UNIVERSITY OF CALIFORNIA,
IRVINE

Participation in a Video Club: Influences on Teachers and Teaching

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Education

by

Tara Barnhart

Dissertation Committee:
Associate Professor Elizabeth A. van Es, Chair
Professor Judith H. Sandholtz
Assistant Professor Hosun Kang

2016

DEDICATION

To teachers and those who teach them.

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ACKNOWLEDGMENTS

If you end up with the story you started with, then you weren't listening. – Albert Maysles

I would like to express the deepest appreciation to my advisor, Elizabeth van Es. Thank you for your patience and for challenging me to do my best work. You transformed the way I view teaching and teacher education.

Much thanks to the Teacher Learning Lab, in particular Jennifer Long, Huy Chung, Jessica Tunney, Jennifer Sun, and Doron Zinger. I am indebted to all of you for your ear, your insights, and of course, your snacks. I am so grateful to have shared a small space with you for the past few years.

I am particularly thankful for having the opportunity to work with several faculty members at UC Irvine. Thank you to the wonderful Greg Duncan, Martha Feldman, Judith Sandholtz, and Hosun Kang for serving as members of my committee. Your comments and critiques greatly improved this work. Thanks also to Rebecca Black, Rosella Santagata, Judith Sandholtz (again), whose courses were particularly influential in my development as a teacher educator and researcher.

Thank you to the faculty, staff, students, and administration of the Whittier Union High School District, in particular those who opened up their classrooms, their ideas, and their practice to me. I admire your unflagging efforts to improve the lives of your students.

I owe a debt of gratitude to my mentors and teachers, in particular Melavel Robertson, Roberta Berg, Vikki Costa. Thank you for preparing the soil, planting the seed, and watering the seedling.

And finally, thank you to my friends and family, without whose support this would not have been possible. Thank you to my parents for teaching me persistence. Freda, Burrell, Marlene, Tracy, Suzette, and Sue have been my biggest cheerleaders in this endeavor. Thank you for your unending support and occasional badgering. And at the end of the day, Emily and Ethan make it all worthwhile, much love to you.

CURRICULUM VITAE

Education

Ph.D., University of California, Irvine, 2016
Education

Dissertation: *Participation in a Video Club: Influences on Teachers and Teaching.*

M.A., Whittier College, 2001
Education

Thesis: *Attitudes, Academics and Participation: An Investigation of the Relationship Between Extracurricular Participation and Student Academic Achievement, Aspirations and Attitudes.*

B.A., Whittier College, 1995
Biology

Professional Experience

California State University Fullerton 2007-2016
Lecturer, Department of Secondary Education,
Designed and taught the following courses
EDSC 591 *Professional Seminar in Secondary Teaching [web and face-to-face] (3 units)*
EDSC 449S *Seminar in Secondary Science Teaching (3 units)*
SCED 554 *Issues in Science Education (1 unit)*
EDSC 442 *Methods in Secondary Science Education (3 units)*

Taught the following courses:
EDSC 310 *Introduction to Secondary Education [web] (3 units)*
EDSC 320 *Adolescent Development [web] (3 units)*
EDSC 440S *General Pedagogy of Secondary School Teaching Seminar (3 units)*
EDSC 440F *General Pedagogy of Secondary School Fieldwork (3 units)*
EDSC 449E *Externship in Secondary Education (variable units)*
EDSC 449I *Internship in Secondary Education (variable units)*
EDSC 599 *Independent Graduate Research in Secondary Education (3 units)*
EDSC 594 *Project Seminar (3 units)*
EDSC 542S *Advanced Teaching Methods of Teaching Middle School Science (3 units)*

Additional responsibilities:
AIMS Program Science Coordinator
Partner District Cohort Coordinator

Pioneer High School, Whittier Union High School District 1997- 2009
Teacher, Science Department
Designed and taught the following courses:
Integrated Science I; Introduction to Life Science; College Preparatory Biology; Honors Biology; Advanced Placement Biology; Guided Study

Research Interests

Teacher learning ▪ Teacher noticing ▪ Science teacher professional development

Honors and Awards

Engage in STEM US Department of Education Grant ($1500) - 2014
National Board for Professional Teaching Standards NBCT System Leadership Innovation Grant Recipient ($5000) - 2013
National Science Foundation Graduate Research Fellowship Honorable Mention - 2010
Phi Delta Kappa J. Skalski Scholarship Recipient ($500) - 2010
Instructional Leader Award, Whittier Union High School District (2005)
Outstanding Senior in Secondary Education (1995)

Credentials

California Clear Ryan General Science: Biological Science	1997
CLAD	1997
Administrative Certificate of Eligibility	2006
National Board Certification: AYA Science	2005

Peer-Reviewed Publications

Barnhart, T., van Es. E. (2015). Studying teacher noticing: examining the relationship between pre-service science teachers' ability to attend, analyze and respond to student thinking. *Teaching and Teacher Education, 45*, 83-93.

Ellis, M., Barnhart, T. and Milch, L. (2012). Understanding National Board Certification: A guide for teachers and those who support them. Boston, MA; Allyn & Bacon.

Manuscripts Under Review

van Es, E., Cashen, M., Barnhart, T., Auger, A. Understanding the Development of Pre-Service Teachers' Noticing of Ambitious Mathematics Pedagogy.

Invited Presentations

Barnhart, T. and Tommerup, M. (2014). *Elementary Teachers are Science Teachers Too!* Santiago Canyon Future Teachers Conference.

Barnhart, T. (2014). *Navigating the Next Generation Science Standards and Integrating them into Science Education Programs.* CSU/ISI Collaborative Symposium to Promote Science Education, Fullerton, CA.

National Board Certification as Professional Development. Guest lecture in EDUC 237, Teacher Thinking and Learning, University of California, Irvine, 2011.

Barnhart, T. (2010). *Helping Students Construct Science Knowledge*. Santa Ana, CA. Road to Teaching Conference at Santa Ana College.

Barnhart, T. and Ellis, M (2009). *Pursuing a Single Subject Math or Science Credential.* Costa Mesa, CA: TEACh^3 Program at Orange Coast College.

Barnhart, T. and Alaux, S (2009). *Pursuing a Single Subject Math or Science Credential.* Orange, CA: Santiago Canyon College Future Educators Conference.

Peer-Reviewed Presentations

Barnhart, T and van Es E. A. (2016). *Critical colleagueship among secondary science teachers.* Roundtable session at the American Educational Research Association Annual Conference, Washington, DC.

Barnhart, T. and Rutherford, L. (2015). *Supporting students' argumentation writing in science*. Breakout session at the California STEM Symposium, Anaheim, CA.

Barnhart, T. and Guggino, P. (2013). *Beyond recognizing excellence: Understanding the affordances of National Board Certification as a professional learning opportunity*. Breakout session at the National Association for Alternative Certification Annual Conference, Marina del Rey, CA.

Barnhart, T. and van Es, E. (2012). *Watch and learn: Developing pre-service math and science teachers' ability to attend, analyze, and respond to student thinking.* Poster presented at American Educational Research Association Annual Conference, Vancouver, BC.

Barnhart, T. (2012). *EEI in the OC TTT.* Presentation at the National Association for Alternative Certification Annual Conference, Washington, DC.

Barnhart, T., Chung, H., & van Es, E. (2011). *Learning to analyze teaching across the disciplines.* Breakout session at California Council on Teacher Education Fall Conference, San Diego, CA.

Barnhart, T., and van Es, E. (2011). *Learning to analyze teaching: Developing pre-service teachers' ability to notice, analyze, and respond to student thinking.* Paper presented at Science and Mathematics Teacher Imperative National Conference, Portland, OR.

Barnhart, T. (2010). *Learning to Learn from Teaching: Promoting a more student-centered classroom discourse in a pre-service teacher education program.* Poster presented at California Council on Teacher Education Fall Conference. San Diego, CA.

Barnhart, T and Ellis, M. (2009). *Utilizing National Board Standards and NBCTs in Higher Education.* Presented at National Board for Professional Teaching Standards National Conference, Atlanta, GA.

Service

Professional

CSET Content Validation Survey participant
Expert Panel Member: Argument from Evidence Companion Documents for California Science Standards, Fall 2015
Reviewer: *Science Education*, *Teacher Education Quarterly*, *Teaching and Teacher Education, Universal Journal of Educational Research*
WASC Visiting Committee Member, Spring 2011, 2012
Cal TPA Task 1 validity panel member, Spring, 2009

Community

Senior Projects Exit Interview Guest Panelist Santa Ana High School – Spring 2014
Judge NOVA Academy Science Fair – Spring 2012
Judge LBUSD Science Fair – Spring 2009, 2011, 2014

Professional Associations and Development

AERA – American Education Research Association, Division K
NSTA – National Science Teachers Association
NABT – National Association of Biology Teachers
AAAS – American Academy for the Advancement of Science
PDK – Phi Delta Kappa
CCTE – California Council on Teacher Education
NARST – National Association for Research in Science Teaching

ABSTRACT OF THE DISSERTATION

Participation in a Video Club: Influences on teachers and teaching.

By

Tara Barnhart

Doctor of Philosophy in Education

University of California, Irvine, 2016

Associate Professor Elizabeth A. van Es, Chair

This dissertation examines the development of critical colleagueship among five secondary science teachers in a semester-long video club. The design of the video club was intended to promote a focus on student thinking and experimentation with elements of ambitious science teaching. Over time, participants sustained a focus on interpreting students' disciplinary thinking using evidence and began to problematize aspects of instruction related to making student thinking visible. Some participants attempted to change instruction to gain greater access to students' disciplinary thinking while others did not. Efforts to experiment with instructional practice appeared related to alignment between participants' learning goals and curricular contexts and the goals of the professional development design. Features such as framing activities, types of artifacts used, and facilitation, interacted differently over time to influence participant learning. Analysis revealed various tensions among the elements of the learning ecology that influenced participation. Findings from this study contribute to what is known about the importance of skilled facilitation as part of a learning ecology (Cobb, Confrey,

diSessa, Lehrer, & Schauble, 2003) and has implications for the design of site-based professional development with secondary teachers.

INTRODUCTION

The images that many people have of science and how it works are often distorted. The myths and stereotypes that young people have about science are not dispelled when science teaching focuses narrowly on the laws, concepts, and theories of science. Hence, the study of science as a way of knowing needs to be made explicit in the curriculum.

- *AAAS Benchmarks for Science Literacy*

Background and Problem

Current proposals for the improvement of science teaching and learning emphasize teaching students how to collect, interpret, and evaluate evidence to formulate scientific explanations of observed phenomena (Braaten & Windschitl, 2011; Duschl, Schweingruber, & Shouse, 2007; Minstrell, 2000; National Research Council, 2012; Sandoval, Deneroff, & Franke, 2002; Windschitl, Thompson, & Braaten, 2008). There are several reasons for this emphasis, the first being pragmatic. We are currently living in a “knowledge-intensive era” (Hurd, 2000). Because the body of knowledge is increasing exponentially, it is simply not feasible to “cover” it all (Gleick, 2011). To manage the flood of information, one must focus on developing critical thinking and reasoning skills—that is, a “rational utilization of science knowledge,” or “learning to learn” (Hurd, 2000, p. 5). Secondly, inquiry approaches that promote critical thinking skills such as problem-solving and explanation-building lead to deeper and longer-lasting conceptual understanding as opposed to curriculum that focuses on the memorization of facts and principles (Bransford, Brown, & Cocking, 2000; Osborne, Erduran, & Simon, 2004; Windschitl, Thompson, & Braaten, 2008). Moreover, there is evidence that these approaches have even greater positive learning impacts on low-income and minority students (Sandoval & Harven, 2011). Finally, learning situations of this type have been found to be more engaging and motivating for both teachers and students (Palmer, 2009), which can lead to greater persistence, effort, and understanding of concepts as well as perceived value for science (Pintrich, 2003; Stipek, 1996).

However, although the merits of this pedagogical approach have been demonstrated by the research, it has not been widely adopted by classroom teachers in the US. The obstacles to implementation are numerous. Curriculum materials available to science teachers may not be aligned to science inquiry goals (Kesidou & Roseman, 2002; Krajcik, McNeill, & Reiser, 2008). Teachers may have not experienced models of this type of teaching as students in science classrooms (Lorte, 1973; Santagata, Gallimore, & Stigler, 2005; Windschitl & Thompson, 2006), or they lack an appropriate frame of reference through which to enact this type of teaching (Kennedy, 1999). The institutional settings in which teachers teach may not support the adoption of techniques and philosophies espoused by educational reformers (Grossman, Smagorinksy, & Valencia, 1999). Further, the inquiry approach advocated by research places greater demands on teachers in terms of their skills and knowledge. Teaching students how to develop a scientific habit of mind, integrated *with* rather than separate *from* a body of knowledge, requires greater access to resources and knowledge of the students and the communities in which teachers teach (Dede, Honan, & Peters, 2005). It also necessitates deeper levels of pedagogical content knowledge and knowledge of science content (Ball, Thames, & Phelps, 2008; Driver, Asoko, Leach, Scott, & Mortimer, 1994; Park, Jang, Chen, & Jung, 2011; Shulman, 1986). Teachers must know what science concepts are difficult for students to understand and anticipate them, how best to sequence the learning of those concepts, how best to structure experiences that afford the development of productive conversations about science concepts, and how and when to press students when engaging in scientific discourse in the classroom (Berliner, 2004; Braaten & Windschitl, 2011; Carlsen, 1992; Levin, Hammer, & Coffey, 2009). These teaching practices focus on student thinking rather than on the discrete teaching techniques that many teacher education programs promote (Cochran-Smith & Lytle, 2009; Grossman & McDonald, 2008; Kang, Bianchini, & Kelly, 2013; Windschitl, Thompson, & Braaten, 2011). Considering these obstacles, it is not surprising that efforts to improve science teaching over the last 50 years have been "modest at best" (NRC, 2007).

The Study

The purpose of this study was to examine the impact that participation in a video-based professional development program designed to sharpen science teachers' attention to and analysis of students' disciplinary thinking had on teacher learning and practice. This study design attempted to acknowledge the challenges of curriculum alignment, institutional support, and lack of appropriate models and frames for engaging students in scientific thinking and for interpreting students' ideas with colleagues. The design of this semester-long study of a group of in-service high school science teachers drew on concepts from three bodies of research: teacher professional development in science education, the use of video to support teacher learning, and the design of learning environments for educators. By using a format in which teachers collaboratively examined videos of their students engaging in the discussion and analysis of data, participants were encouraged to focus on how students made sense of data and how students communicated their understandings to members of their classroom community, and developed conceptual tools for thinking about student ideas (Grossman et al., 1999). Because it captures classroom interactions in real time and can be viewed multiple times for multiple reasons, video permits a closer examination of student thinking and learning than classroom visitation or analyses based on recollections (Brophy, 2004; Sherin, 2004). This level of focused attention is required to unpack student thinking and reasoning about data during classroom discussions.

In particular, this study sought to answer the following questions:

1. Does participating in a video club help to develop critical discourses for analyzing student thinking and reasoning in science?
2. What influences, if any, did participation in a video club have on participants' thinking and willingness to experiment with practice?
3. How did the design elements of the video club influence the desired outcomes of participation in the professional development?

Significance

It is hoped that the findings of this study will make several contributions to the field. It attempted to link changes in teachers' participation in the professional development context itself to changes in their practice, specifically the ways that teachers design tasks and promote science discourse in their classrooms. Additionally, this study examined the tensions between design and enactment of professional development series for practicing teachers. The findings enable a fuller understanding of the complexities of teacher learning in school contexts.

Organization

Chapter 1 provides a review of the literature on the goals of science education, teacher learning, and the characteristics and challenges of designing effective teacher professional development. Chapter 2 outlines the research methods and design of the study with particular emphasis on the design of the video club professional development series. Chapter 3 consists of a summary of the findings related to teacher learning and the impact on teacher practice during participation in the video club. A discussion of the video club design and tensions that arose during the implementation of the design is found in Chapter 4. Chapter 5 contains a discussion of the study's implications, as well as its limitations.

CHAPTER 1 – REVIEW OF THE LITERATURE

Goals of Science Education

A scientifically literate populace is seen as essential for the well-being of a nation (Anelli, 2011; Dewey, 1927; Hurd, 2000). Science "permeates nearly every facet of modern life" (NRC, 2007, p. 1), and is critical to meeting current and future social challenges (American Association for the Advancement of Science, 2009; Duschl, 2008; NRC, 2012). Questions such as: Is global warming caused by human activity? Is it acceptable to forcibly vaccinate people in order to prevent a pandemic? And, when does life begin and end? are frequently debated in the media. But, despite its importance, the lackluster state of science literacy in this country has been portrayed as a crisis. Only 20% of U.S. citizens are considered scientifically literate (Bauer, Allum, & Miller, 2007). U.S. students score far behind students in other industrialized nations in international tests (NRC, 2007). Increasingly, STEM jobs and degrees are awarded to recent immigrants who were educated elsewhere (Xie & Killewald, 2012). Because 20% of all U.S. jobs require a high level of knowledge of at least one STEM field, these statistics indicate a looming intellectual and economic crisis (Rothwell, 2013). Will the next generation of Americans be able to contribute knowledgably to public discussions of science-related issues and participate as productive members of the economy?

In response, several documents refining and clarifying the goals of science education have been published. A common emphasis in these frameworks and policy papers is the need to integrate understanding of scientific ideas with the practices of science. Specifically, K–12 students should know how to use and interpret scientific explanations of the natural world;

generate and evaluate scientific evidence and explanations; understand the nature and development of scientific knowledge; and participate productively in scientific practices and discourse (NRC, 2007). Further, students should be able to ask questions; develop and use models; plan and carry out investigations; analyze and interpret data; use mathematical and computational thinking to model scientific data; develop evidence-based argumentation skills; and obtain, evaluate, and communicate information (NRC, 2012). Moreover, students should recognize and weigh alternative explanations of events, and learn to deal sensibly with problems that involve evidence, numbers, patterns, logical arguments, and uncertainties (AAAS, 2009). Rather than emphasizing the conveying of discrete facts, or the "detailed products of scientific labor" (NRC, 2012, p.43), these documents urge science educators to help students understand how these facts were established and what scientific enterprises are "up to" (AAAS, 2009; Duschl, 2008; Sandoval, 2005; Sinatra & Chinn, 2012). To do this, policymakers state that connections between science activities and science knowledge must be explicitly supported through instructional practices (Krajcik et al., 2008; NRC, 2012). Without this overt and careful blending of practice and knowledge, scientific procedures become the aims rather than the means of instruction, and students develop disconnected, disorganized, and at times contradictory notions of science concepts (NRC, 2012). By engaging in scientific investigations and argumentation around a limited number of core ideas and concepts, students will be able to achieve the depth of understanding required for them to have sufficient knowledge to be careful consumers of information, participate in society as educated citizens, make sense of how the natural and designed worlds work, and continue to learn about science outside of school (AAAS, 2009; Hurd, 2000; NRC, 2007, 2012).

These reform frameworks are not curricula in themselves, but are intended to guide the development of curricula and instructional approaches. Though the frameworks acknowledge that science is a social endeavor and that students bring with them important ideas and theories about the way the world works, their authors do not advocate one particular instructional approach over another. What this means is that science educators may enact principles of the framework regardless of what textbook, technology, or laboratory materials are available for their use. However, classrooms in which the teacher's goal is to transfer a body of knowledge to students tend to be tied to the textbook and the scripted laboratory activities that accompany it — the textbook is viewed as an authority that drives instruction (Anderson, 2002). Even when high-quality, inquiry-based materials are adopted by teachers, barriers such as a lack of professional development in how to use the materials with students and conflicts between teachers' epistemological beliefs and that of the curriculum designers can prevent full implementation (Abd-El-Khalick et al., 2004; Anderson, 2002). Textbooks, technology, and materials are of much less significance than are the goals, norms, and structures teachers establish for science discourse in their classrooms, as these goals and structures greatly influence the type of quality of discussions students have (Carlsen, 1992; Duschl & Gitomer, 1997; Erduan, Simon, & Osborne, 2004; Furtak & Ruiz-Primo, 2008; Mortimer & Scott, 2003; Pimentel & McNeill, 2013; van Zee & Minstrell, 1997). Because of the importance of discourse in promoting rich explorations of science content and scientific ways of thinking, a clarification of the types and various purposes of classroom discourse is warranted.

A central feature of the classroom discourse envisioned by reform documents involves students and teachers engaged in on-going *discussion*. It is important to distinguish discussions from other types of teacher-student questioning in science classrooms (van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001). Discussions involve constructing knowledge and drawing out students' own ideas, unlike *recitations*, which often follow an initiation, response, evaluation (IRE) pattern, and are primarily designed to assess knowledge and determine the accuracy of predefined ideas (Cazden, 2001; Mehan, 1979; van Zee et al., 2001). IRE patterns fit into what Bakhtin considers monologic discourse, tightly controlled discourse designed to transmit inherent truths (Nystrand, Wu, Gamoran, Zeiser, & Long, 2003). The purpose and form of monologic discourse is unlike dialogic discourse, which is an unscripted, open discussion of ideas shaped by both teacher and student (Nystrand et al., 2003). Though common, IRE patterns can limit classroom discourse (Dillon, 1998; Lemke, 1990; Nystrand & Gamoran, 1991; van Zee & Minstrell, 1997). It is through discussions, rather than through rapid-fire question-and-answer sessions often associated with IRE patterns that science becomes relevant and students become "competent outsiders" — citizens who can evaluate conflicting evidence and participate in "democratic conversations" about science issues as they relate to society (Feinstein, 2011; Hurd, 2000; Roth & Lee, 2002). The role of the teacher in a discussion, then, is to elicit student ideas rather than to evaluate them, and to provide criteria by which students can evaluate the strength of each other's explanations or models. Developing student understanding of the use of criteria such as conceptual coherence, evidential fit, and clarity are critical in advancing student understanding of argumentation and the modeling process (Pluta, Chinn, & Duncan, 2011).

