected to stay with the program.

Initially teachers made small changes that did not require radical reengineering of how they managed their classrooms; the most readily adopted strategies were related to teacher centered instruction and the least adopted were ones that would be found in more student centered classrooms. A fully realized SCDC would be a classroom in which students

were empowered to generate questions for investigation, had access to resources to support their learning, and had structured opportunities to reflect upon their own learning to develop executive control and self-monitoring capabilities as lifelong learners. However, teachers also tended not to use much formative assessment to guide their instructional decisions, which indicates that they needed more explicit PD in how to be more responsive to students' learning needs (Black & Wiliam, 1998). Thus, it appears that the larger issue was that many of these science teachers resisted releasing control and struggled with generating more opportunities for student choice and self-regulation. The easiest paths to new types of instruction were taken first; those that were more difficult, more central to teachers' beliefs about effective science instruction, presented greater institutional and social friction and required more PD.

Teacher Change Over Time

The length of time that the teachers received PD, or their experimental group membership, was chosen as the predictor of teacher change whereas a schools' percentage of students who qualified for free and reduced lunch was chosen as the exclusive predictor of the intercept or starting point. Over 2 years, the teachers who had participated for longer periods of time used more of the CISIP model strategies and had higher rates of change than newly participating teachers. The model indicated, with statistical significance, that SES predicted teachers' initial levels of PD-associated behavior. While the overall SES of the school's students was important in determining where teachers began, the amount of PD accounted for how teachers changed over time. When these commonsense results were supplemented with additional survey data, teacher beliefs were shown to be a dominating force. Specifically, survey data suggested that teachers believed students were the nearly singular barrier to implementing the CISIP model.

That said, the claim that CISIP was effective in changing teachers' practices was supported by both models. Because the same conclusion could have been drawn from both models about the effect of treatment, despite the different ways of coding treatment or non-treatment group membership, we concluded that the results did not depend on the coding system we used, but rather reflected a measurable change in teacher instruction. Our conclusion has several caveats. First, consider the multileveled regression lines in Figure 4. On a long enough timeline, the comparison group teachers' PD-associated behaviors would become negative and the CISIP teachers' PD-associated behaviors would approach infinity. But the CISIP measure has no meaningful negative or very large values. The linear nature of the relationship, outside the range of our data, was *de facto* absurd. This indicated that, although our models fit tolerably well, such a fit would not apply outside the range of our data. That is, we do not know whether increases in CISIP-related instructional practices over time will continue or drop off. For example, Rogers (2003) found that PD that requires less fidelity is more likely to be sustained over time. The CISIP model of a SCDC is complicated with a high cognitive load and appears to require multiple iterations to increase fidelity and teacher change, but did allow for teacher choice. Second, our final models suggested that initial implementation of PD was positively influenced by the average SES of the teachers' students with lower implementation associated with lower SES schools and higher implementation with higher SES schools. Our findings, produced using modern statistical methods, support the work of Anyon (1981) and Oakes and Guiton (1995) in that tracked, low-SES students in this study were initially taught with little or no inquiry-based science instruction. Statistically significant variance components, however, led us to believe that there might be other hitherto, unidentified factors that influenced the initial

implementation of the CISIP strategies. Other possible factors could include teacher beliefs, systemic barriers, school culture in terms of what constitutes good teaching, high-stakes testing, community expectations, the number of early adopters in the school, and the cognitive complexity of the CISIP instructional strategies.

Teachers' Desire to Change Instructional Practices

As they began CISIP, teachers expressed a desire to increase the frequency of how often students engage in behaviors that reflect a rich SCDC. For instance, teachers wanted their students to develop and recognize alternative explanations for data, construct their own understanding of scientific concepts, defend their ideas with scientific evidence, and engage in hands-on activities more frequently. Teachers also wanted to include more student presentations, peer-to-peer discussions of their data, and whole-class discussions about NOS than they currently did. The science teachers also had a statistically significant desire to increase the frequency of having their students write about scientific investigations and revise their writing about science and their investigations. This suggests that the desire to change is often strong, but the reasons for teachers' actual change or resistance to change requires more information about what supports and prevents such changes as a result of PD.

Barrier and Supports to Implementing Learning From Professional Development

In general, CISIP teachers identified administrative support, the PD strategies, and teacher collaboration as strong support for implementing new instructional methods. The lead CISIP designer had been a state science specialist and recruited teachers from districts that already had the support of the administration for the types of changes that the PD had proposed; thus it is not surprising, but rather validating, that the teachers identified administrative support of change. That the teachers also identified the PD strategies themselves as supportive reinforces the CISIP design as a viable model of an SCDC. Finally, the fact that teachers identified positive collaboration as a support for implementing new ideas underscores the value of engaging teachers in a community of practice. However, the teachers viewed students' grade-level science knowledge, diverse language skills, and discourse abilities as the greatest barriers. We recognize that teachers' beliefs and decisions about what and how to teach are complex and that in the future survey items may need to be weighted in terms of how critical teachers view each factor.