In addition to affording richer discussions and explorations of student ideas to develop student reasoning, the promotion of inquiry-based instruction using dialogic discourse about data has been shown to impact student motivation, specifically interest in and value of science (Palmer, 2009; Sandoval & Harven, 2011). Students are more likely to develop sustained interest in science when classroom structures promote agency and include opportunities for students to participate in ways they value and are familiar with (Basu & Barton, 2007). Improved student interest and perceived value are linked to increased cognitive engagement and persistence (Wigfield & Eccles, 2000). Interest and value is particularly important during middle school, a time marked by decreases in challenging tasks and opportunities to work collaboratively when students need more and a resulting tendency of students to disengage from school (Eccles, 2004; Galton, 2009).

Calls to promote the development of science literacy through discussion and blending of content and practice are not new. Dewey called on educators to help students develop a scientific “habit of mind” as early as 1909 (Rodgers, 2002), and emphasized the need for students to develop a “scientific attitude” in 1935 (Anelli, 2011). Both cited a focus on the critical evaluation of evidence and the importance of discourse as important activities for science learners. Yet, teaching and learning in science classrooms has changed little over the past century. It remains an encyclopedic curriculum and consists largely of the conveyance of discipline-specific bodies of language and skills often isolated from their real-world contexts. (AAAS, 2009; NRC, 2012; Schwartz, Sonnert, & Tai, 2008; Sinatra & Chinn, 2012). To overturn this pervasive and persistent teaching pattern in the US and achieve the vision of science education reformers, researchers must explicitly link what is known about how to structure and foster productive and rich discussions in science classrooms to what is known about how teachers learn (Alozie Moje, & Krajcik, 2010; Cochran-Smith & Lytle, 1999; Little, 1993; Pimentel

& McNeill, 2013). The following section consists of a brief review of the literature on teacher learning.

Teacher Learning

Reviews of teacher professional development have indicated that to be effective, professional development programs must be of sufficient time and intensity, about the work that teachers do, active, collaborative, content-focused, and aligned with department/school/district goals (Darling-Hammond, 2008; Garet, Porter, Desimone, Birman & Yoon, 2001; Guskey, 2000; Putnam & Borko, 2000). Hawley and Valli (1999) and, more recently, Desimone (2009) identified collaborative problem solving and collective participation as critical components of effective professional development programs. This component has its roots in the situated cognition literature (Brown et al., 1993; Lave & Wenger, 1991; Rogoff, 1990). According to this perspective, not only does individual knowledge develop through dialogue with peers but also collective expertise exceeds the knowledge of any single participant. It is through focused discussion that teachers' work is deprivatized, problems of practice are identified, and solutions are developed such that the products of a collaborative group are expected to be richer than what could be achieved alone (Little 2002; Thompson & Zeuli 1999; Vescio, Ross, & Adams, 2008).

One tool to assist in the deprivitization of practice is the use of video. Analyzing video clips with colleagues affords an opportunity to slow down and closely analyze classroom interactions. Video provides an opportunity for a more expert other to highlight salient details of classroom interactions not possible in observations based solely on remembered events (Sherin, Russ, & Colestock, 2011). Viewing video with colleagues also permits making student learning the focus of collaborative examination and discussion (Santagata et al., 2005). Video permits the teacher to be “in the classroom,” analyzing interactions without the in-the-moment teaching demands a teacher normally experiences while teaching (Sherin, 2004). Video allows for multiple views of the same teaching event at different times, for example, at the beginning, middle, and end of a professional development program, thus providing for increasingly deeper cycles of analysis of the same clip and the potential to assess development of reflexive skill over time (Brophy, 2004; Star & Strickland, 2008; Santagata & van Es, 2010).

Despite the value of video, numerous authors have cautioned about its use in teacher education and professional development. Without a guiding framework to direct attention to particular aspects of classroom video, viewers tend to attend to superficial aspects of classroom management, teacher personality, or how enjoyable the task appears (Miller & Zhou, 2007; van Es & Sherin, 2002; 2008). In addition to a clear framework, guidance can also be provided by a skillful facilitator — one who keeps viewers focused on evidence and the details of student thinking (Borko, Jacobs, Eiteljorg, & Pittman, 2008; Coles, 2013; Nemirovsky & Galvis, 2004; Sherin & Linsenmeier, 2011; van Es, Tunney, Seago, & Goldsmith, 2014). Some researchers have argued that skilled facilitation is *required* to recognize and navigate openings in the curriculum –places where participants’ learning requires the most support (Remillard & Geist, 2002; Schifter & Lester, 2005; Seago, 2000). Additionally, the type of video clip chosen for analysis influences what viewers can learn. Videos that focus primarily on the teacher limit what can be inferred about students and student thinking (Miller & Zhou, 2007). Conversely, videos that provide “windows” into student thinking afford opportunities for teachers to focus on student thinking as well as meaningful conceptual ideas in their discipline (Sherin, Linsenmeier, & van

Es, 2009). Videos lacking "high windows" limit productive discussion of the clarity and depth of student thinking (Dyer, 2013). The actor in the video may also matter, as teachers tend to respond differently to videos of themselves teaching versus videos of others. Though viewing videos of themselves was more motivating for experienced teachers, they tended to be less likely to call out "critical incidents" in their own videos as compared to videos of others (Seidel, Sturmer, Blomberg, Kobarg, & Schwindt, 2011). Care must be taken in choosing both the clip and facilitating the analysis of the clip.

One important goal behind the careful selection of video and skillful facilitation is to shift viewers' professional vision: the socially organized way of seeing and understanding events particular to a certain group (Goodwin, 1994). Through scaffolding the viewing of videos that feature student thinking, teachers shift to a more student-centered professional vision and, as a result, develop more sophisticated ways of noticing (Sherin & van Es, 2009). *Noticing*, as defined by van Es and Sherin (2002), consists of three aspects: "identifying what is important in a teaching situation; making connections between specific events and broader principles of teaching and learning; and using what one knows about the context to reason about a situation" (pp. 573). Because high-quality classroom discourse is required to achieve the goals detailed in science education reform documents and because proficient mediation of this type of discourse demands a particular type of attention and response to students' ideas, collaborative video analysis is an ideal and valuable professional development tool. Analyzing video of teacher-student and student-student interactions with a skilled facilitator can help develop science teachers' professional vision of reform-based scientific argumentation and discussion, and develop conceptual tools to notice the salient details of classroom interactions, and frame their analyses of these details to interpret and respond to student thinking about science.

An approach that blends the affordances of collaborative work with video to develop teachers' professional vision is a video club. A video club is a meeting of a group of teachers in which they watch and discuss videos of their teaching (Sherin & Han, 2004). Over time, in a video club led by a skilled facilitator, teachers can become less evaluative and more interpretive, less focused on pedagogy and more focused on student learning, and less general and more specific about what they observe (Sherin & van Es, 2005; van Es & Sherin, 2006, 2010). Though not the explicit purpose of the video clubs documented by Sherin and van Es, shifts in teacher noticing in the video club were accompanied by changes in instructional practice, specifically, making more space for student thinking, more probing and pressing students for explanations and elaborations, publicly recognizing that students had ideas to contribute, eliciting multiple methods or solutions for students – all aspects of a professional vision of reform mathematics teaching (Sherin & van Es, 2009; van Es & Sherin, 2010). A similar shift in attention to students and the development of a more analytic stance was observed by Borko and colleagues (2008) over the course of a two-year professional development program during which mathematics teachers collaboratively examined videos of their teaching. This finding suggests that sustained collaborative analysis of video of teaching can contribute to shifts in noticing and teaching practices that promote discourse-rich environments.

Russ and Sherin (2013) proposed a model to explain how changes in teacher noticing can produce changes in student learning. This model, shown in Figure 1, differs from other proposed models connecting teacher and student learning by emphasizing the importance of recognizing the centrality of students' ideas rather than just changing teacher practice. In measuring the effectiveness of teacher professional development, attention must be paid not only to inputs (time, duration, intensity, content of professional development), and changes in teacher practice, but also to the ways teachers recognize, respond, and make space for student ideas in the act of teaching. Understanding professional learning requires attention beyond simple measures of the frequency with which teachers enact a list of desired behaviors. Rather, careful analyses of the ways teacher-student interaction and student participation in a classroom community are influenced by and influence teacher practice are needed. This same idea is advocated by Coffey, Hammer, Levin, and Grant (2011), who argued that even when teachers engage students in a discussion of ideas in an attempt to understand what students already know, they often approach these discussions with the goal of identifying "correct" or "target" ideas rather than unpacking students' preconceptions. The purpose teachers identify as their goal for the discourse influences what teachers notice as well as the ways in which students and teachers participate in classroom dialogue. The type and structure of classroom dialogue achieved by a teacher whose professional vision is focused on ferreting out students' correct and incorrect ideas will be strikingly different than the dialogue in the classroom of a teacher whose professional vision is to reveal how students come to make sense of science content.

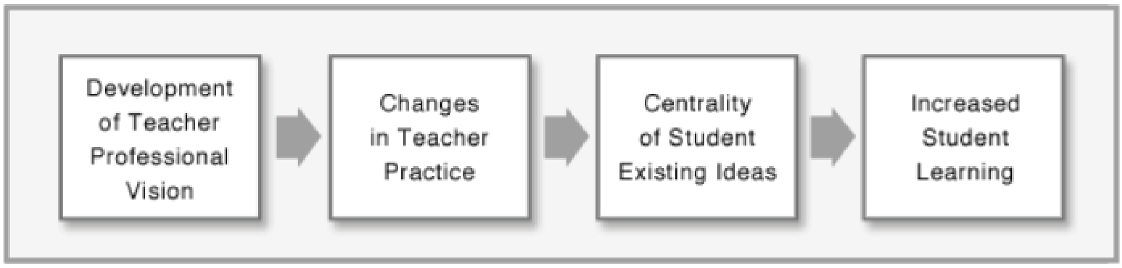


Figure 1.1. Modeling the relationship between teacher noticing and student learning (Russ & Sherin, 2013).

Recent research has proposed epistemological framing as one way to analyze changes in teacher attention and local patterns of noticing (Levin et al., 2009; Russ & Luna, 2013). *Framing* is a participant's attempt to make sense of an interaction or situation. In a general sense, one's frame serves as a "structure for expectation" for a situation and greatly influences how he or she will interpret events and interactions (Tannen, 1993). In a classroom setting, epistemological framing is "how a participant thinks about knowledge as it relates to teaching and learning," (Russ & Luna, 2013, p. 286). For example, the authors described a science teacher who, when adopting the frame "connecting biological ideas" for a whole class discussion, attended to student attempts to make connections between old and new ideas. This same teacher, when adopting a different frame, "using procedural knowledge" for lab activity, consequently attended to students' behavior rather than their ideas to interpret that classroom setting. Because framing influences what teachers notice, introducing alternate frames for teachers to interpret classroom settings may be a useful way to develop more student-centered noticing (Lau, 2010; Levin et al., 2009; Russ & Luna, 2013). The frames teachers adopt to make sense of student ideas influence the instructional choices teachers make about how students participate in the lesson. These instructional choices, particularly the discourse associated with these choices, may either open up or limit opportunities for students to participate (Olitsky, 2006; Turner et al., 2002).

Understanding the Impact of Professional Development

To understand the potential impact participation in professional development has on participants, one must look beyond the structures of discrete elements of a particular professional development design and instead conceptualize the design as a learning ecology in which the elements and participants interact with each other (Cobb et al., 2003). Rather than seeking to simply answer “what works,” design research seeks to understand “what works when, how, and for whom?” and “what capacities does the system need to continue to improve?” (Penuel, Fishman, Haugan, Cheng, & Sabelli, 2011, p. 335).

What has been lacking in many design research studies is an “argumentative grammar” that increases both the rigor of the work and the reliability of the results by tying together a set of methods into a methodological logic (Kelly, 2004). To rigorously explore the influence of the design, one must first make explicit: what theory of learning informs the design; how this theory informs the embodied elements of the tools, tasks, and discourse structures of the design; what mediating processes result from the enactment of the embodied design elements; and how the mediating processes lead to the desired outcome of the design.

Sandoval (2014) proposed conjecture mapping to make overt the theories that undergird the design elements, the processes the elements are hypothesized to support, and how those processes lead to desired outcomes. These multiple conjectures can be displayed in a conjecture map (see Figure 1.2).

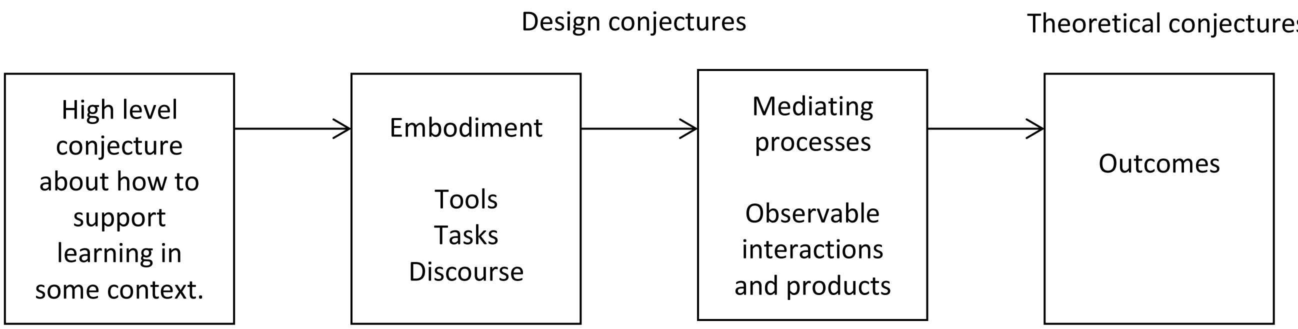


Figure 1.2. Generalized conjecture map for design research from Sandoval (2014).

Conjecture maps contain six main elements. Reading from left to right, the first element is a high level conjecture about how to support learning in a particular context. This is the theory of learning that informs the design environment. The next box indicates the embodied design elements of the tools and materials, tasks and participant structures, and discursive practices informed by the high-level learning conjecture. The third box indicates the mediating learning processes theorized to result from the embodied design. The box on the far right indicates the outcome theorized to result from the embodied design and mediating processes. Arrows connecting the embodied design and mediating practices and the mediating practices and the outcomes are testable conjectures of the design.

To more fully understand the influence participation in professional development has on practice, one must not only examine conjectures concerning how teachers interact with tools, tasks, and each other *in* professional development, but also how participants attempt to make sense of professional development *outside* the professional development and how their experimentation with practice then feeds back into their participation patterns in the ongoing professional development meetings (Gregoire, 2003; Kazemi & Hubbard, 2008). Both approaches, overtly identifying and testing conjectures about the design and systematic documentation of how participants' experiences in the professional development and classroom settings influenced each other, informed the study design described in Chapter 2.

CHAPTER 2 – RESEARCH DESIGN AND METHODS

Study Context

I conducted this study in an urban school district in Southern California. The participants were five high school science teachers from two schools serving primarily nonnative speakers of English from low SES families. I invited the science faculty from both schools to an informational meeting after school to inform them about the video club study. I selected these sites because I was a former member of the science faculty at one school and had ongoing working relationships with science teachers and administrators in both schools as a teacher education faculty at a local university.

Five faculty elected to participate in the study. Table 2.1 indicates the discipline of their degree, what courses they taught at their campus, how many years of teaching experience they had at the time of the study, and any relevant leadership experience each brought to the group. Each earned a stipend for attending meetings and for consenting to be recorded in their classroom. I obtained consent from the parents/legal guardians of the students in the participants' classrooms.

Table 2.1

Study Participants

Participant	Campus	Degree(s)	Course(s) taught	Years of experience	Leadership experience
Ron	North HS	BS biology MA Public Health	biology, honors biology, anatomy & physiology	12	mentor teacher
Mitch	North HS	BA liberal studies (geology, music, French)	earth science, AP environ-mental science, physics	20	mentor teacher; department chair; director of internship program at JPL
Vincent	North HS	BS geology MA teaching science (physics)	physics, AP physics	15	mentor teacher; former department chair; Science Olympiad advisor
Laurel	South HS	BA Spanish, biology, & education MA education PhD education (astronomy education & educational technology)	earth science, AP environ-mental science	15	adjunct professor for science credential students; National Board Certified Teacher
William	South HS	BS chemistry MA education (in progress)	chemistry, honors chemistry	10	

The teachers at both sites had experience working in collaborative groups. For the previous six years, both schools had dedicated segments of the school day to subject-alike faculty meetings with the purpose of examining practice. This time was typically spent designing and analyzing the results of common assessments or labs. Course-alike meetings were also regularly hosted during the school day at the district to design common assessments and, more recently, Common Core–aligned science writing tasks and rubrics. Many were also involved in teacher education projects. For example, Laurel was National Board Certified and served as an adjunct professor at a local university. Mitch worked with NASA coordinating a new teacher intern program at the Jet Propulsion Laboratories during the past three summers. Mitch, Vincent, and Ron had previously served as mentors for student teachers as part of a local university's Noyce Fellowship grant. Several currently served in leadership positions at their school sites. Mitch was a current department chair, and Vincent was his immediate predecessor. William was in the middle of a two-year master's program and in the early stages of conducting an action research study which would ultimately be published in *The Science Teacher*.

Not every participant was able to attend each meeting. Mitch and Ron attended four of the five meetings, William and Vincent attended three meetings, and Laurel attended two meetings. Family obligations, school field trips, and personal medical issues prevented participants from attending some meetings.

Video Club Design

Edelson (2002) identified three decisions that must be made when engaging in design: who will be involved in the design process; what problem or challenge will the design intend to address and what goals the design intends to achieve; and what is the resulting design that best meets the desired goals while balancing potential challenges and affordances of the particular context of the design.

To answer Edelson's (2002) first question, I served as the designer, facilitator, and researcher in this design study. I consulted the literature as the next step in the design process: an analysis of the local problem and development of goals to address the problem.

Initial Problem Analysis

NGSS and CCSS call for increased focus on leveraging evidence to support claims, scientific habits of mind, composing evidence-based explanations (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010; NRC, 2012). In so doing, the authors of these standards hope to integrate understanding of scientific ideas with the practices of science. The goal is for students to learn how ideas are generated by science, in essence, how science works (AAAS, 2009; Duschl, 2008; NRC, 2012). By engaging in science practices to make sense of disciplinary core ideas, students will be able to achieve the depth of understanding required for them to have sufficient knowledge to be careful consumers of information, participate in society as educated citizens, make sense of how the natural and designed worlds work, and continue to learn about science outside of school (AAAS, 2009; Hurd, 2000; NRC, 2007, 2012).

These new goals require an instructional shift away from the transmission of facts toward more ambitious science teaching by encouraging students to engage in multiple rounds of revising evidence-based explanations of anchoring phenomena and developing a culture of talk that promotes students' sense-making of these phenomena (Windschitl, Thompson, Braaten, & Stroupe, 2012). The center of this instructional approach is noticing and responding to student thinking (Stroupe, 2014). This type of teaching is demanding because it requires deeper knowledge of content and deeper knowledge of students. Teachers must be able to recognize how students are thinking about a disciplinary core idea and make decisions on-the-fly about how best to respond (Chin, 2007; Hammer, 2000; Levin et al., 2009). This form of instruction also requires a redefining of roles for both the teacher and his/her students (Anderson, 2002; McNeill & Pimentel, 2010; van Zee et al., 2001). Ownership for building knowledge shifts from the teacher and/or the textbook to the students through their collaborative sense-making.

Enacting this instructional change is challenging because, like any change, it means giving up what is practiced and familiar (Guskey, 2002). Further complicating this shift is the lack of a mental model for what this type of science instruction looks like, either as a teacher or a learner (Lorte, 1973; Santagata et al., 2005; Windschitl & Thompson, 2006). The design of the professional development should, then, provide models of students and teachers engaging in iterative explanation building; encourage a focus on the content of students' ideas, and provide opportunity to discuss challenges of implementation. A description of the initial design that resulted from this problem definition follows.

Conjecture Mapping of the Initial Design Solution

The design was informed not only by the problem analysis, but also by previous work on video clubs as ways to promote a professional vision of ambitious teaching as well as research of professional Communities of Practice. Additionally, during interviews conducted in January, I asked participants what their motivation was for participating in the study and what they hoped to accomplish through their participation so I could be responsive to their goals while maintaining the general aims of my video club design. The interview protocol can be found in Appendix A.

The resulting design is depicted in Figure 2.1. This figure indicates the desired outcomes to address the perceived problem, as well as the conjectures that connect the design principles, embodied design, and hypothesized mediating practices theorized to achieve the stated outcomes.

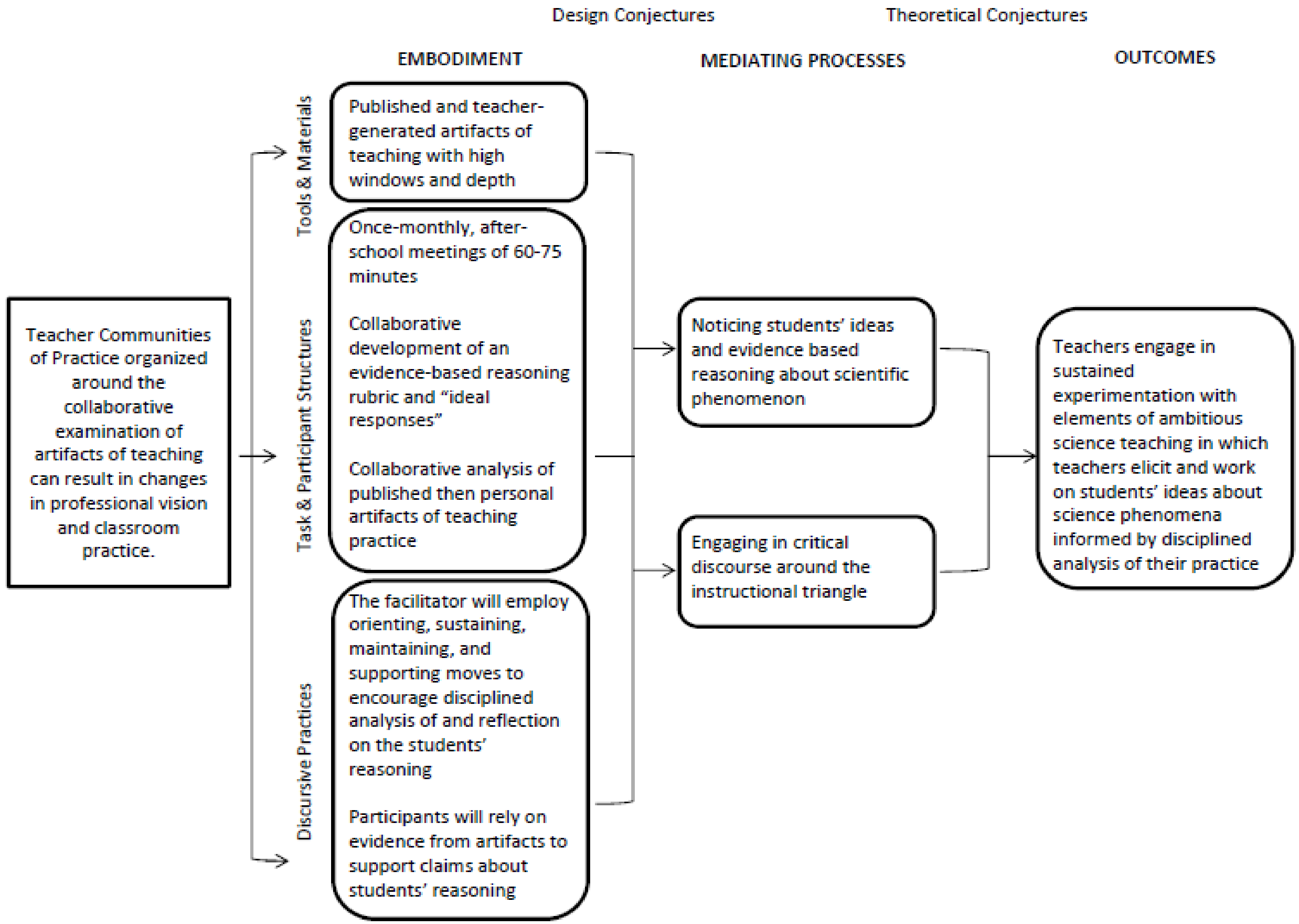


Figure 2.1. Design principles and conjecture map for a video club promoting ambitious science teaching.

Reading the conjecture map. Conjecture maps contain six main elements. Reading from left to right, the first element is a high-level conjecture about how to support learning in a particular context. This is the theory of learning that informs the design environment. The next column indicates the embodied design elements of the tools and materials, tasks and participant structures, and discursive practices informed by the high-level learning conjecture. The next column indicates the mediating learning processes theorized to result from the embodied design. The box on the far right indicates the outcome theorized to result from the embodied design and mediating processes. Arrows connecting the embodied design and mediating practices and the mediating practices and the outcome are testable conjectures of the design.

Design outcome. The desired outcome for the professional development design is that participants engage in sustained experimentation with elements of ambitious science teaching in which they elicit and work on students' ideas about science phenomena informed by disciplined analysis of their practice. Experimenting with ambitious science teaching addresses the instructional changes because it responds to calls by AAAS and NGSS to shift the responsibility for knowledge construction to students by making observations of scientific phenomenon and using these observations to construct explanatory models. The video club design is hypothesized to provide teacher participants with support to first notice, then elicit and work with students' ideas about science phenomenon during instruction. The outcome is one departure from the model video clubs in this design. The goal of the model video clubs was to develop a professional vision of ambitious math teaching through the development of participants' noticing of students' mathematical thinking. In this video club, development in teacher noticing was not an outcome, but rather a mediating process to achieve instructional change.

Theory of learning. The theory of learning that informs this design is based on Lave and Wenger's concept of a Community of Practice (1991). A Community of Practice is a group of people who engage in collective learning and development in the course of their shared pursuit of a common interest, goal, or problem (Wenger, 2011). Learning is social and contextual, occurring while in the act of joint activity related to their work (Greeno, Collins, & Resnick, 1996). One type of Community of Practice featured in education research, a Teacher Community of Practice, is organized around the collaborative examination of artifacts of teaching. Teachers who meet, formally or informally, to discuss issues of practice form a Community of Practice even though they return to their classrooms to teach alone (Wenger, 2011). A substantial body of work describes the benefits of teachers collaboratively examining artifacts of practice, be it student work, lesson plans, or videos of classroom interactions (Kazemi & Stipek, 2001; Levin & Richards, 2011; Lewis, 2000; Little, Gearhart, Curry, & Kafka, 2003; Tripp & Rich, 2012). Video club participation in particular has been shown to shift teacher noticing. Video clubs designed to focus on understanding the content of students' mathematical thinking has resulted in increased in-service teachers' attention to student ideas and a shift to a more interpretive rather than evaluative stance over time (Borko, Koellner, Jacobs, & Seago, 2011; Brantlinger & Sherin, 2006; Sherin & Han, 2004; van Es & Sherin, 2008). In this study, the video club approach was used with high school science teachers, an under documented group in the literature.

Design elements. This particular Teacher Community of Practice was embodied in several design elements. These elements were organized around tools, tasks, and talk. The tools that the group used to engage in the video club included artifacts of teaching — specifically videos of classroom interactions in which students were engaged in evidence-based reasoning about a science phenomenon. In particular, the artifacts chosen for collaborative examination should feature high windows into and depth of student thinking about science (Sherin et al., 2009). Artifacts with high windows provide evidence from several sources (written, verbal, gestures) that make student thinking visible and therefore available for discussion. Artifacts in which students grapple with substantive disciplinary ideas as opposed to correctness or rote completion of routines or algorithms are said to have high depth. Clips with these features in combination are more likely to stimulate rich discussion about students' disciplinary reasoning (Sherin et al., 2009).

The group used published artifacts as the subject of their analysis in the first few meetings, another departure from the model video clubs. Not only would these clips include high windows and depth, but because the design outcome of this particular video club was experimentation with practice, utilizing published artifacts provided teacher participants with a model of the elements of ambitious science teaching concerned with eliciting and working with students' ideas about core disciplinary ideas (Lorte, 1973; Santagata et al., 2005; Windschitl & Thompson, 2006). One assumption this design sought to validate was that teacher engagement in video-based analysis of student thinking can influence their own classroom practice in ways that make them more responsive to student thinking (Sherin & van Es, 2009; van Es & Sherin, 2010). Teaching in ways that make student thinking more visible might then increase the likelihood that participant-generated artifacts to be used in the second half of the video club would have high windows and depth to support rich discussion.

To honor the desire that participants expressed in their pre interviews to learn about what their colleagues were doing and to have the opportunity to explore their own practice in depth, I planned to utilize artifacts from participants' classrooms in the second half of the video club. I initially planned to use only video clips, but due to constraints with participants' varying familiarity with different science disciplines, the number of classroom observations that were possible during the study, and the limited number of those observations that were of sufficient audio quality, I chose some participant artifacts that were student work samples without accompanying video and some that did not feature high windows into and depth of student thinking.

However, artifact selection was only one aspect of the professional development design. Simply having a high-quality artifact to discuss does not ensure a rich discussion will result. Skilled facilitation of both the conversation around the artifact and the pre work needed to frame and focus the conversation is a critical element of productive discussion (Coles, 2013; Nemirovsky & Galvis, 2004; van Es, Tunney, Goldsmith, & Seago, 2014; Zhang, Lundeberg, & Eberhardt, 2011). As a result, this design involved two tasks intended to focus participants' attention to students' disciplinary thinking: development of a rubric to characterize the quality of students' evidence-based explanations and discussion of "ideal responses" to the prompts featured in the artifacts. Defining the desired components of students' explanations in the rubric should frame the examination of artifacts as an analysis of student reasoning and focus participants on the student thinking in the artifacts (Borko et al., 2011; Levin et al., 2009). The rubric was not intended to be something to give to students or to formally assess student work but rather to serve as a touchstone to help the participants know where they might want to press students for more elaboration and evidence to support their reasoning about the science phenomenon they observed both during the analysis of artifacts and during experimentation with practice.

Though I had my opinions based on research on students' explanations – that students should leverage their detailed observations to make inferences about what occurred and why rather than simply describe what transpired or simply use textbook definitions without further elaboration (McNeill & Krajcik, 2007; Windshitl et al., 2008) – I kept these largely to myself to allow the participants space to explore their own ideas of what counted as a desired student explanation of a phenomenon. I reiterated that the rubric could and would change as we learned more about what we wanted to capture with the rubric by applying it to the artifacts of teaching.

An additional pre work activity to frame and focus the participants' work was engaging in discussions about their "ideal response" to the prompt featured in the artifacts. Working through the prompt given to students would provide insights into student approaches to the problem that might otherwise be overlooked and increase clarity on the content goal of the lesson (Borko et al., 2011; Morris, Hiebert, & Spitzer, 2009; Santagata, 2009). Both activities were designed to promote noticing of students' disciplinary thinking and its relation to elements of ambitious science instruction.

During the analysis of the artifacts of teaching, research suggests that facilitation moves can contribute or inhibit productive collaboration (Borko, Koellner, & Jacobs, 2014; Gröschner, Seidel, Pehmer, & Kiemer, 2014). Facilitation moves include actions that provide needed context about the artifact, sustain an inquiry stance, encourage working with and maintaining focus on evidence of thinking and learning in the artifacts, support collaboration, and introduce new ideas about the instructional triangle that encourage participants to "break set" (Cartier, Smith, Stein, & Ross, 2013; Coles 2013; van Es et al., 2014). The assumption this aspect of the design attempted to validate was that by engaging in these facilitation moves, I would clarify discursive norms and expectations for the teacher participants in the video club, specifically with respect to how the group would work with the artifacts (Gröschner et al., 2014). In so doing, participants would become more adept noticers of students' disciplinary thinking and of the relation of student thinking to elements of ambitious science instruction.

The design tactic of this study recognized that rather than *telling* participants how and why to enact specific instructional moves and curricular designs, participants should build their own understanding of the affordances of student-centered approach through collective exploration with support (Gregoire, 2003; McLaughlin & Talbert, 2006). My role as the facilitator and designer in this study was to encourage disruption of normal patterns of examining practice by promoting focus on participants' noticing of students' thinking. By entering into the instructional triangle through the frame of student thinking, participants might better understand the relationship instruction has on students' disciplinary thinking and become more attuned to the potential impacts adjustments to instruction have on student learning (Levin et al., 2009). When participants have opportunities to construct their *own* understanding of how instructional approaches influence student thinking, they can apply it to new situations and future problems that they, themselves, identify (Franke, Carpenter, Levi, &

Fennema, 2001). An approach in which those who must actually implement change play a central role in both identifying instructional problems and proposing solutions increases ownership of the problems and solutions, promotes continuous professional growth, and typically results in better solutions to practical challenges (DuFour & Eaker, 2005; Flinchbaugh & Carlino, 2006; National Staff Development Council, 2001; Wakamatsu, 2009). In so doing, participants are more likely to avoid “lethal mutations” in their enactment of the targeted instructional reform, in this case, enacting the elements of ambitious science teaching without adopting the underlying theoretical principles of teaching and learning (Brown & Campione, 1996; Cohen, 1990; Davis & Krajcik, 2005).

In the next section, I discuss the data I collected to address the three research questions and video club design conjectures in this study.

Data

Data for the study consist of observations and videos of each video club meeting, and individual interviews with the participants, classroom observation data, and student data. First, I video-recorded all five video club meetings. The group met once monthly from January to June. These meetings typically lasted about 80 minutes and were conducted in the participants’ classrooms after school. I transcribed the videos of each meeting. I also wrote field notes during the meetings. After each meeting, I wrote a memo about my impressions of the meeting, important ideas raised by participants, or themes I saw emerging over several meetings. I also made notes to inform the subsequent design of future meetings – a key element of design research. The purpose was to preserve a record of my design changes as the professional development played out over the semester so they could later be analyzed to test the design conjectures and understand potential design tensions.

I also conducted pre and post interviews with each participant. The focus of the interviews was to learn what each participant hoped to or did gain by participating in the video club, what they considered as their role as science teachers, and how they knew learning occurred in their classrooms. I was also interested in any shifts in how participants viewed student learning and their roles as teachers in structuring learning opportunities for students as a result of participating in the video club. The interviews were audio recorded and transcribed.

Additional data include videos of the participants' teaching, as well as student work samples from the recorded lessons. Initially, I planned to observe each participant at least once a month during the course of the study. I asked that they notify me whenever they planned a lesson that involved students in the collection and analysis of data through inquiry. Two participants (Vincent and William) extended invitations to me during the first month of the study. Others, however, either did not respond to my request, informed me that their students were not engaging in the type of activity I described during that part of the curricular year, or told me after the fact or with too short of notice when they changed plans to include a data-analysis based lesson. One participant, Laurel, had personal issues that made scheduling very difficult. As a result, I did not obtain the number of observations I had planned for each participant. I completed 13 observations total: six from William, three from Vincent, and two from Ron and Mitch.

In several cases, I also conducted and audio recorded a debrief session with a participant after recording his lesson. Some of the classroom observation recordings and student work samples were used as a subject of analysis in the fourth and fifth video club meetings. These were also used to get a sense of how participants were changing their practice in response to ideas raised during the video club meetings.

A summary of which data were used for each research question is shown in Table 2.2. A description of how these data were analyzed follows.

Table 2.2

Data Utilized for Each Research Question

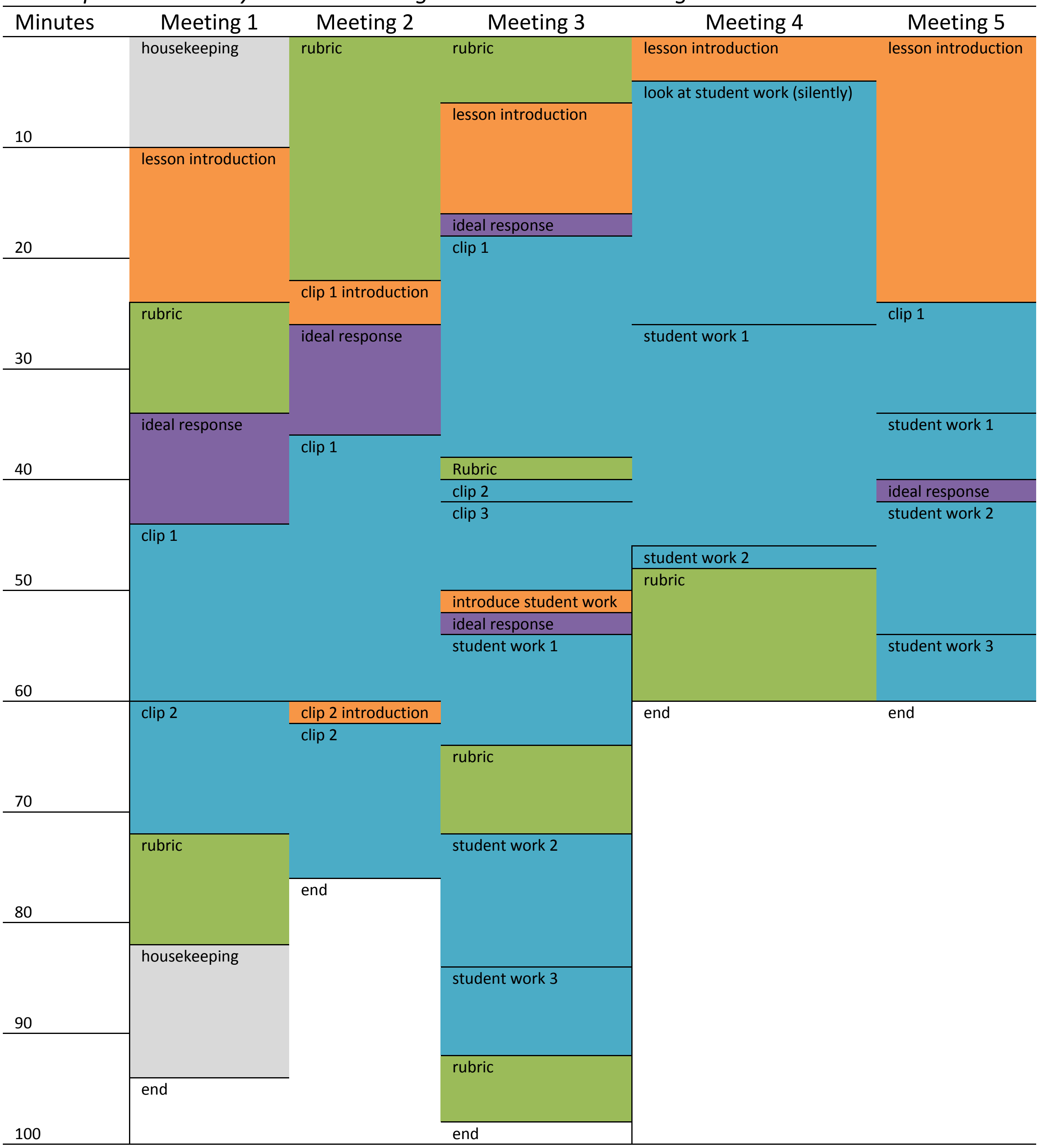
Research question	Data
How does participation in a video club influence the types of critical discourses teachers develop in a video club for analyzing artifacts of practice with colleagues?	transcripts from the five video club meetings artifacts of practice utilized in video club meetings
What influences, if any, did participation in a video club have on participants' thinking and willingness to experiment with practice?	transcripts from the five video club meetings transcripts of participants' pre and post interviews videos and student work samples from participants' classrooms audio recordings of post observation debriefs with participants
How did the design elements of the video club professional development influence the desired professional development outcomes?	transcripts from the five video club meetings artifacts of practice utilized in video club meetings videos and field notes of observations of from participants' classrooms

Analysis

Research question one. To answer research question one, I used an interpretive approach as described by Hatch (2002). First, to gain a sense of the entire set of meetings, I wrote analytic memos and meeting summaries for the five meetings. Second, for ease of later analysis, I divided the meeting transcripts into sections based on the activity phase of the meeting (i.e., introducing the clip, discussing the ideal response, analyzing the clip, discussing the rubric). The time spent engaging in each activity in each meeting is represented in Table 2.3.

Table 2.3

Time Spent on Primary Activities During Five Video Club Meetings



Because the discourse was likely to change depending on the nature of the task participants engaged in, dividing the meeting transcripts in this way would permit focus on the meeting phases of most interest; for research question one the phase of interest was the collaborative analysis of artifacts of teaching. As described earlier in this chapter, the other meeting segments were designed to *prepare* participants for the work of artifact analysis and did often not require close attention to the details in the artifacts. The development of the evidence-based reasoning rubric, did not require examination of the student thinking in artifacts. Segments devoted to the development of the "ideal response" only referenced the prompt students were given in the artifact, but did not involve any examination of student responses to the prompt. These segments, therefore, were unlikely to reveal instances of the critical discourses of interest in research question one.

Because the quality of the artifact would likely influence the quality of discussion (Sherin et al., 2009), the artifact analysis sections were divided by discussion around each artifact (e.g. clip 1, clip 2, student work 1, student work 2) and further divided by idea unit. An idea unit is defined by a set of turns at talk focused on a broad topic (student thinking about the disciplinary core idea) or object (the drawn explanatory model featured in the student work). Five artifact segments from the five meetings were discussed by a research team to gain consistency in identifying idea units. This yielded one to six idea units for each of the 13 artifacts for a total of 54 idea units.

Informed by the analytic memos and literature on teacher collaboration (Lord, 1994), science teacher learning (Thompson, Windschitl, & Braaten, 2010), and teacher noticing in video clubs (van Es & Sherin, 2010), I developed a framework to capture likely elements of critical discourse in the meetings. To be clear, *critical* in this study is used to convey the level of constructive critique among colleagues from Lord's (1994) critical colleagueship and should not be confused with the critique of power dynamics in broader social context in critical theory. This framework included three dimensions: What was being discussed, how participants interacted with ideas, and how participants interacted with each other. Tables 2.4, 2.5, and 2.6 illustrate the framework I used to analyze these dimensions.

The development of the framework was an iterative process using the constant comparative method (Lincoln & Guba, 1985). Previous research on teacher noticing and analysis of artifacts of practice helped me identify likely topics of focus (Levin et al., 2009; Star & Strickland, 2008; van Es & Sherin, 2009), which I used to preliminarily code a portion of the meeting transcripts. I noted areas where segments of talk were not adequately described by the existing codes and grouped these into newly identified codes. After multiple rounds, I determined the codes that best described the topics under discussion across the five meetings. The topics of discussion were categorized as either focusing on instruction, classroom management, student behavior, student thinking, classroom climate, assessment, disciplinary core ideas, or other (see Table 2.4). I coded each turn at talk during meeting segments in which the group examined artifacts of practice, identifying the topics addressed in each utterance. Many times, a single utterance could address multiple topics; for example, participants could discuss a student thinking about a disciplinary core idea as measured by an assessment. Using these turn at talk codes, I identified the dominant topic or topic cluster of focus for each idea unit.

Table 2.4

Analytic Framework for Topics of Discussion in Video Club Meetings

Code	Description	Example
Instruction & Curriculum	Any discussion of teaching moves, descriptions or analysis of teacher-student interactions about the science content in which the primary focus is the teacher. Any discussion of how tasks are designed, the sequence of how skills and concepts are introduced to or explored by students, the texts or materials teachers are provided with by the school, district, or state.	So I would think ok, do your drawing, and when you're walking around you ask these questions, like, "Well now are these dots and arrows representing water or the gas?" Sometimes it's not even the phrasing of the question, it's like, they're engaging in the wrong task. I assume they already had kinetic theory?
Classroom management	Any discussion of how the teacher addresses distribution or collection of materials, addressing student behavior, and facilitating the transition from one classroom task to the next.	She spent a lot of time with that group and I'm not sure I'm comfortable like spending so much time. I have 9 groups and so, spending that much time with just one group while the other 8 are off drawing cartoon characters.
Student behavior	Any discussion of student actions disconnected to their thinking and reasoning, such as fidgeting, getting out of their seats, engaging in non-science talk.	I don't understand how that teacher can tolerate that kid yelling.
Classroom climate	Any discussion of the norms for participation in the classroom. This includes discussions of who participates and how, perceived expectations for participation and students' comfort level with those expectations, and what types of tasks and contributions students are expected to make in the classroom.	In some classrooms, that's a complete shift. And that means I'm in a place where the teacher is going to with a microscope look at what I'm writing and can I really describe ideas or not. When you're a teacher doing that it's a different job than if you're a teacher just saying, "Look, this gets a stamp you get five points out of five."