It is problematic that CISIP teachers perceived their students to be a barrier to using what they learned in PD. When teachers, especially those teaching lower tracked students or students in working-class communities (Anyon, 1981; Lee et al., 2013), believe that students are unable and/or unwilling to engage in critical thinking and inquiry-based science investigations, they fail to provide such opportunities, thus limiting students' access to a standards-based science education (Oakes, 1995). Even for experienced teachers who are past the induction phase of teaching and are confident in their teaching abilities, PD may need to explicitly address teachers' dispositions toward equity in the classroom (Kelly, 2014).

Professional Development Interaction With Policy and Politics

Van Driel, Beijaard, and Verloop (2001) emphasized the value of teachers' practical knowledge as experts in their own classrooms and recommended engaging teachers in long-term staff development so that teachers have time to restructure their knowledge and beliefs and integrate new information with their practical knowledge. National priorities for science, technology, engineering, and mathematics (STEM) education and recruiting

students into STEM careers have been outlined in numerous policy documents (e.g., Committee on Prospering in the Global Economy of the 21st Century, 2007). When U.S. National Science Education Standards were introduced, there were clear goals for reformed science teaching to use constructivist inquiry-based instruction to foster more robust learning opportunities for students (NRC, 1996), thus preparing them to be scientifically literate citizens and perhaps productive STEM professionals. A decade later, these recommendations had become increasingly difficult to address within the pressures of high-stakes testing (Nichols & Berliner, 2007). These challenges require several responses if we desire educational reform. First, administrative support for science teacher PD needs to permeate schools and districts so that there is institutional momentum that supports teacher change. Administrative support is critical so that teachers know that they will be supported when they adopt new instructional methods (Locks-Horsley, Stiles, Munday, Love, & Hewson, 2009). Second, and perhaps more importantly, PD itself must empower teachers to change their instruction and institutions to change their attitudes toward teacher instruction. PD cannot only be for teachers, but must be for entire organizations, requiring changes to support, or hinder, behavior that helps, or hurts, students.

Methodological Limitations

The effect of this instance of teacher PD and our inferences about it were limited by the methodology in four primary ways. First, we were unable to evaluate treatment infidelities. Teachers may have attended the PD sessions, but there are multiple levels of engagement and each teacher has their own unique learning experience. How teachers translated the CISIP program concepts and instructional strategies into their classrooms was evaluated, but the extent to which it systemically changed their instruction, perhaps even permanently, was unknown. In fact, our assumption was associated with the teachers' interaction with the PD, which limited our generalizations to other groups of teachers.

Second, our sample was one of convenience; teachers were not randomly selected to be or not be in our study, nor were they randomly assigned to treatment or control (nontreatment) groups. This limited our inferences by the sampling procedure we employed. Third, we must limit our inferences to the boundaries of our data. In the same way that we cannot make judgments about teachers' change over the first year of their PD, we cannot make inferences about changes due to more sustained PD beyond the 2-year study. Research has shown that sustained PD creates lasting effects (Blank et al., 2008), but we were unable to verify those results in that our research and the PD itself was limited to the project's funding.

Lastly, and perhaps most importantly, we were unable to construct sufficient validity and reliability arguments for the DiISC to ensure that measurement error itself did not limit our inferences. We are able to make claims about the effect of the PD, but only an effect as demonstrated on our measure of treatment implementation. Other, more distal measures would require further study and more complete validity and reliability arguments associated with our outcome measures.

In summary, while we were able to make inferences, we were unable to make the broad generalizations we would have liked. Specifically, we were limited by an inability to assess systemic changes in teacher practices or to infer beyond the boundaries of our data, especially with respect to sustained PD over longer periods of time and to other studies that also used our DiISC instrument. Future studies should involve a reliability and validity argument sufficient to make such generalizations, better measures of systemic teacher change, and should take advantage of the possibility of extended data collection or traditional random assignment and its advantages.