Assessment	Any discussion of how student thinking and skill development is measured. This includes written assessments, verbal assessments, formal and informal means of assessment.	I think, my impression is he's on the right track and maybe he just needs a little more to be higher quality, um. For example, if he was consistent like in the fork on the right.
Student thinking	Any discussion of what students say or write, misconceptions that students may express, interpretations or descriptions of how students approach tasks and problems.	See, it says "you place it in cold water and it popped. It smashed." It crunched, I guess. And there's a difference between the hot and cold in the observation and the result. But not in the conclusion.
Disciplinary core ideas	Any discussion of the science concepts, such as the relationship between variables in a system, the nature of science, and cross-cutting concepts such as the relationship between structure and function or the role of models to explain ideas. This does not include the development of discrete skills such as measurement, equipment use, and the rote use of mathematical computations.	But see, this is, the common misconception here is that something is pulling in from the inside. Something's happening on the inside that's pulling the tanker closed. And that's the misconception. That's the really tough sell – it's that the forces are greater on the outside than on the inside. That's what causes the implosion.
Other	Discussions of issues not directly related to the above, for example students' acquisition and use of academic vocabulary, or students' persistence.	They lack the discipline, and they lack the desire to push things through, they lack the "stick with it ness." Because they mainly, our students, they're not armed with appropriate vocabulary yet. They don't have any confidence.

To characterize *how* participants interacted with ideas, each idea unit was coded for stance and use of evidence (see Table 2.5). I determined the stance and use of evidence based on the most frequent approach employed by the participants when analyzing artifacts (evaluative, descriptive, interpretive) and what they most commonly used as evidence (anecdotes, artifact-based evidence, or scientific theory).

Table 2.5

Analytic Framework for Analyzing how Participants Interact With Ideas

Stance	**Use of evidence**
Evaluative; simplistic; seeking to label the teaching or learning.	**Anecdotal** evidence from professional experience.
Descriptive; detailed observations and thick description of teaching and learning.	Evidence based on the shared **artifact.**
Interpretive; problematizing teaching and learning; asking questions to make sense of teaching and learning; attempting to understand the underlying science ideas.	Evidence based on **science** theory/knowledge.
	Mixed anecdotal, artifact-based evidence, and/or evidence from science theories.

To capture how participants interacted with *each other*, the idea units were coded as increasing levels of sophistication (*low, medium low, medium high,* or *high*), depending on how many participants were involved in the discussion, whether each participant's contribution built upon earlier comments or consisted of disconnected, discrete conversations, and whether participants critiqued each other's "weak practices or flimsy reasoning" (Lord, 1994, p. 192). This coding framework is displayed in Table 2.6. There is evidence in the literature that various gradations of critical colleagueship exist among groups and so the framework intends to capture different levels of sophistication and engagement (Grossman, Weinburg, & Woolworth, 2001; Hammer, 2000; Little, 2002, Tannen, 1990; van Es, 2012).

Table 2.6

Analytic Framework for Characterizing how Participants Interacted with Each Other

Level	Participation
Low	1 person dominant
Medium low	2 or more participating equally, but discrete, serial, or parallel conversations
Medium high	2 or more participating in ways that build upon each other's contributions, instances of cooperative overlapping talk
High	2 or more participating in ways that build upon each other's contributions and challenge each other's interpretations and practice, instances of cooperative overlapping talk

An example of how the three-part framework was applied to the video club transcripts, including codes for topic, stance, use of evidence, and participation, follows in Table 2.7.

Table 2.7

Sample of Coded Meeting Transcript

Line	Participant	Transcript	Codes
1 2 3	Facilitator	So if you were to ask this kid a question, and you're going to press this kid, what, what question might you ask, to get at this?	
4 5 6 7 8	Vincent	I would actually point to both right sides and ask him you know, can you tell me a little about the lines here. And kinda, what the difference is there. Maybe even clarify oh this one should be this, and this one should be wider this one should be.	STUDENT THINKING, ARTIFACT, INSTRUCTION, DCI
9 10	Facilitator	So you want him to say something about the distance between the lines.	
11	Vincent	Yes.	
12 13	Facilitator	And that would tell you he understands the difference in the pitch, right? OK.	
14	Ron	Especially for the bigger fork	STUDENT THINKING, DCI
15	Vincent	Yeah I don't think-	
16 17	Ron	[pointing] -'Cause the lines are different on the left side and the right side of the bigger fork	DESCRIBING, STUDENT THINKING, ARTIFACT, DCI
18 19	Vincent	And here's the interesting thing, I don't know if he thought that they were maybe be colliding in the middle	INTERPRETING, STUDENT THINKING, ARTIFACT, DCI
20	Facilitator	Ohhh, that might be.	
21 22	Vincent	Instead of squeezing [gesturing] when they hit each other, you know? 'Cause that would clarify a lot.	INTERPRETING, STUDENT THINKING, ARTIFACT, DCI
23 24	Facilitator	Yeah, if that's why they didn't . Although that still doesn't explain like why the outside ones are the way they are.	STUDENT THINKING, ARTIFACT, DCI
25	Vincent	No.	
26 27	Facilitator	Cause yeah, you're right. If you just look at the outside, that one looks spread out.	STUDENT THINKING, ARTIFACT, DESCRIBING
28	Vincent	Yes.	
29 30 31 32	Facilitator	This one looks more compressed. So he would understand the pitch. It doesn't seem like he's conveying anything about volume here. Or the loudness, but he wasn't really asked about that.	DESCRIBING, INTERPRETING, STUDENT THINKING, ARTIFACT

In this part of Meeting 3, participants examined one student's drawing of how sound emanated from two different sized tuning forks. In the previous idea unit, the participants described and interpreted what they saw in the student's drawing and his verbal explanation of the two different tuning forks. In line 1, I launch this idea unit with a question about how they might respond to the student given what we established about their understanding of sound. Vincent identified a question he might ask the student to gain clarity on his thinking, and in line 14 Ron elaborated on what this proposed question would help clarify. Vincent continued to interpret and question the work in lines 18–19 and returned to the importance of his follow up question in line 21.

In summary, participants in this segment interpreted the student thinking about a disciplinary core idea in the artifact rather than just describing or evaluating the response, participants relied on details in the artifact, and Ron's contributions sustained Vincent's idea rather than launching a new idea. Based on these interactions with the artifact, I coded the topic of focus of this idea unit as instruction, student thinking, and disciplinary core ideas. This was considered interpretive in stance and grounded in the artifact. This idea unit was coded as medium high for participation. The results of the application of this coding approach are discussed in Chapter 4.

To determine which idea units were highly productive and which were less productive, I coded the idea units from each artifact for each of the five meetings for topic, stance, use of evidence, and level of participation. Stance and evidence were considered together because they were components of "how participants attended to ideas." I then tabulated the frequency of topic clusters and the corresponding turns of talk devoted to each topic by idea unit (see Appendix B), the sequence of stance and use of evidence by idea unit for each artifact, and the levels of participation for each idea unit across the five meetings (see Appendix C). I synthesized these tables to develop a summary of how topic, stance, evidence, and participation functioned together across the five meeting sequence and used the turns of talk for each idea unit to determine the proportion of each meeting devoted to each phase of artifact analysis (see Figure 3.1 in Chapter 3). Idea units focused on the instructional triangle in which participants were interpretive and grounded in evidence from the artifact, and maintained medium-high to high levels of participation were considered highly productive.

Research question two. My second research question examined how participation in a video-based professional development influenced participants' thinking and willingness to experiment with practice. Prior research found that participating in the collaborative examination of artifacts could help teachers learn to engage in practices that are more responsive to student thinking (Kazemi & Franke, 2004; Levin et al., 2009; Sherin & van Es, 2009; van Es & Sherin, 2010). I was interested in understanding whether participation in the video club I designed encouraged enactment of ambitious science teaching. By ambitious teaching, I mean that teachers elicit and work with student ideas about science phenomenon and shift responsibility for constructing knowledge to students. I reviewed prior research that highlighted the importance of task, questioning, and discourse to identify a framework to help me analyze their practice on these dimensions (Cartier et al., 2013; Chin, 2007; Ruiz-Primo & Furtak, 2006; Minstrell & van Zee, 2000; Windschitl et al., 2012).

Phase one. In the first phase of analysis, I wanted to get a sense of whether the teachers were beginning to change their practice in ways that were more student-centered. I chose to use the EQUIP (Electronic Quality of Inquiry Protocol) (Marshall, Smart, & Horton, 2010) (see Table 2.8) framework as one analytic tool because it was specifically designed to evaluate science teacher professional development as it pertains to the quality and quantity of inquiry experiences in science classroom and has been shown to be a valid and reliable measure (Marshall, Smart, & Horton, 2010). More specifically, I narrowed the analysis to two dimensions of the EQUIP framework, Discourse and Instructional constructs, because they aligned with the goals of the video club: increase participants' noticing of students' disciplinary ideas and experiment with aspects of instruction that would make student ideas public and enable the teacher and classmates to work with these ideas. When teachers make visible and attend to the quality and details of students' thinking and reasoning about science ideas, the students' attention to these ideas is enhanced and the culture and activity of the classroom becomes more scientifically authentic (Levin, 2008).

Table 2.8

EQUIP Measure for Quality of Discourse and Instruction in Inquiry-Based Science (Marshall, Smart & Horton, 2010)

	Pre-inquiry (Level 1)	Developing inquiry (Level 2)	Proficient inquiry (Level 3)	Exemplary inquiry (Level 4)
Instructional Factors				
Instructional strategies	Teacher predominantly lectured to cover content.	Teacher frequently lectured and/or used demonstrations to explain content. Activities were verification only.	Teacher occasionally lectured, but students were engaged in activities that helped develop conceptual understanding.	Teacher occasionally lectured, but students were engaged in investigations that promoted strong conceptual understanding.
Order of instruction	Teacher explained concepts. Students either did not explore concepts or did so only after explanation.	Teacher asked students to explore concept before receiving explanation. Teacher explained.	Teacher asked students to explore before explanation. Teacher and students explained.	Teacher asked students to explore concept before explanation occurred. Though perhaps prompted by the teacher, students provided the explanation.
Teacher role	Teacher was the center of lesson; rarely acted as facilitator.	Teacher was center of lesson; occasionally acted as facilitator.	Teacher frequently acted as facilitator.	Teacher consistently and effectively acted as a facilitator.
Student role	Students were consistently passive as learners (taking notes, practicing on their own).	Students were active to a small extent as learners (highly engaged for very brief moments or to a small extent throughout lesson).	Students were active as learners (involved in discussions, investigations, or activities, but not consistently and clearly focused).	Students were consistently and effectively active as learners (highly engaged at multiple points during lesson and clearly focused on the task).
Knowledge acquisition	Student learning focused solely on mastery of facts, information, and/or rote processes.	Student learning focused on mastery of facts and process skills without much focus on understanding of content.	Student learning required application of concepts and process skills in new situations.	Student learning required depth of understanding to be demonstrated relating to content and process skills.

Discourse Factors				
Questioning level	Questioning rarely challenged students above the remembering level.	Questioning rarely challenged students above the understanding level.	Questioning challenged students up to application or analysis levels.	Questioning challenged students at various levels, including at the analysis level or higher; level was varied to scaffold learning.
Complexity of questioning	Questions focused mostly on one correct answer; typically short answer responses.	Questions focused mostly on one correct answer; some open response opportunities.	Questions challenged students to explain, reason, and/or justify.	Questions required students to explain, reason, and/or justify. Students were expected to critique others' responses.
Questioning ecology	Teacher lectured or engaged students in oral questioning that did not lead to discussion.	Teacher occasionally attempted to engage students in discussion or investigations but was not successful.	Teacher successfully engaged students in open-ended questions, discussions, and/or investigations.	Teacher consistently and effectively engaged students in open ended questions, discussions, investigations, and/or reflections.
Communication pattern	Communication was controlled and directed by teacher and followed a didactic pattern.	Communication was typically controlled and directed by teacher with occasional input from other students; mostly didactic pattern.	Communication was often conversational with some student questions guiding the discussion.	Communication was consistently conversational with student questions often guiding the discussion.
Classroom interactions	Teacher accepted answers, correcting when necessary, but rarely followed-up with further probing.	Teacher or another student occasionally followed-up student response with further low-level probe.	Teacher or another student often followed-up response with engaging probe that required student to justify reasoning or evidence.	Teacher consistently and effectively facilitated rich classroom dialogue where evidence, assumptions, and reasoning were challenged by teacher or other students.

I prepared the recordings of classroom observations for analysis by creating lesson graphs to capture the various activities of the lesson. The lessons varied in length from 55 minutes to 120 minutes depending on whether the lesson fell on a "regular" or "block" day. As I watched the videos with the EQUIP dimensions in mind, I made a note of confirming and disconfirming evidence and recorded notes on the lesson graph and wrote an analytic memo for each lesson. I then reviewed the lesson graph notes and memo to determine a score for each category in the instruction and discourse dimensions on the EQUIP. Lessons were coded holistically with the unit of analysis being the entire lesson. Because lessons have different phases, such as whole-class direct instruction, collecting data in small groups, independent seat work, or group presentations of lab results, instructional techniques and resulting discourse change throughout the lesson. Breaking the lesson into smaller units would yield several units that could not be adequately addressed by the EQUIP tool; for example, during direct instruction there may not be any teacher-student questioning, rendering the discourse ratings not applicable. An example of one lesson graph with running notes and the accompanying memo can be found in Appendix D.

The example lesson graph is based on my observation of Vince's lesson on the kinematics of a rolling ball. This was day two of a two-day lab in which his Advanced Placement physics students collected data on the behavior of a ball rolling down a ramp, on a straight track, and off the end of a ramp as a projectile. This is one of the required labs for the Advanced Placement course. According to Vince, he lectured on the target ideas for the lab such as calculating acceleration and rotational velocity, using data to create position-time graphs, and representing motion in a mathematical equation prior to the start of the lab the previous day. During the lesson I observed, the students were quickly released into their lab groups to continue collecting data on ball bearings rolling down a ramp. Students operated off a set of lab instructions that directed them how to set up the apparatus, what data to collect (in this case, position on the ramp and the time for the ball to roll a set distance down the ramp), and what calculations to do with the data (rotational velocity and acceleration). Students did have to set up the equipment on their own, and did so with minimal assistance from Vince. For the most part, students were able to collect their data and perform the calculations. When they had questions, students would ask their lab partners for help. During data collection, Vince circulated among the lab groups to check their progress. Occasionally, he would ask the students questions about the concepts in the lab but most of the interactions Vince had with students were about the accuracy of their data collection and the correctness of their calculations. At one point, he took a student's pencil and wrote the correct calculations on his lab paper.

During the lab debrief, which started almost an hour into the period, Vince reviewed some of the concepts from the lab, such as how energy is transformed, then led a walk-through of the calculations. Vince solicited answers from the students about what step came next in the calculations, and he recorded their responses on the whiteboard. This questioning was rapid and resembled an IRE structure. At times, Vince would ask a question but then answer it himself. Vince pointed out to the students what some of the "main points" of the lab were. He then provided some guidance for the writing of their lab conclusion and released them to finish their writing at their desks.

Using these notes and the memo, I assigned the following EQUIP codes for the instruction and of the lesson. The instruction in this lesson can be characterized as a mixture of developing inquiry and proficient inquiry. The students engaged in a verification lab (*instructional strategies* = 2) following direct instruction (*order of instruction* = 1). Vince primarily facilitated the students' work by setting up the task (*teacher role* = 3) and the students were active as learners for most of the lesson collecting data and completing calculations (*student role* = 3). The purpose of the lab was to demonstrate understanding of how to accurately collect data, complete calculations, and represent the data mathematically and visually, which did not require students to apply the concepts of acceleration and rotational velocity to novel situations (*knowledge acquisition* = 2).

The discourse of the lesson can be characterized as solidly developing inquiry. Vince's questions were typically at the "understanding" level (*questioning level* = 2) and were primarily focused on the accuracy of the data and correctness of the calculations (*questioning level* = 2). Vince occasionally attempted to engage students in discussion, but these were not sustained either because students did not choose to press or elaborate on each other's answers or because Vince initiated another questioning cycle before ideas could be further explored (*questioning ecology* = 2). Vince was the primary driver of discussion; he asked nearly all the questions (*communication pattern* = 2), and was responsible for any follow-up probes to students' answers (*classroom interactions* = 2).

To increase the trustworthiness of my coding approach, I met with a colleague who was familiar with ambitious science teaching and the EQUIP framework to discuss ratings of three lessons using EQUIP. Our initial inter-rater agreement across the three lessons was 90%. We resolved disagreements in three codes through discussion. The EQUIP scores for the classroom observations (N = 13) is found in Appendix E.

Phase two. Although the EQUIP framework provides one way to examine what participants are or are not doing in teaching, it does not provide insight into why that might be the case. Knowing that each participant's perceptions of the video club would likely influence his/her individual classroom experiences and that his/her intervening classroom experience would then inform his/her participation in future video club meetings, it was important to capture the dialectic between video club meetings and practice (Kazemi & Hubbard, 2008). An individual level of analysis would elucidate the mechanism by which the video club did or did not influence practice – critical information if the purpose of research is to enable interventions to be improved and implemented more widely (Lewis, Perry, & Murata, 2006).

Additionally, after having interacted closely with the participants over the course of the video club, observing their lessons, talking with them before and after an observation as well as prior to and after video club meetings, I noted that the participants each raised issues related to some of the ideas we were exploring about teaching science that the EQUIP framework did not always capture. Therefore, the second round of analysis also sought to capture nuances in participants' experimentations with practice that might otherwise remain undocumented and unexplored.

In this second phase of analysis, I drew on a range of data sources, including the pre and post interview transcripts and analytic memos; analytic memos of classroom observations that captured some of the discussions we had prior to and after observations; and video club transcripts and analytic memos. An analysis of these data served to help me construct cases about their instruction over time to understand how their goals for participation in the professional development informed instructional decisions, how their practice and their commentary on their teaching reflected ideas about ambitious science instruction being promoted in the video club, as well as what they envisioned as opportunities and struggles to enact the vision of science teaching that we discussed. These categories informed my initial review of the various data sources, but I was also open to other themes that emerged.

To construct the participant cases, I created a time-ordered matrix for each participant that included the different sources of data as they were collected over time: Pre interview, Video Club Meeting 1, Observation 1, Video Club Meeting 2, Observation 2, and so on, concluding with the post interview (Miles & Huberman, 1994). In the cells for each data source, I noted evidence from the data that highlighted their interests, struggles, perceived obstacles and opportunities, changing roles, and their goals for their teaching relative to the goal of the video club. Using this time-ordered matrix and the EQUIP codes and memos for each lesson, I wrote an analytic memo for each case (Miles & Huberman, 1994). An example of a participant case and resulting analytic memo can be found in Appendix F.

I then looked across the five participants' cases to identify common themes across participants as well as differences between participants with regard to their goals, their instruction, their perceived learnings, obstacles, and concerns going forward in relation to the model of ambitious teaching discussed in the video club (McWhorter, Delello, Roberts, Raisor, & Fowler, 2013; Ottenbreit-Leftwich, Glazewski, Newby, & Ertmer, 2010). This was an attempt to capture elements of instruction not captured by the EQUIP as well as to shed light on how each participant made sense of the video club and what that understanding meant for his/her practice. I was then able to look across cases to find patterns of similarities and differences to understand who experimented with their practice, what did they experiment with, and why.

Also, just as importantly, I wanted to understand what parts of practice were not open for experimentation, and why. I grouped elements from the cases into five categories: goals, learnings, concerns, and constraints/freedoms. I then added a brief summary of their practice. This cross case display is found in Chapter 3.

Research question three. The third research question examined the degree to which design choices influenced the desired outcomes of participation in the video club series. The video club was designed to promote participants' sustained experimentation with elements of ambitious science teaching in which teachers elicit and work on students' ideas about science phenomena informed by disciplined analysis of their practice. This design is built on two theoretical conjectures: Conjecture 1. If participants notice students' ideas and evidence-based reasoning about scientific phenomenon, then they will experiment with elements of ambitious science teaching in which teachers elicit and work on students' ideas about science phenomena; and Conjecture 2. If participants engage in critical discourses around the instructional triangle, then they will experiment with elements of ambitious science teaching in which teachers elicit and work on students' ideas about science phenomena. These conjectures were tested using the methods described in research questions one and two.

Four conjectures addressed the relationship between the video club design elements and learning processes tested by the theoretical conjectures identified above: Conjecture 1. If participants examine artifacts with high windows and depth participants will notice students' evidence based reasoning and use critical discourse; Conjecture 2. If participants engage in constructing an evidence-based explanation rubric and ideal responses they will notice students' evidence based reasoning and use critical discourse; Conjecture 3. If participants examine published and personal artifacts of science teaching, they will notice students' evidence based reasoning and use critical discourse; and Conjecture 4. If the facilitator employs moves to focus participants' attention on student thinking they will notice students' evidence based reasoning and use critical discourse.

Phase one. Because I hypothesized that the design elements would interact in ways that influenced the productivity of discussion, I needed to identify characteristics of each of the design elements (artifacts, framing activities, and facilitation) to explore how they varied for each idea unit.

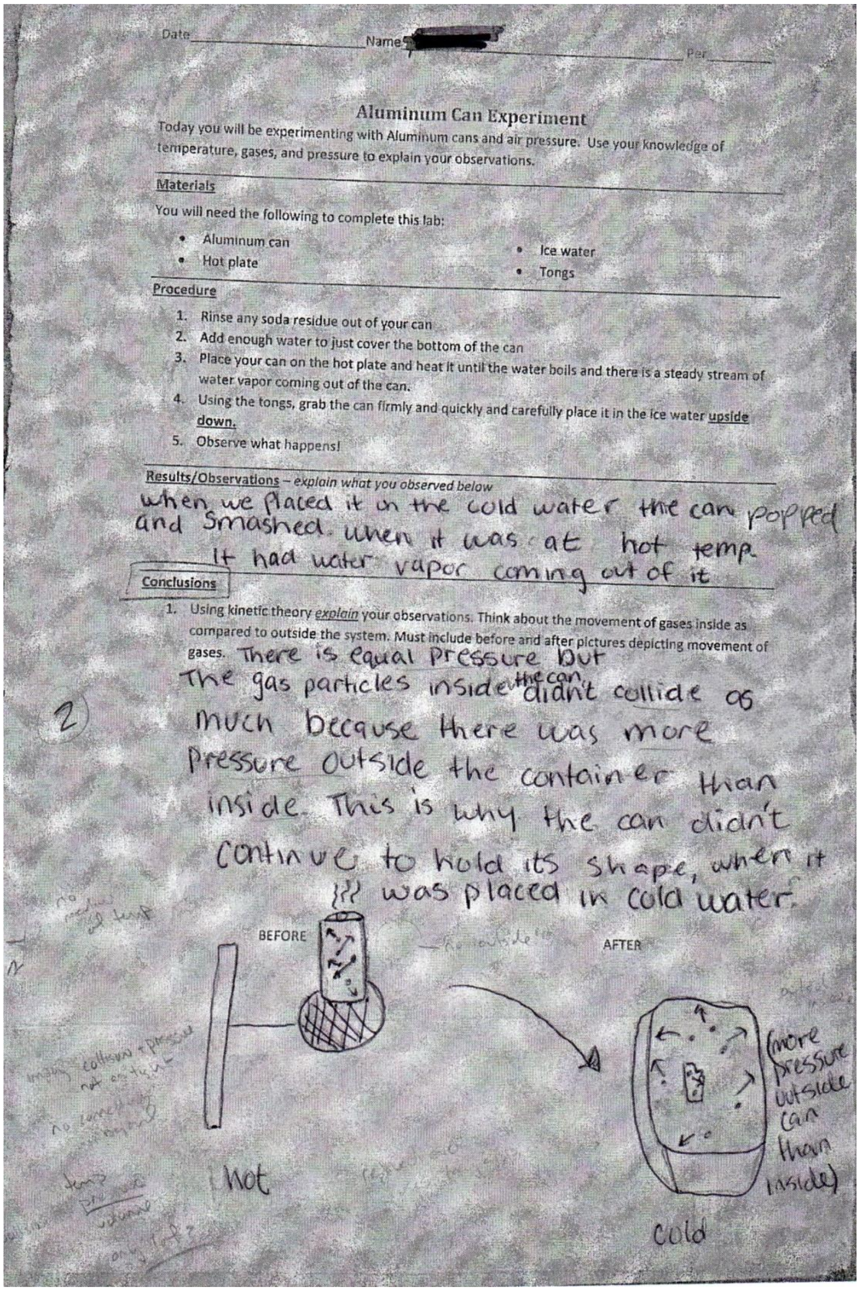
To ascertain the quality of the artifacts used in the meetings, I adapted a framework developed by Sherin et al. (2009) to characterize the windows, depth, and clarity of student thinking in the video and student work artifacts (see Table 2.9).

Table 2.9

Criteria for Characterizing Artifacts of Student Science Reasoning

Criteria	Key Question	Level Low	Medium	High
Windows into student thinking	Is there evidence of student thinking in the artifact?	Little evidence of student thinking from any source (e.g., very few comments from students; little is elicited from students)	One or more sources of information exist (writing, drawing, graphing, verbal explanation), but little detail provided (e.g., IRE exchanges dominate)	Detailed information from one or more sources (e.g., student narrates and provides written explanation and/or drawn model).
Depth of student thinking	Are students exploring substantive science ideas?	Task is routine for student; calls for memorization or recall on part of student; calls for simple procedure following when collecting or manipulating data	Some sense making applied to routine task (e.g., student questions procedure; student provides some evidence-based reasoning); task rooted in classroom scenario.	Student engages in sense-making about science, works on task at conceptual level (e.g., applies science knowledge, makes and tests a prediction, revises predictions based on observations and evidence); task rooted in everyday experience.
Clarity of student thinking	How easy is it to understand the student thinking shown in the artifact?	Student thinking not transparent (e.g., "What is that student talking about?")	Much of student thinking is transparent, though some ideas may be unclear (e.g., "I think I understand, but what did she mean by 'straight?'")	Student thinking transparent; viewer sense-making not called for or single interpretation obvious (e.g., "She gives a very clear explanation.")

The following is an example of an artifact used in Meeting 4 (see Figure 2.2). This piece of student work came from William's lesson on gas laws in which students heated an open soda can containing a small amount of water until it boiled and then quickly submerged the can into a room temperature water bath. Students were prompted to describe their observations of the can and then draw and describe what happened inside the can before and after it was submerged using what they knew about kinetic theory. This work sample includes some written evidence of student thinking. The student also included a labeled drawing that provides some additional information about their ideas. Neither the writing nor the drawings are highly detailed. For this reason, this sample was coded as having medium windows into student thinking. The prompt in this sample requires some reasoning beyond simple recall and data collection. Students were prompted to connect what they knew about kinetic theory to their lab observations. This scenario was firmly rooted in a classroom context rather than an authentic every-day experience. For these reasons, this sample was coded as having medium depth of student thinking. It was clear that the student had some understanding that molecules were moving inside the can, and the student was attempting to connect molecular collisions with pressure. However, the student contradicted herself when she wrote that there was equal pressure and that there was more pressure outside the can in the same sentence. Her written answer claimed that there was more pressure outside the can, which caused the deformation in shape, but her drawing does not show any arrows directed toward the crushed can. Her before drawing only shows arrows inside the can, but none outside the can which would be required for there to be equal pressure. This answer leaves some of unanswered questions for the observer, and for this reason, this sample was coded as medium in clarity of student thinking.



Date____________ Name [redacted] ____________ Per________

Aluminum Can Experiment

Today you will be experimenting with Aluminum cans and air pressure. Use your knowledge of temperature, gases, and pressure to explain your observations.

Materials

You will need the following to complete this lab:

- Aluminum can
- Hot plate
- Ice water
- Tongs

Procedure

1. Rinse any soda residue out of your can
2. Add enough water to just cover the bottom of the can
3. Place your can on the hot plate and heat it until the water boils and there is a steady stream of water vapor coming out of the can.
4. Using the tongs, grab the can firmly and quickly and carefully place it in the ice water upside down.
5. Observe what happens!

Results/Observations – *explain what you observed below*

when we placed it in the cold water the can popped and smashed. when it was at hot temp. it had water vapor coming out of it

Conclusions

1. Using kinetic theory *explain* your observations. Think about the movement of gases inside as compared to outside the system. Must include before and after pictures depicting movement of gases. There is equal pressure but the gas particles inside the can didn't collide as much because there was more pressure outside the container than inside. This is why the can didn't continue to hold its shape, when it was placed in cold water.

2

Figure 2.2. This student work sample resulted from a video club participant's lesson on gas laws in which students boiled a small amount of water in an open soda can, and then inverted the can into a room temperature water bath. Students were directed to describe their observations and use kinetic theory to draw and explain what was happening inside the can before and after being submerged in the water bath.

To increase the trustworthiness of my coding approach, I met with a colleague who was familiar with ambitious science teaching and the analysis of artifacts of teaching. Our initial inter-rater agreement across five artifacts was 74%. We resolved disagreements in four codes through discussion.

I then needed to identify moments in the video club meetings in which participants referenced discussions of the evidence-based reasoning rubric and “ideal responses” to the artifact prompts during their analysis of artifacts. Using the most current version of the evidence-based reasoning rubric for each meeting, I looked for key elements identified in the rubric in the artifact analysis phase of the meetings. Table 2.10 shows an example of a coded version of the rubric and the coded discussion during the artifact analysis portion from a segment of Meeting 5.

Table 2.10

Evidence-Based Reasoning Rubric and References to Key Elements during the Collaborative Examination of Artifacts

Dimension	Low Quality	Medium Quality	High Quality
Use of evidence	Evidence used by unrelated and poorly chosen		Evidence is relevant and accurate
Depth of explanation	"fragile" – does not stand up to questioning Not well thought out		"toughness" survives scientific criticism Student can respond/defend with scientific argument
Use of scientific vocabulary	Vague language, not connected to the scientific concept		Specific and academic Clear Correct Well chosen Precision of language
Claims	No, irrelevant, or unclear claim made		Clear and relevant claim made
Making connections	No connections	Makes connections but does not move beyond example at hand	Explanation connects evidence to "big idea" and moves beyond the specific example at hand

Coded Transcript Segment

Mitch	So you'd have to say it's in ***between low quality, vague language not connected***? Or it's in between I think, uh.
Laurel	Is there enough language there? It's just four words.
Mitch	I haven't asked them to explain. It says "what do you notice about the period length?" So They're not at, they're not at. Well I don't -
Facilitator	T Cause what I -
Mitch	They're ***making a claim*** right?
Facilitator	Yeah. And it's ***grounded in the data***. I mean it's -
Mitch	Right.
Facilitator	So what I thought was interesting was I looked at this one and I thought, wow, this is kind of a crummy answer, right? Like it's got this diagram, you know, OK longer length, they didn't even use like, the word pendulum, but they pointed to the proper point.
Mitch	Yeah.
Facilitator	You know, they didn't show what a period is, like by drawing like it swinging, but ok, they mention the word period, so I'm thinking, they don't have a lot of writing here, but then by looking at the ***rubric***, I thought, I think I was struggling, like, well.
Mitch	Yep.
Facilitator	They're kind of, they're ***making a claim this is an appropriate relationship*** and they're ***using some vocabulary***, like, I thought, wow. But I would probably be dissatisfied, you know, with this answer. So I know we mentioned last time one of the difficulties was like what, how do we phrase the question to get the answer that we want? Cause what do we -
Ron	Well, but is the problem that they didn't um, put it into sentence form? If that's the case then you just need to tell them for the question to use complete sentences.
Mitch	Yeah, and I have to say, that, that I'm more swayed, the more I look at it, the more I look at the ***rubric***, you know, as far as ***the use of evidence***, I mean, it is hard to ***tie their picture to their evidence*** unless you have their graph, right?
Facilitator	Mmm hmm.
Mitch	But, but as far as the ***connection that they make and the claim and the scientific vocabulary***, it, you know, the ***depth of explanation*** you would, don't know until they ***answer some, some problems*** about it, right?
Facilitator	Yeah.
Mitch	So that one is that one is, you almost need a different kind of prompt. But for the prompt I said "What do you notice about the period and the length?" ***They got that there was a relationship*** between the two, so sometimes I think as a teacher you have to back off and say this shows me that ***they knew the relationship.***

In the above example, participants identified relevant and accurate use of evidence, a "toughness" of the explanation that stood up to critique, clearly and appropriately using academic vocabulary, positing a clear and relevant claim, and making connections to "big ideas" outside the classroom as elements of a high-quality evidence-based explanation. In Meeting 5, the group analyzed a student work sample from Martin's lesson on pendulums. Students were to record the period for 10 different pendulum lengths, graph them, explain the relationship between the length of the pendulum and the period, and identify the mathematical function that best fit their data. In the above portion of the discussion, participants referenced the students' claim, how well their data matched their claim, their use of academic vocabulary, as well as the connections they made between their data, their claim, and the mathematical function. The frequency of turns at talk that included a reference to the rubric elements were tabulated for each idea unit in the five meeting sequence with each reference counting as an "instance" of the activity being leveraged. These frequencies can be found in Appendix G.

I employed a similar approach to the "ideal response" discussion. I identified key elements from the participants' discussion about the "ideal response," and then looked for those key elements in the artifact analysis phase of the meeting. Table 2.11 shows an example of a coded discussion about the "ideal response" and the subsequent analysis of the artifact.

Table 2.11

Transcript Segments From "Ideal Response" and Analysis of Artifact Discussions

"Ideal Response" Segment	
Facilitator	So maybe on the back of this, you would draw like what would you want to see kids draw, or if they labeled it
William	Draw what I want to see, not what I'm expecting?
Facilitator	Knowing that they were talking about what is sound, how does sound move, and how is sound perceived. [work on task] So what are some things that folks wrote?
William	Well in the first one uh I drew like the tuning fork and ***some lines vibrating.***
Facilitator	T mmm hmm.
William	Being struck. And I drew, um, subsequent, um, I guess***, lines away from the tuning fork that are closer together and as they get further away they get more and more spread apart and the lines outside get bigger and bigger.***
Facilitator	Can you hold it up so we can see it?
William	So here. [pointing] All right? So they get closer and they get bigger and bigger.
Facilitator	OK, so that's accounting for the change in pitch. So, Victor, what, what did you?
Facilitator	OK, well what I have I know that sound ***waves are compressional***, uh, longitudinal waves, so if what I put is for the short one, it has ***a higher frequency so you have a bunch of little lines close together then spreading apart, close together, then spreading apart*** [gesturing] so that represents what's happening to the particles of the air. For the longer one, you've got a similar situation***, you've got the particles a little bit more spread apart but in the beginning, and then spread apart a little bit more, and then come in a little bit, then spread apart, come in a little bit [gesturing]. But compared to the short one the, there's going to be more space between particles.***
Facilitator	In the which one?
Vincent	In the long one, so.
Facilitator	OK, so the wavelength is longer in, for the long one.
Vincent	Uh, yes. Sometimes I, I'm hesitant to use wavelength because ***sometimes kids think of like a sinusoidal wave and it's a compressional wave,*** so it's more like this [gesturing].
Facilitator	Oh, uh huh, uh huh.
Vincent	So yes, the wavelength would be longer this way and this way [gesturing].
Ron	More accordion.
Vincent	More accordion, exactly.

Artifact Analysis Segment	
William	The left hand side of that, it's like ok that looks good compared to the left hand side of the other one ***because they're more spread apart*** [gestures]. But then I look at the other side, [chuckles] just the right side of each of the fork, they look, ***the spacing looks similar***.
Facilitator	Yeah.
Vincent	But, I don't know. Actually, as a matter of ***fact, the one on the right looks like a little bit wider*** than the one on the left, so there, I think he's on the right track, but I don't know, for sure.
Facilitator	So if you were to ask this kid a question, and you're going to press this kid, what, what question might you ask, to get at this?
Vincent	I would actually point to both right sides and ask him you know, can you tell me a little about the ***lines*** here. And kinda, what the ***difference*** is there. Maybe even clarify oh this one should be this, and this one should be ***wider*** this one should be.
Facilitator	***So you want him to say something about the distance between the lines***.
Vincent	Yes.
Facilitator	And that would tell you he understands the ***difference in the pitch***, right? OK.

In the above example from Meeting 3, the group first discussed the "ideal response" to a prompt that asked students to draw what the sound wave would look like from two different size tuning forks. William and Vincent mentioned that they would want to see lines representing compression waves coming away from the tines of the forks; that there should be a pattern in the lines showing areas of less compression and more compression; and that the spacing between the lines would be greater for the shorter, lower pitch tuning fork as compared to the longer, higher pitch tuning fork. These elements are referenced in the artifact analysis discussion later. William and Vincent mentioned the spacing between the lines drawn around the two tuning forks, noting that there was a difference in the spacing of the lines drawn between the two tuning forks as compared to the lines on the outside of the tuning forks. The inconsistency between the compressions drawn on the left and right of each tuning fork caused Vincent and William to question how well the student understood how pitch was related to the compression pattern in the sound waves. As with references to the rubric, the frequency of turns of talk that referenced the ideal answer were tabulated for each idea unit in the five meeting sequence with each reference counting as an “instance” of leveraging. These frequencies can be found in Appendix G.

To understand how facilitation influenced the productivity of analysis of artifacts of teaching, I slightly modified an existing video club facilitation framework (van Es et al., 2014) using additional facilitation literature and moves I noticed in the transcripts (Borko et al., 2014; Coles, 2005; Gröschner et al., 2014; Zhang et al., 2011). These frameworks focus on facilitation moves associated with productive discussions about student thinking in artifacts of teaching. I created a category I called “other” to capture facilitation moves that were not described by an existing category. The “other” category included comments that did not focus on students’ disciplinary thinking or the instructional triangle. The modified framework is below in Table 2.12.

Table 2.12

Analytic Framework for Facilitation Moves Employed During Artifact Analysis

Facilitation move	Definition	Example
Orienting group to the analysis of the artifact	Launching examination of the clip and situating the artifact by providing information about the lesson goals and context.	OK, so let's look at Renaldo. Does this rubric capture some of what's happening in this conversation? She does have them briefly report out on their model. And they stay up in the room um, because they pull them back down and work on them a little some more through the unit.
Promoting an inquiry stance	Highlighting evidence from the artifact; posing a question about student thinking in the artifact; making an inference about a student idea; pressing participants to explain their thinking; clarifying and revoicing their position; offering an alternative point of view or information to promote discussion or challenge assumptions.	So they write, "the length changes the pendulum and how fast the period moves. It increases and then begins to become more consistent." So I'm wondering if he's, like, if he's thinking about speed as in the compression waves come faster, meaning like more frequent versus the speed at which the wave is traveling. (And there are no arrows pushing out on any of the diagrams right now), so there's no acknowledgement yet that there is actually pressure still inside it's just changed. What do you see in what he wrote? You're talking about the dent and there's an arrow right by that dent?

		So you want him to say something about the distance between the lines? Yeah, but, you know, if we wanted them to use a complete sentence they could say, they could add two these and this becomes a complete sentence and it doesn't really fundamentally change anything about this answer, like about the science anyway.
Maintaining a focus on the artifact	Redirecting attention to the artifact; making connections between different ideas in the discussion.	Yeah, but well what was the conversation about? What were they talking about?
Supporting group collaboration	Allowing group members time to discuss an issue by "standing back"; inviting participant's contributions; validating and affirming contributions; using humor; use of minimal responses to signal active listening.	What would you want to ask him about, Vince? I struggle with this too. Yeah, I think it's tough. Mmm hmm.
Other	Commentary on issues other than the shared artifact or about the instruction isolated from the instructional triangle.	I think a lot of the science vocabulary words, like theory, hypothesis, gravity, um, force are hard because they have been co-opted by laypeople to mean something very different. Yeah, this one group that we're not actually going to watch, but it's pretty interesting. It's like they know that this air is moving inside, and they're like, "it's a tornado."

To increase the trustworthiness of my coding, I met with a colleague who was one of the co-authors of the source framework (van Es et al., 2014). Together, we watched a 10-minute segment from one of the five meetings and discussed how we would each characterize the facilitation moves observed during the clip. Through discussion, we finalized the wording of the framework. I then used the framework to code my turns at talk as the facilitator during the remaining meeting segments in which participants examined artifacts of teaching and tabulated the frequencies of each move by idea unit.

Table 2.13 features an example of a meeting segment and how the facilitation moves were coded using the framework. In this segment during Meeting 3, the group was examining student work in which they were asked to describe how two people, Gina in the front row and Jill in the back row, would experience sound at a concert. They were specifically asked about how the bass and lead guitar would sound and how the volume of the drums would sound in both locations. Ron mentioned that he wanted to look at Jack's work sample, so I launched the examination of that artifact in line 1. I used several moves to promote continued focus on the student thinking in the artifact (lines 43, 46, 60, 55, and 61), summarized what participants observed (lines 23, 32, 42, 54, and 60), and pressed for elaboration (line 5). There was a use of humor as a supporting move (line 57), and a few instances of minimal responses (lines 7, 26, and 39).

Table 2.13

Facilitation Moves During Artifact Analysis

Line	Participant	Transcript	Code
1	Facilitator	So, Ron, what is it, what's going on with Jack's explanation	Orienting
2		that talks to you?	(launching)
3	Ron	No, I don't know exactly, I was just impressed with the	
4		drawings. Um.	
5	Facilitator	Well what do you see in his drawing that you like?	Promoting (pressing)
6	Ron	Everything's clearly labeled.	
7	Facilitator	OK.	Supporting (minimal)
8	Ron	And um, the top drawing is much better than the bottom	
9		drawing but.	
10	Facilitator	He kinda ran out of steam, or ran out of time.	Promoting (offering explanation)
11	Ron	Or yeah, but uh.	
12	Vincent	Bass, drums, cymbals.	
13	Ron	Yeah, he went all out. Like, [inaudible]	
14	William	Yeah I like I like it cause you know her, her picture, or his	
15		picture is definitely, definitely includes um, ah,	
16		information not, not that I have to interpret, he's saying	
17		the information already. He's saying well these are sound	
18		waves and they show that the bass drums are low, right?	
19	Ron	Yeah, but and in the back, in the lower drawing too actually.	
20	William	He even shows cymbals.	
21	Ron	The, the close, he shows what it looks like close up and far,	
22		far away.	
23	Facilitator	So it's labeled.	Promoting (revoicing)
24	Ron	Yeah everything's labeled.	
25	William	He even shows cymbals, you see the cymbals?	
26	Facilitator	Mmm hmm.	Supporting (minimal)
27	William	On the drums on the bottom on Jill. The lines are closer	
28		together because of the high pitch.	
29	Ron	And he does close and far away.	
30	William	And then those, the drums, the bass, the bass drum, is more	
31		spread out and so they're a lower pitch.	
32	Facilitator	So he's getting the pitch, like the compressions [gestures].	Promoting (revoicing)

William	Low and high, so he, he sorta, right? Pitch and high so it's going to be a higher pitch and lower pitch, so and he, he even shows what far away looks like versus up close.	
Ron	Mmm hmm.	
Vincent	I like the spacing, both of them use the word distorted less or more.	
Facilitator	Mmm hmm.	Supporting (minimal)
William	Yeah.	
Vincent	That, that's good.	
Facilitator	So he's using the vocabulary. And we still get the compression seems to hold up, on the drums, I'm just looking at the drums picture. Whether they're close or far away.	Promoting (revoicing)
Vincent	Mmm hmm.	
Facilitator	Although we do see, the bass drum, like there's fewer lines on the bottom picture.	Promoting (highlighting evidence)
Vincent	Mmm hmm.	
William	Yeah, I noticed just noticed that too, yeah the cymbals, there's a, there's lot of lines and then the drums, bass drums have more space between them. Low. This kid knows what's going on. Good.	
Ron	Yeah, the high.	
Facilitator	They're getting the spacing. They're getting the difference in the volumes. I haven't looked at the guitar thing very closely.	Promoting (revoicing)
William	He's probably a sound guy at [inaudible].	
Facilitator	Probably a roadie.	Supporting (humor)
William	[laughs] He's probably a roadie.	
Ron	Probably cleaning up after.	
Facilitator	So we see the spacing. One thing I wish, he does say low, medium, high, but does he talk at all? "the closer you are the less distorted," "clearest," "hear the drum clearest out of all sitting in the front row," I'm not quite sure why. They talk, they use the word distorted but they don't talk about like, what does it mean to get distorted and how does distance cause distortion.	Maintaining (redirecting) Promoting (highlighting evidence)
William	Or what is the distortion? Right?	