Conclusions

This study investigated changes in teachers' science instruction as they progressed through a particular, iterative teacher PD program. Within the categories that were used by van Driel et al. (2012), this study would be classified as one that explored the relationships among the external domain, domain of practice, and the personal domain. A framework of cognition, beliefs, and situated learning allowed us to analyze teachers' perspectives and change to make limited inferences. Like the CISIP model itself, the members of the learning community demonstrated that "learning is not merely a condition for membership, but is itself an evolving form of membership" (Lave & Wenger, 1991, p. 53). Teachers who entered into the PD acquired, through oral and written discourse, practice, and collegiality, an initial understanding of how to build scientific classroom discourse communities.

The CISIP model is based on the concept of teacher learning communities as a means for affecting positive change for student learning within inquiry-based science instruction. By participating in the CISIP learning community, individuals increased their awareness of many different types of teaching strategies. Further research on SCDCs and other similar PD programs may not agree with the CISIP model, but it was the background for the data generated and analyzed in this study. The longitudinal model clearly indicated that the CISIP model of iterative PD works, although not without its challenges, to change teachers' instruction to incorporate more aspects of scientific communication, and we believe others like it will similarly work, drawing on the same learning principles and relationships previously described.

Teacher PD has equity and policy implications at the school, district, state and national levels. Thus, we make the following recommendations. First, that complex, change-inducing PD should be iterative. On average, teachers used more of the CISIP model as they engaged with it repeatedly over time. Initially, more easily changed teacher-centered strategies were adopted, followed by strategies that were student centered, as these actions required more radical departures from extant instruction. Second, facilitate teacher learning by structuring PD through legitimate peripheral participation and ZPD. In our study, as teachers became mentors and facilitators their use of the CISIP model was more sustained. Previous participants acted as formal and informal mentors to newer participants, and these more experienced CISIP teachers shared the results of trying new approaches in their own classrooms. Third, use explicit modeling and planning in PD activities to encourage implementation. For example, all the teachers in CISIP used science notebooks with their students to some degree. It was the most readily adopted piece of CISIP, and the PD activities were very clear regarding how to use notebooks with students. Fourth, striking a balance between presentation and practice of PD material at the workshop sessions, combined with planning time throughout the academic year, potentially increases teachers' levels of implementation. In our study, teachers valued planning time with their team members during the PD sessions. Finally, teacher perceptions and expectations of student learning must be challenged during PD. Teachers who had equitably high expectations for student learning were more open to using the CISIP model with all of their students, not just their high-performing students. Teachers who differentiated between students used more of the model, and more inquiry-based instruction, with the students they perceived as being generally more capable (e.g., college bound) in science; and these students usually had a higher SES. Ultimately, through PD, teachers must view all their students as capable of engaging in inquiry-based scientific thinking.

Science teacher PD providers can benefit educational reform movements by leveraging broader conceptions and frameworks of teaching and learning, such as a SCDC. External factors, e.g., school culture, can unwittingly block teachers from implementing new ideas.

In particular, the pressures on science teachers concerning low-performing students and state-mandated testing can have an unintended effect of derailing a teacher's efforts to enact equitable constructivist instruction. Thus, administrative support is critical to teacher change. Internal factors, such as teachers' beliefs about students' cognition, also have both great potential and danger to affect the range of learning opportunities made available to all students.

Recommendations for Future Research

Considering teachers' overall view of students as a primary barrier, and their parents as a secondary barrier, to implementing new instructional methods, researchers should investigate how PD might confront teachers' differential views of students' abilities and capability to engage in scientific inquiry. When implementing a new teaching approach, teachers in CISIP appeared to adapt it according to their own institutional contexts and beliefs. In future studies, contexts and beliefs would be important predictors to investigate more closely to better understand teacher change. Simple group membership and amount of PD, while important for understanding teacher change, needs to be expanded to encompass the factors within that PD and teacher learning that matter most.

In addition to Wilson's (2013) summary of needed research in teacher PD, we offer several recommendations for future research to construct longitudinal models of teachers' use of PD, change, and effectiveness: (a) account for discrepancies in sampling procedures to eliminate plausible, alternative hypotheses in search of causal links; (b) frequently observe teachers over long periods of time and long after the PD has ended; (c) make more frequent observations of teachers over time with a stronger understanding of baseline practices for a more precise chronicling of teacher change; (d) in making claims about the effects of PD, researchers must take care to ensure that the measures used to make those claims have adequately developed validity and reliability and/or credibility and transferability arguments; and (e) include student outcomes. Providing high-quality PD that results in teacher learning and implementation, as well as a positive effect on student learning outcomes, is an aspect of educational research that has been neglected. We cannot expect to improve schools, thus fulfilling their democratic mission through equitable student achievement, if teacher PD programs are not built upon both sound learning theories and reliable findings as to their effectiveness to reform science instruction.

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