The final step of phase one was organizing the design element data in a summary table (Appendix G).

Phase two. After analyzing the qualities of the various design elements, I looked for patterns in their variation in relation to discussion productivity. I wrote a summary statement for each element for each meeting, and an overall statement describing the function of each design element across the five meeting sequence. I then examined their co-occurrence with the units of highly productive and less productive idea units I identified in the analysis for research question one. I looked for idea units where there were high or low frequencies of references to the framing activities and returned to the transcripts to understand the nature of the references in relation to the type of artifact being examined and the facilitation moves around those references. I wrote analytic memos for each meeting to capture interactions I noted between the design elements. I then cross referenced my pre and post meeting design notes to look for any tensions I noted between elements, and compared these to the interaction memos and looked for confirming and disconfirming evidence of these tensions and interactions. Next, I wrote a summary statement of the interactions and tensions for each meeting and compared this to the summary outcome statements from each meeting in Figure 3.1.

CHAPTER 3 – TEACHER LEARNING IN PROFESSIONAL DEVELOPMENT

Evolution of Critical Discourses

The first research question asked if participation in a video club helped secondary science teachers develop critical discourses for analyzing student thinking and reasoning in science, particularly when they analyzed artifacts of practice. Critical discourses are defined as collaborative conversations in which participants problematize practice, focus on students and evidence of their learning, and explore how teaching opens or closes opportunities for learning.

I anticipated that, given the high level of professional and leadership experience of the participants and their familiarity with professional learning community work, they would quickly engage in collaborative and critical analysis of teaching artifacts. However, as someone who participated in a professional learning community in this same district a few years prior and worked with National Board candidates in their analysis of artifacts of their teaching, I also knew the level of critique during collaborative time likely had ample room for enhancement; protocol-based examinations of practice can often become unproductive absent a continued push to focus on student thinking and its links to instruction (Curry, 2008; Little, 2006; Little et al., 2003). I conjectured that a video club design focused on the content of students' thinking about evidence would elevate participants' collaborative discussions. These conjectures were supported by research on teachers' collaborative examination of practice; over time, teachers who systematically analyze artifacts of teaching can learn to shift focus from the behavior of the teacher and the students and instead attend more closely to student thinking about important disciplinary ideas (Levin & Richards, 2011; Rodgers, 2002; Santagata, 2009; van Es & Sherin, 2002). Teachers learn to take a more interpretive stance as opposed to an evaluative stance when viewing artifacts (Sherin & Han, 2004; van Es & Sherin, 2008) and use artifact-based evidence to support their interpretations of student learning and teaching (Santagata & Angelici, 2010; van Es & Sherin, 2005). Patterns of participation can become more collaborative, focused, and constructively critical over time as well (Gröschner et al., 2014; van Es, 2012).

This particular study differed from previous explorations of teachers' collaborative examinations of artifacts of practice in the goal of the design as well as in the type of participants. Although participants in other video club designs had demonstrated changes in classroom practice, achieving instructional change was not the focus of these video clubs; the primary goal was, instead, to help teachers "learn to notice and interpret key features of classroom interactions," (van Es & Sherin, 2010, p. 156). In other video clubs, videos were not intended to serve as models for potential instruction; however in this design, the artifacts were intended to serve a dual purpose: to develop participants' noticing of student thinking as an entry into discussions of the instructional triangle, as well as to provide an example of what ambitious science instruction might look and sound like with a student population the participants would recognize as familiar to their own (Sherin & Han, 2004). Of interest here is to explore whether the divided focus on student thinking *and* instruction would change the ways participants engaged with the artifacts.

An additional difference is the type of participant involved in this video club. Several studies have documented the learning of preservice, elementary, and mathematics educators in artifact-rich professional development; less is known about in-service, high school science teachers. The difference is more than semantic. Although the participants in this group all fell under the umbrella of "science teacher," each science discipline (biology, chemistry, geoscience, and physics) requires a different California credential. This credentialing difference is distinctive compared to other secondary school departments, such as English language arts, social science, and mathematics, or even primary school teachers, whose members often share the same credential. Sharing a credential indicates a degree of disciplinary familiarity with the core concepts of each course in their respective departments sufficient for the issuing agency to deem each other fit to teach each other's courses. This degree of familiarity is noteworthy when engaging in close analysis of students' thinking about core concepts from different science disciplines. This type of analytic work typically requires participants to leverage robust content knowledge as well as pedagogical content knowledge to attend to and offer informed insights into students' disciplinary thinking (Davis, Petish, & Smithey, 2006; Kersting, Givvin, Sotelo, & Stigler, 2010; Shulman, 1986). It is therefore worth exploring whether teachers of different science disciplines can participate in deep explorations of students' disciplinary thinking outside their credentialed area of expertise in an artifact-based professional development design.

Drawing on my three part framework, I present findings about what participants attended to in artifacts of practice, how they interacted with the ideas, and how they interacted with each other across the five meeting sequence. This will be followed by an examination of how the particular ways these participants engaged in the examination of artifacts differed from patterns of engagement in other video club studies.

Findings

The central finding of the analysis of the video club participants' discourse is that the group attended closely to the substantive ideas of students' disciplinary thinking throughout the series of meetings but that over time, they came to more systematically puzzle about problems of practice that arose in their own instruction. Figure 3.1 illustrates the shift in discourse over the period of the video club meetings. First, it shows how different elements of critical discourse were coordinated as teachers analyzed various artifacts over time. Second, it reflects the proportion of meeting time that was devoted to different types of discourse. Third, it represents the nature and shifts in critical discourse from the beginning to the end of the series of meetings.

Below, I explain each of these findings in greater detail to illustrate how the group came to utilize critical discourses to more systematically analyze student thinking and their instruction over time. I begin with a summary of the nature of teacher discourse in each meeting. This serves to articulate how participants used elements of critical discourse in their examination of artifacts of science teaching. I then describe the three main discourse patterns that evolve over the study semester.

<table>
<tr><td>Meeting 1</td><td colspan="2">Highly descriptive and interpretive, collaborative focus on student thinking about the DCI in the artifact.</td><td colspan="2">Evaluative, sometimes collaborative, sometimes individual focus on correctness/incorrectness of student thinking about the DCI, effectiveness of the instructional moves in the clip and general teaching scenarios to elicit student thinking about DCI.</td></tr>
<tr><td>Meeting 2</td><td>Interpretive and collaborative focus on the DCI featured in the artifact.</td><td colspan="3">Evaluative and collaborative focus on generic instructional principles for DCI, cross cutting concepts and practices in science. Mixed use of the artifact and professional experiences.</td></tr>
<tr><td>Meeting 3</td><td colspan="4">Highly descriptive and interpretive, collaborative focus on the student thinking about the DCI in the artifact. Some collaborative exploration of specific questioning moves to gain more insight into students' thinking about the DCI.</td></tr>
<tr><td>Meeting 4</td><td>Highly descriptive and interpretive, collaborative focus on the student thinking about the DCI in the artifact.</td><td colspan="2">Interpretive and collaborative problematizing prompt design and questioning to gain more insight into student thinking about DCI.</td><td>Collaborative expressions of concerns about student motivation and persistence when engaging in inquiry based on professional experiences.</td></tr>
<tr><td>Meeting 5</td><td>Highly descriptive and interpretive, collaborative focus on the student thinking about the DCI in the artifact, with some discussion about the affordances of the task design to elicit student thinking about the DCI.</td><td>Expressing collaborative and individual concerns about student motivation and different expectations when engaging in inquiry based on professional experiences.</td><td>Interpretive, collaborative focus on student thinking about the DCI in the artifact and the affordances of the task design to elicit student thinking.</td><td>Expressing collaborative and individual concerns about student motivation and different expectations when engaging in inquiry based on professional experiences.</td></tr>
</table>

Figure 3.1. Evolution of critical discourses across a five meeting sequence. This figure represents changes in topic, stance, evidence, and participation for each phase during the analysis of artifacts. The horizontal space of each phase in the figure is proportional to the turns at talk devoted to that phase of analysis.

An Overview of the Nature and Evolution of Critical Discourses across Meetings

Interpretation and critique of student thinking and general teaching strategies based on anecdotes. Meetings 1 and 2 were characterized by two types of discourse patterns. One segment of discourse focused on a descriptive and interpretive approach to analyzing student thinking about disciplinary core ideas. But in both meetings, this type of talk accounted for only a quarter to a third of the total idea units of the meetings (see Table 3.1). Instead, the majority of the segments in both meetings were characterized by an evaluative stance to analyzing student thinking and teaching. The teachers drew on general teaching scenarios or anecdotes from their own instruction rather than using the artifacts as a point of evidence for supporting claims about learning. For the most part, the conversations were collaborative in nature, though there were some segments of talk when one or two teachers would dominate the discourse.

Table 3.1

How Participants Interacted with Ideas and Each Other in Meetings 1 and 2

Segment	Topic	Stance	Evidence	Participation	Turns of Talk
Meeting 1					
Clip 1					
Idea unit 1	DCI/ST	interpretive	artifact	medium high	55
Idea unit 2	INST/ST	evaluative	anecdote	medium high	38
Idea unit 3	INST/ST	descriptive	artifact	low	9
Idea unit 4	INST/ST	evaluative	anecdote	medium high	6
Idea unit 5	CM	evaluative	anecdote/artifact	low	17
Clip 2					
Idea unit 1	DCI/ST	interpretive	artifact	medium high	49
Idea unit 2	DCI/ST/INST	evaluative	anecdote/artifact	medium low	14
Idea unit 3	DCI/ST/INST	evaluative	artifact	high	16
Idea unit 4	DCI/OTHER	interpretive	artifact/science	medium low	15
Idea unit 5	DCI/INST	evaluative	anecdote/artifact	medium high	30
Meeting 2					
Clip 1					
Idea unit 1	DCI	interpretive	anecdote/artifact/sci	high	68
Idea unit 2	DCI/ST	evaluative	artifact/science	medium high	21
Idea unit 3	INST	evaluative	artifact	high	16
Idea unit 4	DCI/INST	interpretive	artifact/science	high	23
Idea unit 5	INST/ST	evaluative	anecdote/artifact	high	52
Idea unit 6	INST/ST/BEH	evaluative	artifact	medium high	43
Clip 2					
Idea unit 1	INST	evaluative	artifact	medium high	51
Idea unit 2	INST	evaluative	anecdote/artifact	high	20
Idea unit 3	INST/MOT	evaluative	anecdote	high	71

Note. DCI = disciplinary core idea; ST = student thinking; INST = instruction; CM = classroom management; BEH = behavior; MOT = motivation.

I provide an example from Meeting 1 to illustrate the interpretive discourse segment of the meetings. In this example, the group examined two different video clips featuring students developing their explanatory models for why a tanker truck that had been steam cleaned and sealed shut collapsed. This clip was selected because it illustrated a core disciplinary idea about gas laws, specifically the relationship between temperature, pressure, and volume. In addition, it represented the instructional approach advocated in the NGSS that was being promoted in the video club – teachers engaging in practices that elucidate students' evolving thinking and in evidence-based reasoning through modeling of observed phenomena.

Participants were engaged in collaboratively describing and interpreting the student thinking about the disciplinary core idea featured in the clip. The following is an example of a descriptive and interpretive sequence about the students' drawn models depicting the gas molecules and forces inside and outside the tanker before, during, and after the collapse (see Example 1).

Example 1

Describing and Interpreting Students' Ideas About the Tanker Truck Collapse

Facilitator	So we do see some arrows here on the bottom diagram on the last one going down.
Mitch	I thought this would happen. Look at the arrows on the bottom drawing. So these are kids who are trying to explain why it bent where it bent.
Vince	Ahh, yeah.
Mitch	So I thought about that. I thought about they're going to have some crazy side conversation about why some parts of the tank were so weak and they're going to go off on a total explanation of well there are seams in the thing that are way weaker than other seams and so they're going to stray, you know away from-
William	-That might be the case dude.
Mitch	Yeah.
Facilitator	Yeah you can, and, well, her arm is kinda obscuring it but you see, it doesn't look like the arrows are different lengths like in the middle diagram. Well, we'll see if she moves her arm maybe we can get a better look at it. But there's no arrows, right now, in the top diagram.
Vince	Yeah.
Mitch	Yes.
William	I see they're starting to, if you look at the bottom ones, right now there's more big arrows in the bottom one like there's more pressure on that side.
Facilitator	Yeah.
William	But then again, those arrows to me, to me it seems like the kids are identifying length of pressure, or pressure amount to length of arrow where then we were thinking about length of arrow is how fast it would be.
Facilitator	Well. Yeah.
Mitch	Well that's the forces. But the forces on Vince's were along, but see, this is a

common, the common misconception here is that something is pulling in from the inside. Something’s happening on the inside that’s pulling the tanker closed. And that’s the misconception. That’s the really tough sell – it’s that the forces are greater on the outside than on the inside. That’s what causes the implosion. So but it’s very, I you know this is what they say about the can or whatever-

Ron -Right.

Mitch -they think something has to be pulling it from the inside.

Facilitator Right. And there are no arrows pushing out on any of the diagrams right now.

Laurel Yeah.

Facilitator So there’s no acknowledgement yet that there is actually pressure still inside, it’s just changed. And there are no external arrows on that first diagram.

As the facilitator, I launched the analysis of this segment by describing the use of arrows in one of the drawings in lines 1 and 2. Mitch took this information, added to it by noting where the arrows were on the bottom diagram, and made an interpretation of what the arrows meant about students’ ideas about the forces working on the tanker in his next turn at talk. I returned attention to the drawing in line 13 by describing another feature of the students’ model. William took this up by noting another feature of the students’ model in line 19 and followed this with an interpretation of what that evidence might indicate about student thinking in his next turn at talk in line 22. Mitch added to this interpretation in line 27, connecting what the group saw in the drawings to Vince’s “ideal response” to the question and a common “can crush” demonstration that Vince mentioned prior to watching the clip. These cycles of describing followed by interpreting were typical of the opening interpretive sequences across all meetings. The tight pairing of describing and interpreting was similar to what I noted in a previous study of teacher candidates’ written examinations of video artifacts (Barnhart & van Es, 2015).

Though it was encouraging that in the two early meetings the teachers were engaged in critical discourse – attending to kids' thinking, interpreting, and reasoning about their ideas using evidence from the artifacts to support their analysis and collaboratively building on each other's ideas – it is also the case that this discourse pattern was not sustained in these two meetings. Of the 19 total idea units for the two meetings, only six were focused on this discourse pattern.

The more common discourse pattern early on was one in which the participants commented on the correctness of the student ideas and the effectiveness of the teachers' moves to elicit and respond to the students' ideas in the clip. This pattern can be seen in Table 3.1 when the topic is instruction and/or student thinking, the stance is evaluative and the source of evidence is the artifact; this particular pattern occurred in nine of the 19 idea units, accounting for nearly half of the total turns at talk, from Meetings 1 and 2. Evidence from the artifact served as a launching point for discussion for general teaching moves one should employ when working with students' ideas, but often drifted to general individual recommendations based on anecdotal evidence. Of the 19 idea units from the two meetings, nine included evaluations involving the instruction and five of those at least partly relied on anecdotal support.

An example of such a sequence occurred after watching the teacher press students to explain more about their before, during, and after drawings of the tanker truck collapse in the first clip. Ideally, based on the "ideal response" discussion the participants had prior to watching the clip, the students should indicate increased kinetic energy of the gas molecules due to the increased temperature caused by the steam and a balance of forces inside and outside the tanker in the “before” drawing. The “after” drawing should depict a decrease in kinetic energy as the gas cooled and a caused an imbalance of forces inside and outside of the tanker. The students featured in the clip conferred with the teacher several times to refine their model. At first, though students included some arrows in their drawings, they did not include any arrows outside the tanker in the “before” drawing and no arrows inside the tanker in the “after” drawing. The teacher in the clip asked the students questions about what their arrows represented and how their drawing explained what they saw in the tanker truck video. Through these discussions, students added to and revised their drawings to more accurately depict their evolving ideas about the forces involved in the tanker collapse.

After spending time as a group interpreting what the students’ changing models revealed about their understanding, Mitch launched a discussion about a tension he experienced when trying to lead students to “correct” ideas without “giving too much away” but being aware of the limited instructional time available. He commented:

> The teacher’s role is interesting. I can never. Is she? You wanna restate right? You wanna restate it’s their process. You wanna restate their process so that they, you know, so that you’re make, so that you’re fostering their ability to come up with it. And in that moment whenever I have those discussions like, you’re always scared you’re going to give too much away. And you’re so tempted! You’re like looking at the clock, you’re thinking about the lunch bell, they’re, I could just make this happen!

Mitch pointed to a teaching dilemma that started with a reference to the clip (“the teacher’s role is interesting,”) but then became more general. The tension between moving students along in a limited period of time and honoring their process for changing their ideas is one that could have taken place after many of the clips featured in the video club. William acknowledged this tension by adding a comment based on his experience:

> You have to skirt between, like brush, the frustration point . . . And sometimes when you go too fast and it's just like [gestures]. It's almost like playing with it, you gotta play with it. Like just a little, like tease 'em enough. But don't go overboard because they'll stop.

Both Mitch's and William's comments implied a that there was a "correct" way to go about managing this interaction: afford students time to puzzle over problems rather than giving them the answer right away, but pull them along before they get frustrated. Though focused on the relation between student thinking and instruction, the fix-it approach to the instructional dilemma marks this as an evaluative response based on a professional anecdote and not on evidence from the artifact.

Similarly, in Meeting 2, Mitch and Ron used an evaluative stance to critique the way the teacher in the second clip set up the students' investigation of mechanical advantage using pulleys, masses, and spring scales. Mitch and Ron remarked that the lesson was "chaotic" and "at this point in the lesson he's [the teacher] swamped with the logistics of what they're going to do. He's not able to get to even figure out what their experience is with the ideas." Though this does hint at some classroom management issues, the broader concern for both Ron and Mitch was the lack of access the teacher seemed to have to students' understanding of the core disciplinary idea of mechanical advantage in this investigation. However, their critique lacked specific evidence about the content of students' ideas. They followed this critique with general suggestions to give clearer directions before releasing students to lab groups and focus on data collection one day and discussion of the data on a different day because, in their professional experience, that approach is “more effective.” Both suggestions inferred that there was a “right” and a “wrong” way to go about the activity featured in the clips. This evaluative approach changed in Meeting 3.

Sustained collaborative inquiry into the instructional triangle. Meeting 3 was distinctive because participants remained largely descriptive and interpretive and focused on evidence from the artifact throughout. Table 3.2 provides a summary of the topics, stance, use of evidence, and level of participation during this meeting. Discussions of student thinking about the disciplinary core idea were interspersed with questions about instruction throughout the meeting. Unlike the more simplistic teaching corrections offered in the first two meetings, instructional moves in Meeting 3 were a subject of inquiry rather than critique. Of particular interest for the participants was how task design and questioning types featured in the clip and work samples might afford or limit windows into student thinking. As shown in Table 3.2, there were three instances of a focus on the disciplinary triangle using an interpretive stance and grounded in evidence from the artifact that were preceded by interpretation of students’ disciplinary thinking. This indicated participants’ attention to the instructional triangle by integrating specific student ideas about a particular core disciplinary ideas and specific instructional moves in relation to those ideas.

The most common focus for participants in Meeting 3 was student thinking about the disciplinary core idea. Of the 20 idea units in Meeting 3, 10 focused on student thinking about disciplinary core idea combination, and an additional four idea units focused on student thinking about disciplinary core ideas combined with elements of instruction or assessment.

This is a marked increase in Meetings 3 as compared to Meetings 1 and 2 (70% of idea units compared to 36%). The remaining six idea units were about assessment, the disciplinary core idea, or the use of science vocabulary by students.

Interpretive talk was much more common in Meeting 3. Evaluative talk in this meeting was brief and separated by long sequences of interpretive talk. Evaluative idea units averaged nine turns at talk compared to 31 turns at talk for descriptive and interpretive idea units. There was only one idea unit coded as low participation in this meeting. That particular idea unit occurred when I moved the group of off an unproductive artifact in an idea unit that lasted nine turns at talk.

Table 3.2

How Participants Interacted with Ideas and Each Other in Meeting 3

Segment	Topic	Stance	Evidence	Participation	Turns of talk
Clip 1					
Idea unit 1	DCI/ST	interpretive	artifact	medium high	32
Idea unit 2	DCI/ST/ASSESS	interpretive	artifact	medium high	14
Idea unit 3	DCI/ST/INST	interpretive	artifact	medium high	22
Idea unit 4	ASSESS/VOCAB	evaluative	artifact	medium high	4
Idea unit 5	DCI/ST	interpretive	artifact	medium high	18
Clip 2					
Idea unit 1	INST	evaluative	artifact	low	9
Clip 3					
Idea unit 1	DCI/ST	interpretive	artifact	medium high	32
Idea unit 2	ASSESS	evaluative	artifact	medium high	4
Idea unit 3	DCI/ST	interpretive	artifact	medium high	17
Idea unit 4	DCI/ST	descriptive	science	medium high	33
Idea unit 5	DCI/ST	interpretive	artifact	medium high	18
Student work 1					
Idea unit 1	DCI/ST	interpretive	artifact	medium high	65
Idea unit 2	DCI/ST/INST	interpretive	artifact	medium high	8
Idea unit 3	DCI/ST/INST/ASSESS	interpretive	artifact	medium high	49
Student work 2					
Idea unit 1	OTHER	evaluative	artifact	medium high	14
Idea unit 2	DCI	descriptive	anecdote/science	medium high	18
Idea unit 3	DCI/ST	interpretive	artifact	high	70
Idea unit 4	ST/VOCAB	interpretive	anecdote/artifact	high	36
Idea unit 5	DCI/ST	evaluative	artifact	medium high	17

Note. DCI = disciplinary core idea; ST = student thinking; ASSESS = assessment; INST = instruction; VOCAB = vocabulary.

The following excerpt from Meeting 3 illustrates how participants moved from descriptive and interpretive sequences to explore how specific questions might answer some of the questions they had about the student thinking about disciplinary core ideas (see Example 2). The first clip the group watched in Meeting 3 focused on students' written and oral explanations for what sound waves would be generated by two different sized tuning forks. I launched a discussion of this first artifact with a question referring to the "ideal response" discussion we had prior to examining the clip. The group had established that students should depict compression waves emanating from both tines of the fork, with the larger, lower pitch fork producing waves that are more spaced out (lower frequency) and the smaller, higher pitch fork producing waves that are closer together (higher frequency). Assuming both forks were struck with the same intensity, the amplitude, or size, of the waves should be equal.

Example 2

Examining Student Understanding of Tuning Forks

Facilitator	OK. So, what do we see in this drawing that we wanted?
William	The lines? Compression waves?
Vince	Yeah the separation between the lines, yeah.
Ron	Yeah.
Facilitator	Mmm hmm. Do you see a difference in the separation between the low pitch and the high pitch?
William	I see I see more lines in the high pitch than I see in the low pitch.
Vince	Yeah.
William	And to me there-
Vince	-On one side, like on the low pitch side, there seems to be more space there by compared to just the left hand sides. There's the one on the right they are closer together than the one on the left.
Facilitator	Mmm hmm.
Vince	The drawings on the right, it is kind of hard to tell, I know the one on the right has more lines than the one on the left, but-
William	-Low pitch means like low voice, right, like low?
Facilitator	Mmm hmm.
William	See that right now to me, means the kid has a higher, like wants to say a higher volume for the one on the right versus to the one on the left so pitch versus volume, I mean, I get what you're trying to say with pitch but as the student I think that he might, there might be a, there might be a kinda like, not understanding pitch and volume, right?
Facilitator	Yeah, it's unclear right now.
William	I mean he clearly writes high pitch and low pitch.
Facilitator	Yeah, "it would sound lower and have lower sound waves."
William	But if I ask him which one would be a higher volume, essentially, they would both be the same volume, at the same distance, right?
Ron	According to the [inaudible] they would both be the same sound, same amplitude.
William	Yeah, but they, but if they start at the same time, [gestures] they have the same energy, they would have the same volume at the same distance, right? Then that's a good question I would ask the student. And that would confirm or deny that they understand high pitch if it has those lines or not.

In this sequence, participants collaboratively described, interpreted, and responded to student ideas about sound using specific evidence from the clip. In lines 2–15, the group collaboratively described the details of the work, building on what each other noticed about differences in the number and spacing of the lines representing compression waves coming from the different tuning forks. In line 16, William conjectured what these details might mean about the students' understanding about pitch and volume, suggesting that the student might have been confusing pitch and volume because the student wrote that one of the forks would sound "low." It was unclear if the student understood that low pitch did not always mean low in volume as well. In line 19, he proposed a teaching move that might clarify if the student understood that pitch and volume were separate factors, making a connection between the students' disciplinary thinking and instruction.

This interaction with the artifact differed from Meetings 1 and 2 in that William's response to the teaching dilemma here — how well does the student understand that different-sized tuning forks will create different compression wave patterns — identified a problem particular to the clip. His solution was also specific to the dilemma and integrated elements of the student's understanding of a core disciplinary idea as well as a specific response to the students' particular idea. William's response to the artifact marked an integration of the elements in the disciplinary triangle informed by a description and interpretation of student thinking.

The nature of participation in this meeting also differed from Meetings 1 and 2. Every person present at the meeting, Ron, Vince, and William, contributed in the examination of the artifact, despite the fact that neither William nor Ron taught sound in their respective courses (chemistry and biology). There were two instances of cooperative overlapping talk, in lines 9 and 13, which was an indication of engagement (Tannen, 1990). Later in Meeting 3, Vince took the initiative to raise an artifact for discussion saying, “Do you guys want to talk about Lisa? I want to talk about Lisa.” In Meetings 1 and 2, I directed the activity of the group and selected the samples for examination. I provided the group more student samples than I anticipated being able to work through, but had prioritized some over others for discussion. Lisa’s intricate dot work demonstrating how individual particles behave in sound waves caught Vince’s attention, and he wanted to discuss her model; this indicated attention to how students were thinking about the core disciplinary idea as well as taking a more active role in the work of analyzing artifacts.

The combination of maintaining focus on the instructional triangle based on evidence from the artifacts, and the increased collaboration and initiative demonstrated by the group demonstrated that this group of experienced science teachers was able to use critical discourses to notice salient details in the artifacts relatively quickly. Achieving this level of effectiveness in reflection at the third meeting was unexpected and encouraging. In Meetings 4 and 5, the focus of discussion and the ways participants collaboratively engaged in the work shifted when they turned to examine artifacts from their own classrooms.

Problematizing own instruction. The discourse of Meetings 4 and 5 took a departure from the previous meetings in that the teachers began looking at artifacts from their own practice for the first time, rather than artifacts from published materials. What was noteworthy about these meetings was that description and interpretation of student thinking about disciplinary core ideas was followed by a discussion of teaching practice, but participants now problematized rather than critiqued instruction. Participants relied on anecdotes from professional experience, but in Meetings 4 and 5, these anecdotes were used as a way to puzzle out how to improve their own teaching rather than normalize problems of practice. The segments focused on individual practice tended to be less collaborative than the segments during which the group described and analyzed student thinking. A common question raised by participants was how to address issues around student persistence and motivation as they engaged in instructional practices like those modeled in the artifacts from Meetings 1 through 3.

Though the coding of the segments of talk may appear similar to that in Meetings 1 and 2, the nature of the talk is substantively different (see Table 3.3). Like in Meetings 1 and 2, participants spent a large proportion of meeting time discussing instruction related to student thinking (eight of the 15 idea units) rather than focusing on interpreting student thinking about the disciplinary core ideas (four of the 15 idea units). And, comparable to Meetings 1 and 2, a large portion of the idea units were evaluative (seven of the 15 idea units). Also similar was the mix of collaborative and individual talk. Twenty-one percent (four of the 10) idea units were coded as low or medium low participation in Meetings 1 and 2, and 27% (four of the 15) were coded as low or medium low participation in Meetings 4 and 5. Like Meetings 1 and 2, these more individualistic segments of lower collaboration tended to occur when the topic focused on instruction.

Table 3.3

How Participants Interacted with Ideas and Each Other in Meetings 4 and 5

Segment	Topic	Stance	Evidence	Participation	Turns of Talk
Meeting 4					
Student work 1					
Idea unit 1	DCI/ST	interpretive	artifact	medium high	77
Idea unit 2	DCI/ST/INST/ASSESS	interpretive	anecdote	high	77
Idea unit 3	MOT	evaluative	anecdote	high	18
Idea unit 4	DCI/ST	evaluative	artifact	low	6
Idea unit 5	INST/ST/MOT	evaluative	anecdote	medium high	21
Student work 2					
Idea unit 1	DCI/ST	interpretive	artifact	medium high	20
Meeting 5					
Clip 1					
Idea unit 1	DCI/INST/ST/VOCAB	evaluative	anecdote/artifact	medium low	22
Student work 1					
Idea unit 1	DCI/ST/INST/ASSESS	interpretive	artifact	high	53
Student work 2					
Idea unit 1	DCI/ST	interpretive	artifact	medium high	24
Idea unit 2	INST/ST/CLIMATE	evaluative	anecdote	low	7
Idea unit 3	DCI/ST/INST	interpretive	anecdote/artifact	medium high	16
Idea unit 4	INST/ASSESS/MOT	evaluative	anecdote	medium high	54
Student work 3					
Idea unit 1	DCI/ST/INST	interpretive	anecdote/artifact	high	22
Idea unit 2	ST	evaluative	anecdote/artifact	low	9
Idea unit 3	DCI/ST/INST/ASSESS	interpretive	anecdote/artifact	medium high	24

Note. DCI = disciplinary core idea; ST = student thinking; INST = instruction; ASSESS = assessment; MOT = motivation; VOCAB = vocabulary.

However, important differences exist between the first two and last two video club meetings. First, in Meetings 4 and 5, the opening descriptive and interpretive sequence about student thinking was followed by discussion about the design of the prompts used to elicit the students' ideas about science. Rather than taking an evaluative stance that indicated a "right way" to go about eliciting student ideas, as in Meetings 1 and 2, the comments of participants in Meetings 4 and 5 indicated a stance that problematized rather than evaluated teaching.

An example of this problematizing talk after a descriptive and interpretive sequence occurred when the group examined artifacts from Mitch's lesson on pendulums. Mitch's students spent two days working with pendulums. The first day was spent learning how to use the apparatus and to identify through observation that the mass of the swinging fob and the height (amplitude) from which the fob is released does not influence the time it takes for the fob to complete one swing. On day two, Mitch charged his students with collecting data from 10 different pendulum lengths of their choice, graph them, and orally report their results to the class. The students were also asked to circle the mathematical function that best represented their data and compose a written explanation of what they noticed about the relationship between the period and the length of the pendulum. Specifically, they had to note that the period increases logarithmically as the length of the pendulum increases.

After first examining a video clip and two student work samples from the day two activity, Mitch took the initiative to raise a third work sample for examination. He noted that while many students identified the "basic relationship" that the shorter the length, the shorter the period, this particular group wrote "the shorter the length, the shorter the period, so therefore the higher the string is held, the longer it will take." He noted that the students started with the correct relationship, but in their attempt to clarify their answer they mentioned something that was not in their data — string height — and that this addition was not entirely correct because amplitude has no influence on the period. There was some discussion about what students really meant when they wrote "the higher the string is held," and some alternate possibilities besides amplitude were discussed by the group. This description and analysis of the student thinking in the artifact then led to questions about the instruction and task design (see Example 3).

Example 3

Exploring the Instructional Triangle Around Pendulums

Mitch — I wonder about the medium quality. We're supposed to be getting closer to this medium quality for this. And, uh, I dunno. Is there a difference between medium and high quality in this prompt?

Facilitator — Does the prompt afford that? I don't know. You know and I think that, that is what is really tricky is a lot of what we get from the students hinges on how the prompt, the problem prompt is crafted. And unless you go through this exercise of like, well what do I really want them to know? Well do I really want them to know all that? Do I want more than that? Like, really refining in your head what it is, like being very clear about that. And then, so now, how do I need to phrase this? And sometimes it's not even the phrasing of the question, it's like, I'm having, they're engaging in the wrong task.

Laurel — Yeah.

Mitch — You can see that I changed the prompt, right?

Laurel — Yeah.

Mitch — So now it makes sense because I wanted it to be more about the line matching, and so I changed the prompt to say which one of these looks like a match to what you are seeing. And so I could have asked for more detail there, but clearly, this class probably needed just the idea of the relationship of the longer length to longer period. But I wanted to get into this discussion about is it this one or is it this one [pointing to linear and log graphs].

Mitch shifted the discussion to the design of the prompt. Mitch questioned if the way he worded the prompt provided enough stimulus for students to identify the logarithmic pattern as the matching function for this relationship — a function that Mitch explained that he wanted students to understand when discussing the "ideal response" earlier in the meeting. Many of the student groups identified the logarithmic function as the one that matched their data by circling that function on their paper, but few of their written answers indicated their understanding of the difference between a linear and a logarithmic function. Mitch mentioned in line 14 that he changed the prompt after his first period class to better elicit the connection between the collected data and the graphical representation of the relationship; this change indicated that he was not only attending to what students wrote but also making instructional decisions during teaching to respond to students. He then wondered if he should have focused his comments to students on the simpler relationship of increasing length and period rather than on the more nuanced logarithmic relationship between those variables that — as the group had mentioned earlier — the truncated range of their data didn't make obvious. The puzzling through of the student thinking about pendulums in combination with the instructional choices that elicited and responded to the students' ideas was an example of the group maintaining focus on the instructional triangle when looking at their own artifacts as well as published artifacts, as they did in Meeting 3.

By this point in the video club series, both William and Mitch attempted to integrate more drawing of explanatory models into their practice and experienced some challenges with the shift in practice. Their experimentation led to discussions about the concerns that arose when trying to implement the approaches they saw in the artifacts featured in earlier meetings. Though largely based on anecdotes from their professional experience rather than the clip, these discussions were not attempts to simplify or normalize problems of teaching as in Meetings 1 and 2, but to work through issues of concern with this new instructional approach. Mitch explained one of his concerns at the end of the discussion of one artifact:

> What seems to work, both in the work and in the videos, it is messy and what you want kids to do is talk to each other and try to clarify what they really think. And that takes all kinds of stumbling over the vocabulary and the language and

> somewhat with the drawings. There is some stumbling that is inherent. That's what learning *is* on some level. So you *do* have to throw them out there not completely prepared for the new concept because it's got to break new ground in their head and experience it. But there's almost like, some kids are going to be determined, they're going to be determined to think their way through it. And there are others who won't. You know? And how much, how much stick-to-it-ness do they have?

Concerns with student motivation and persistence were common for the participants, starting in Meeting 1. The time spent discussing them increased in Meetings 4 and 5, presumably because participants were finding these issues even more salient as they asked students to engage in work that was potentially more demanding in terms of language and persistence through multiple revisions of their work. Three different ideas units in Meetings 4 and 5 were devoted to student motivation, either in general or in tandem with instruction and student thinking compared to one idea unit in all other meetings combined. Idea units focusing on student motivation accounted for 18% of the total turns of talk for the two meetings. Student motivation and persistence clearly emerged as an instructional challenge for the participants in the study and not surprisingly as the development of student persistence in this type of practice is explicitly identified in the NGSS and the CCSS.

A Closer Look at Three Patterns of Engagement in Critical Discourses

Looking at the evolution of critical discourses across the five meetings, three noteworthy patterns of engagement arose. These patterns were participants attended to the content of student thinking and viewed elements of teaching as integrated rather than discrete throughout the meetings; participants utilized an evaluative stance and anecdotal evidence in ways to problematize teaching, particularly in later meetings focused on their own artifacts of teaching; participants were highly collaborative when interpreting the student thinking about the disciplinary core ideas but were more individual when sharing issues around the implementation of the type of instruction featured in the artifacts from Meetings 1 through 3. I will now discuss these patterns in turn.

Maintaining selective attention and integrated views of teaching and learning science. Previous video club studies indicate that even experienced teachers do not immediately attend to student thinking about content (Sherin & Han, 2004; Sherin & van Es, 2009; van Es & Sherin, 2008). Results indicated that participants in this study were able to demonstrate selective attention to student thinking about disciplinary core ideas in science starting in the first meeting. Seven of 10 idea units in the first meeting focused on student thinking in combination with disciplinary core ideas or instruction. Across the five-meeting sequence, 70% of the idea units (73% of the turns at talk) from the meetings involved discussion of student thinking. Topics such as student behavior or classroom management were rare (one instance of each).

Selective attention to student thinking is an important component of ambitious and responsive science teaching (Hammer, 2000; Windschitl et al., 2012). In order to learn from teaching, one must not only attend closely to students and their thinking but also connect these observations to broader principles of teaching (van Es & Sherin, 2008). This learning requires an integrated vision of how elements of the instructional triangle (students, instruction, and content) work together in learning environments (Berliner, 2001; Cohen & Ball, 1999; Davis, 2006).

Participants in this study, in addition to demonstrating early selective attention to students and their thinking, saw elements of teaching and student thinking as integrated, rather than isolated, an approach seen as more sophisticated according to Davis (2006). Eighty percent of the idea units (73% of the turns at talk) in the video club sequence involved discussions of at least two of the three components of the instructional triangle. Of the 38 idea units involving student thinking in the video club sequence, all but one included a discussion of student thinking in combination with another idea. Most commonly, student thinking was discussed in relation to disciplinary core ideas, instruction, and assessment.

Shifts in use of evidence and stance. In previous work studying teachers' examination of artifacts of teaching, the adoption of evaluative stance was viewed as less productive (Putnam & Borko, 2000; van Es & Sherin, 2008). Participants who framed the examination of artifacts in this way often tended to view teaching as less complex and envisioned simplistic, quick fixes for instructional challenges (Cochran-Smith & Lytle, 2009; van Es & Sherin, 2008; Weinbaum et al., 2004). For reflection on teaching to be educative, one must instead *problematize* issues surrounding the instructional triangle (Loughran, 2002). Traditionally, problematizing is associated with interpretive stance grounded in the artifact under investigation.

In this study, participants employed an interpretive stance in 26 of the 54 idea units (48%). In every case except one, the evidence used by the participants was from the artifact or a mixture of the artifact and an anecdote or a scientific theory. Participants employed an evaluative stance in 25 of the 54 idea units (46%). Of these, 18 of the evaluations were grounded in the artifact or a mixture of the artifact and an anecdote or a scientific theory. Participants relied more on an interpretive stance in the last three meetings compared to the first three meetings (26% of interpretive idea units versus 60% interpretive idea units). Participants also relied more on evidence from the artifact in Meetings 3–5 compared to Meetings 1 and 2 (53% of idea units relying exclusively on artifact evidence in Meetings 1 and 2 versus 77% of idea units relying exclusively on artifact evidence in Meetings 3–5).

In addition to shifts in the frequency with which participants used interpretive versus evaluative stance and artifact-based versus anecdotal evidence, participants shifted in the ways they used evaluative stance and anecdotal evidence across the five meeting sequence. As seen in the example from Meeting 1, participants proposed suggestions to "fix" the instruction in the clip. These suggestions were often supported by anecdotal evidence from the participants' experience. William's suggestion in Meeting 1 to "brush" and "play with" the edge of students' frustration point and Vince's assertion that the length of block schedule was a remedy for the time crunch posed by Mitch for this type of work lacked the nuance and sense of wondering aloud about teaching seen in Meetings 4 and 5. Issues raised in these later meetings were posed more as questions for the group to examine rather than aspects of instruction the group noted for critique. After an interpretive sequence looking at students' work from William's chemistry students in Meeting 4, Mitch asked, "How do you encourage students to draw things that don't leave us with questions?" There were no pat answers for this dilemma from the group. In the ensuing discussion, William, Mitch, and I all offered potential approaches to the dilemma, but these all included hedges such as "I think," "maybe," or "sometimes." The use of hedging language indicates uncertainty and recognition of the limitations of the suggestions (Toulmin, 2003). Such hedges were largely absent among the suggestions and critiques in Meetings 1 and 2.

The evidence used by participants to problematize teaching was, as in Meetings 1 and 2, based on their professional experience, but they were utilized differently. Rather than leveraged as an "I did it this way and it worked" type of example, or a "yeah, that happens to me too" type of normalizing, participants used professional accounts as ways to launch opportunities to learn from problems of practice (Horn & Little, 2010). In Meeting 5, Mitch asked, "I wonder about the medium quality. We're supposed to be getting closer to this medium quality for this. And, uh, I dunno. Is there a difference between medium and high quality in this prompt?" This question arose from the discussion of student work from his classroom. The group spent several minutes examining student work samples on pendulums and was perplexed by some of what students wrote. Mitch wondered how much his prompt design influenced the type of answers he got from students. He explained how he changed the prompt, and later speculated that he should have had a slightly different goal for the class discussion (the relationship between length and period instead of linear versus logarithmic functions). He reminded the group that his class really struggled with the graphing of the data, and wondered aloud about his choice to use probeware to collect data: "I wonder if the technology helps? You know I did this lab for years without any technology, just a stopwatch. And, so I've got that in my head too."

These questions arose out of his experiences trying to implement the types of tasks he saw modeled in the first three meetings. These sequences, though based on anecdotes, were productive ways to puzzle through problems of practice for the participants. This finding is different from previous studies that found that less productive discussion typically resulted when participants focused on anecdotal evidence rather than on evidence from the shared artifact. However, some segments based on anecdotes in this study were less productive and differed in the type of participation they fostered. Characteristics of those segments will be addressed in the next section on participation.

Shifts in participation. Participants maintained medium high or high levels of participation throughout the series (82% of all idea units). There were 13 instances of high participation across the meetings. Three of these involved challenges initiated by participants about alternate interpretations of the student thinking in the artifact. Two involved challenges initiated by participants about the disciplinary core idea under investigation in the artifact. Two involved challenges initiated by participants about the effectiveness of the instructional move seen in the artifact. Most of the challenges initiated by me occurred in Meetings 2 and 4 and were related to the topics of instruction and student motivation.

There were six instances of low participation, and the average length for these idea unit segments was shorter than the average length (9.5 turns at talk for low participation idea units versus an average of 29 turns at talk for all idea units). Three of the six low participation idea units were initiated by me in attempts to transition the group to a new topic of focus. Instances of low or medium low participation not related to my moving the group on to another artifact occurred when participants raised a concern about instruction, classroom management, or student motivation from a deficit perspective. Often these segments were based on anecdotes of professional experience in which concerns were raised about student persistence in dealing with the increased demands of the types of inquiry tasks featured in the artifacts.

At the time of this study, the communities served by the participants were over 90% minority, over 70% Title I, and over 90% non-native speakers of English. Participants viewed these demographics as challenging and expressed concern about their students' limitations to express what they knew in academic English and experience with rigorous cognitive tasks. Laurel and Mitch, the teachers of earth science students, a non-college preparatory class with high numbers of students with special needs and language support designations, repeatedly expressed concern that their students would find the tasks featured in the clips unfamiliar and challenging and would therefore be inclined to "quit." This concern was not restricted to this group, as previous work had documented that some students become frustrated with and resist efforts to employ inquiry approaches in science (Gormally, Brickman, Hallar, & Armstrong, 2009).

An example of a discussion about persistence concerns occurred in Meeting 5, when the group attempted to make sense of a puzzling answer one group wrote about its pendulum data in Mitch's class. This particular group of students wrote "the length changes the pendulum and how fast the period moves. It increases and then begins to become more consistent." The group noticed that these students might be hinting at a nonlinear relationship between the pendulum length and period with their use of the word, "consistent," but what the students meant by "consistent" was unclear. Students also wrote about the period as if it were the fob that was moving, which led to questions about whether the students understood that a period is a measure of time, not an object, which was an interesting and productive line of questioning about the reasoning featured in the student work. The discussion then strayed away from an analysis of the artifact with a comment by Ron about students' tendencies to write as little as possible: "They try to always shorthand as much as they can. Like even on our BCRs. They know they're short answers, and yet as much as possible they try to only use one or two words."

Laurel expressed agreement and further elaborated on the frustration she and Ron appeared to share (see Example 4).

Example 4

Concerns About Student Resilience

Laurel: Even last week of school I'm telling them your job is to make sure that I understand what you're thinking. Like you, I mean I know you know I know you know, but, and, and I know what you're saying, but I, I, we can have no doubt. Like no doubts. And I was like what am I saying-

Ron: -and very few kids

Laurel: -it's the very last week of school like, it's even like the. You need to make sure I know this is your paper by putting your name on it. Like your job is to communicate with me what you know. And, that, they don't see it that way. They don't they don't see that. They're just trying to get it done or-

Ron: -Mmm hmm.

Laurel: -is that just being a typical teenager or is there something else going on? I think fundamentally its resilience. Like, the lack of academic resilience to push through things that are hard. To take the time. They lack the discipline, and they lack the desire to push things through, they lack the "stick with it ness" to be like I don't understand this. Like, my students would be like, I don't get this.

Ron: Yeah.

Facilitator: Well-

Laurel: -they just scoot back and it's like woah!

Ron: It's easier to quit, it's easier just to quit.

Laurel: It's so much easier just to quit. Well like final projects. My kids aren't turning in final projects. Why? I don't know. We worked a week and a half on it. But it's not what they want so it's easier to just, eh, I'm just not going to do it.

This segment, heavily dominated by Laurel, was based on her own experiences with her students, took a deficit perspective, and did not problematize the issue of student resilience. Ron's and Laurel's contributions to the issue originally raised by Mitch served to normalize and further close down explorations of his teaching challenge. This differed from other segments that, though based on classroom experiences, provided openings for others to participate in ways that were more productive (Little & Horn, 2010). Meetings 4 and 5 included a balance of both productive and collaborative and less productive individual descriptions of instructional challenges.

Discussion

The examination of how critical discourses developed and changed during this video club raises some questions. First, it is apparent that science teachers with different credentials can learn to demonstrate selective attention to the content of students' thinking about science and connect what they notice to other components of the instructional triangle in an interpretive way that problematizes teaching. What was it about this group in this context that afforded their progression to sustained productive discussion? It should be noted that the participants in this study were very experienced and highly accomplished leaders and educators in their district. They were accustomed to working collaboratively to develop lessons and to examine common assessment data; therefore, the deprivatization of practice was already the norm for this group. However, other communities of experienced teachers do not always achieve similar levels of productivity (Curry, 2008; Gallimore, Ermeling, Saunders, & Goldenberg, 2009).

It could be that the focus on student thinking about disciplinary core ideas was due in part to the activities *preceding* the examination of artifacts, namely discussion of the "ideal response" and development of a rubric to clarify expectations for students' use of evidence in their explanations. These "ideal response" discussions likely accomplished three things: providing a frame that put students' thinking about core disciplinary ideas in the forefront; establishing clarity on the disciplinary goal for the segment; and providing an opportunity for teachers working outside of their area of expertise to develop insights into how different disciplines approach scientific concepts. A focus on core disciplinary ideas likely honed participants' attention on the details of students' thinking about science concepts. Discussions of instruction and pedagogy frequently were framed by the affordances the instructional or pedagogical approaches made for making students' thinking about the disciplinary core ideas visible. The absence of such a frame can result in a focus on more superficial aspects of classroom artifacts (Gallimore et al., 2009; Levin et al., 2009).

Establishing goal clarity was also an important aspect of promoting productive discussions. The type of instruction called for by NGSS requires clarity of instructional goal. The importance of disciplinary goal clarity has been echoed by researchers in science education; discussions without clarity on the "big science idea" can lead to ineffective classroom discussions and instructional drift (Cartier et al., 2013; Coffey et al., 2011; Windschitl et al., 2012). However, defining the "big idea" is one of the most challenging aspects of instructional design (Planning for engagement with important science ideas, 2014). It requires deep knowledge of content, PCK, and insights into how students are likely to think about the science ideas. Participants spent a considerable amount of time talking through the science when discussing "ideal responses" to the prompts given to students. All of the participants in this study held undergraduate degrees in science, but there were occasions when extended conversations were needed to clarify the science concept at issue in the lesson. In this study, the "ideal response" discussions likely served to both clarify the disciplinary goal and familiarize those participants working outside of their discipline with how students were likely to approach tasks.

Second, participants often expressed some degree of dissatisfaction with the prompt or task design after ambiguities arose in the student work. They indicated that the prompt did not stimulate a complete enough response from students to make clear what students did or did not understand. In these instances, participants seemed to be concerned with writing the perfect prompt or establishing a classroom culture in which students did not write responses that "leave us with questions." Participants seemed to view the explanatory models students drew in the artifacts as *assessments* of what students knew about disciplinary core ideas, not as a way students *come to know*. The learning that resulted from discussing ideas, committing ideas to paper, discussing them some more and revising them did not appear to be as salient as what the teachers could ascertain about what students learned from the end product.

Complicating the function of assessment is that there is no settled approach in the reform science literature for leading students toward particular answers in guided inquiry; some teachers frame the task as a "guessing game" for students in which the "correct" answer is revealed at the end, and other teachers withhold answers and judgement to permit students to develop their own understanding of the concept, even if their understanding is different than the "accepted" scientific understanding (Furtak, 2006). It could be that the participants and I approached "the problem with answers" in different ways. This disjunction was unexpected, and therefore one I was not prepared to address during the video club. The affordances of each approach do warrant exploration as they likely influenced how participants framed both their interactions with students and how they responded to what they noticed in the artifacts.

A third question related to framing is how participants viewed problems of practice contributed to the productivity of their reflection on artifacts. There were segments in which participants identified instructional challenges. In many cases, particularly in Meetings 4 and 5, which involved the examination of artifacts from their own practice, participants used anecdotes of practice in ways that opened these cases up as opportunities to learn from practice (Little & Horn, 2010). Challenges in these segments placed the "problem" with the teacher or the design and resulted in collaborative attempts to explore solutions.

Other segments that were less productive located the "problem" with the students. These segments were not framed in a way that permitted others to contribute to the exploration of the teaching or learning challenge. I did not anticipate and was not adequately prepared to address this discussion frame. Though I did attempt to challenge the comments participants made about student motivation, I often attempted to simply redirect the discussion back to the evidence in the artifact. A more productive line of questioning likely would have been to reframe the problem of practice as residing in the instruction, the curriculum, or in another realm over which participants could exert some control (Gallimore et al., 2009). One way to accomplish this could be by engaging participants in "counter-stories" in which they shared what their students could do instead of what they couldn't or didn't do might also have been a more productive way to challenge the participants to rethink their assumptions about their students and their instructional practice (Jacobs, Franke, Carpenter, Levi, & Battey, 2007).

Being prepared to confront and encourage participants to question assumptions by specifying and revising problems of practice, as proposed by Little and Horn (2010), seems critical for effective reflection on artifacts. Teachers who participate in professional development that does not utilize a framework that maintains focus on students' learning are more likely to attribute student achievement to external factors such as students' lack of motivation rather than instruction (Gallimore et al., 2009). This speaks to the importance of effective facilitation of discussions around artifacts of teaching, an issue that is just beginning to be examined in video club contexts (van Es et al., 2014) and will be explored further in Chapter 4.

Teacher learning is a complex system of interactions between the participant, his/her professional context, and the content of the professional development (Borko, 2004; Opfer & Pedder, 2011). It is also a cyclical, multidirectional process in which teachers bring knowledge gained from classroom and professional development settings back and forth between the two contexts over time (Kazemi & Hubbard, 2008). An exploration of what teachers learned from participation in this video club series would be incomplete without also examining how participants' instruction changed during the video club semester. Such an examination of the interplay between the video club and participants' instruction is the subject of the next section.

Influences on Perceptions of Science Teaching and Instructional Practice

The literature on teacher professional development identifies features that effective programs share, such as sufficient time and intensity, about the work that teachers do, active, collaborative, content-focused, and aligned with department/school/district goals (Darling-Hammond, 2008; Garet et al., 2001; Guskey, 2000; Putnam & Borko, 2000). Teachers also need opportunities to report successes and talk through challenges of practice (Little & Horn, 2010). When these opportunities are focused and structured, teachers' work is deprivatized, problems of practice are identified, and solutions are developed such that the products of a collaborative group are expected to be richer than what could be achieved alone (Little 2002; Thompson & Zeuli 1999; Vescio et al., 2008).

Engaging teachers in this type of sustained inquiry is indicative not only of effective professional development but of effective schools as well (Bolam, McMahon, Stoll, Thomas, & Wallace, 2005; Eaker & DuFour, 2015). Urban schools in which teachers regularly collaborated to inquire into their practice to develop professional capacity demonstrated sustained and significant growth in student achievement as compared to schools where this was not the norm (Sebring, Allensworth, Bryk, Easton, & Luppescu, 2006).

However, it is not a forgone conclusion that when teachers participate in these types of professional development their practice will reflect the targeted changes (Cohen, 1990; Little & Horn, 2010; Shulman & Shulman, 2004). There are a number of factors that influence the teachers' learning experience beyond just what teachers do, whom they do it with, and how often. Teachers may reject as unrealistic or inappropriate for their learning context ideas and strategies that conflict with their existing ideas about teaching and learning (Timperley, 2008). A participant's interests and expertise influence what he/she finds to be relevant in a situation; participants with different goals will notice different aspects and arrive at different interpretations of an interaction (Goodwin, 1994; Hammer & Schifter, 2001). Accounting for differences in expertise and interests are therefore important when attempting to understand what participants take away from professional development experiences.

Additionally, to understand the influence of teacher professional development on practice, attention must be paid not only to professional development tasks but also to how participants attempt to make sense of professional development and change their practice in light of previous and evolving experience (Gregoire, 2003; Kazemi & Hubbard, 2008). This includes how they recognize, respond, and make space for student ideas in the act of teaching (Coffey et al.; van Es & Sherin, 2010). Teachers often make small and incremental changes to practice, observe the impact of the change, and modify their judgements of what their students are capable of accomplishing (Timperley 2008). This, in turn, changes their participation in subsequent professional development. It is therefore, necessary to account for participants' expertise, interests, and changing experience to understand what is learned in professional development over time.

In this study, the second research question asked how participation in a video-based professional development influenced participants' thinking and willingness to experiment with practice. More specifically, I consider the nature of teachers' beliefs and perceptions of science instruction they may have developed in the video club, how they perceive their practice to have been influenced by participation, and changes, if at all, in their instructional practice. I will first describe changes for each participant in terms of how they responded to the ideas brought up in the video club by looking at their classroom practice, as well as their discourse in the video club meetings and comments in interviews over the course of the study. Next, I will discuss two patterns in experimentation I noted among the participants.

Looking Across Cases

The focus of the video club, as explained to the participants, was to understand how teachers learned about teaching science by focusing on videos of students thinking about data. Participants' discussions in the video club indicated that they were interested in and could demonstrate sophisticated noticing of the content of students' thinking in science. However, Kazemi and Hubbard (2008) mentioned that teachers can have *knowledge about* what it means to engage students in rich tasks that elicit students' ideas about disciplinary core ideas, but that *knowing how* to design and enact this type of task and maintain collaborative classroom discussions is a distinct skill. Developing teachers' *knowing* in classroom practice is developed through experimentation with ideas from professional development (Kazemi & Hubbard, 2008) so looking at participants' experimental efforts is key if one is to understand their learning.

Synthesizing participants' practice along with their contributions during video club meetings and interviews, some similarities and differences emerged (Table 3.5). First, in terms of instructional practice, with the exception of Mitch, all participants relied largely on direct instruction followed by lab exploration. Although a different instructional approach was featured in the first three video clubs - one organized around anchoring events - sequencing instruction was not a focus of the group's discussions. It makes sense then that the lesson format may not be changed as a result of participation. While lesson structure may not have changed, during classroom observations, all of the participants acted as facilitators of activities in which students were actively involved. Furthermore, in video club meetings and in post interviews, all participants expressed awareness that some tasks provided more insight into student thinking than others. They all recognized the value of and desire for more windows into student thinking, and they all expressed interest in putting more responsibility for inquiry on the students, but felt unsure how to enact this type of practice.

Table 3.4

Summary of Findings from Classroom Observations, Interviews, and Video Club Participation

	Experimenters			Postponers	
	William	Mitch	Laurel	Ron	Vincent
Classroom Observations	Longer IRE sequences common. Students were prompted to sketch conceptual ideas.	Consistent questioning of students about their reasoning. Tasks were “stand alone” explorations.	NA	Mostly concerned with correctness. Short IRE sequences dominant.	Mostly focused on correctness of data collection and calculations. IRE sequences were dominant.
Goals for Video Club Participation	“I want my kids to be number one, and the only way I can be number one is to understand what they don’t get.”	“I want to see how other teachers make those conversations [about students’ mistakes] happen.”	“They said use data, use data, so I’m trying to do that.”	“I want to be better.”	“I’m curious about me. What can I change?”
Learnings	Students’ explanatory drawings provide more information about what they are thinking. The drawings lead to more questions.	“I need to stop giving answers. I need to get out of the way.” Talk less, listen more.	“They really just need more practice. And they really need me to show them how to do it. I need to be a modeler.”	Be less “cookbook”	Use a less “cookbook” approach. Go slower, let students develop their own answers
Concerns Going Forward	Need to develop a better rubric to evaluate their arguments and evidence.	“I may not know the correct probing question yet, what’s the question to get this person to talk?”	“It is all about how well you choose your prompt.” “It is a different type of apathy, I need to understand that better.”	“I still have to figure out how to make this work”	“I’m not quite there yet where I ask them questions where it will make them think.”

Further examination of this summary across the participants revealed that three participants attempted noticeable instructional shifts (William, Mitch, and Laurel) and two did not (Vincent and Ron). A description of the ways William, Mitch, and Laurel, whom I call the Experimenters, and the ways Vincent and Ron, whom I call the Postponers, attempted to work with ideas stimulated in the video club follows.

Experimenters and Postponers

Analysis of recordings from William's and Mitch's classrooms along with student work samples indicated that they implemented classroom practices that resembled aspects of the instruction they had come to notice in the video club. These attempts to *experiment* with practice were echoed both in comments each made during the video club meetings as well as in their pre and post interviews. William and Mitch both experimented with ways to make their students' thinking more visible in different ways. Laurel, who did not participate in the classroom observation portion of the study, also reported ways her practice changed as a result of participating in the video club. I will now discuss each in turn.

William –"understanding what they don't get." William, a chemistry teacher with 10 years of experience, experimented with asking students to include drawn representations along with their written explanations of science phenomena. This was in alignment with what William stated as a goal for participating in the video club in his pre interview: "I want to be number one and the only way to do that is to understand what the kids don't get." He built upon this idea starting in the first video club meeting when the group analyzed two video clips of students revising their before and after explanatory models of a tanker truck collapsing.

William's comments during Meeting 1 suggested that he interpreted the students' drawn explanatory models of a collapsed tanker truck as a valuable source of information about student thinking. He closely attended to and interpreted details in the students' drawn explanatory models of the collapsing tanker truck, specifically what the students' arrows inside and outside the tanker meant about their understanding of molecular motion and forces. He wondered aloud about what prior knowledge students were bringing to bear on the task and how that might be influencing how the students were using the arrows in their drawings to indicate how changes in the kinetic energy of the molecules was related to changes in pressure. He then shared this insight about what the drawn representations of student ideas revealed to him as a teacher:

> Doing things like this that are extremely open ended allows the teacher to think about, reflect on, the questions that might not have been brought up by the teacher that are eventually brought up in the group. You see, when we structure let's say, an activity, you're already expecting that the kids should already know this this this and this. But when you don't hey, go ahead, have fun and you observe what's going on, these questions that you might not have thought about are actually probably more important. And it gives you an idea of what you have to assess, right? And I think it really gives teachers a lot of creativity on how to see and to tailor a lesson to the type of kids they have.

William viewed the drawn representations as providing actionable information about what students did and did not know to inform future instruction.

William began to incorporate students' drawn models into his existing instruction in ways he had not prior to the video club. In my January observation of William's classroom prior to our first video club meeting, his students were working in pairs using a computer simulation to explore reactant/product ratios and limiting reagents in chemical reactions. William defined the tasks and circulated to check in on student progress throughout the period. Students were asked to calculate reactant/product ratios and identify and define limiting reagents but were not asked to explain or show at the molecular level how limiting reagents worked or to explain what they thought was happening at the molecular level in the beaker or test tube to cause the results.

However, in the next few classroom observations, William asked students to incorporate drawn explanatory models to explain how processes at the molecular level caused their observed laboratory results. For example, students explored gas laws using an inflated balloon submersed in an ice water bath and a can filled with steam submersed in a room temperature bath. The students were asked to include the usual data tables and calculations but also a response to the following prompt: "Using kinetic theory ***explain*** your observations. Think about the movement of gases as compared to outside the system. Must include before and after pictures depicting movement of gases." These questions were designed to see if students not just understood that temperature and pressure were inversely related to volume, but also *why* that is the case. Though his questioning changed, the structure of the lessons did not – William defined the task and continued to frontload students by delivering a lecture prior to the lab experience.

When the group examined his students’ before and after drawings of the crushed can in Meeting 4, William, again, attended closely to the way students were using arrows to depict molecular movement and pressure. He observed:

> Because we are focusing on the system being the can, the arrows should be, the pressure should be focused on the can, not just kind of randomly all over the place. This person drew arrows in the can, and now the person drew dots in the can. There seems to be, that they understand that the can, and the gases have slowed down inside the can so the arrows aren’t there? But versus the size of the arrows before? Like, is the arrows on the outside actually representing the air particles outside or is it representing the water?

His analysis left him with questions about the students’ understanding of the relationship between pressure, temperature, and volume. He noted at one point that “you can’t use the video to help you,” in reference to answering the questions raised by the student work samples, indicating that he valued the students’ verbal explanations of their drawings as another source of important information about their understanding of the chemistry. He remarked that perhaps he needed to work on how to encourage students to have their written and drawn explanations work together more coherently to communicate what they knew:

> Um, you can, I guess, rely dependently too much on the drawing for the answer. The answer should be in the drawing and the written part is supposed to explain that. Whereas, I think here we’re doing, at least from my perspective, what I’m doing, is teach writing and having the kids supplement that writing with the drawing. But it

should be either way, right? Maybe a combination of the drawing and the written explanation?

William came to view a combination of written, drawn, and verbal explanations working in concert to reveal more information about what students understood. In his post interview, William mentioned that he now incorporated drawings in his bell work as a chance “to explain in more detail what they know.” He expressed the desire to incorporate more drawings “to make sure that the kids are able to illustrate what they are trying to say because writing is challenging for them.”

He also acknowledged some work he felt he needed to do to make the most of students’ drawn representations. He mentioned that he used the drawings to launch a Socratic seminar, and that it raised many questions like “Why did you draw it this way? What do you think this means? How would you draw it differently?” However, William worried that though the drawing led to “so much conversation,” the group may have “got off focus.” He therefore wanted to develop a better rubric to provide students with some guidance as to how to make their writing and their drawing work together to more clearly describe what they knew and to help him focus on the important chemistry ideas he wanted to make sure they understood.

William’s incorporation of drawn explanatory models was a relatively small — but important and manageable — change in instruction given the short duration of the video club. This modification was in alignment with his stated goal for gaining more insight into what his students understood about chemistry. The future plans he shared during his post interview indicated that this was an instructional shift he was interested in continuing to pursue and wrestle with. This willingness to continue to experiment with ways to gain more insight into students' thinking was also shared by Mitch, though it manifested in slightly different ways in his practice.

Mitch – "make those conversations happen." Mitch, an earth science, physics, and Advanced Placement environmental science teacher with 20 years of experience, also experimented with his practice during the video club. Like William, he introduced the use of visual representations, but Mitch's main interest appeared to be stimulating discussion about data. His instructional efforts during the video club centered on how to create opportunities for students to talk about science ideas.

Mitch first mentioned that his goal for participating in the video club was to learn more about students' sense-making by having them talk through their mistakes. He explained: "The process of making mistakes is how learning takes place; they have to talk about it and figure it out." He noted that facilitating discussions with students about science concepts was difficult, and he wanted to see examples of how others "make those conversations happen."

Like William, Mitch attended to the details of students' thinking in the early video club meetings. He highlighted what misconceptions the drawing revealed about the concepts. For example, he noted that because students only drew arrows on the inside of their tanker truck drawing, they thought something must be pulling it closed from the inside. He then experimented with this same tanker truck example with his classes. He showed students the same video clip and asked them to create an explanatory model of what they thought was causing the tanker truck to collapse. He then displayed some of these drawings to the class using a document camera and pointed out features of the drawings and what their use of arrows meant about that group’s understanding about temperature and pressure.

Mitch, when asked if the students had to explain their drawings to the class, said that no, he did the interpreting of the drawings. I thought this was an interesting choice given his goal for stimulating discussion. It sounded like the task Mitch designed encouraged students to talk in their small groups to develop their model, but not to be responsible for explaining their model to the whole class. However, Mitch mentioned that he noticed that stimulating discussions with students in both the first and second video club meetings was “rough going.” He remarked, “It makes it look like a really hard job watching this video. I’m like, man, that’s a hard job she’s got.” So, it could be that, at this early stage, Mitch wanted to slowly introduce both his students and himself to this new type of instruction.

In later classroom observations, Mitch began to experiment with transferring responsibility for discussing their explanatory models with the class. In his “black box” lesson, students were challenged to make observations about what happened to liquid poured into three different bottles. In each bottle, the same volume of clear liquid was poured in, but a different volume and color of liquid came out of each bottle. Mitch challenged his students to work in groups and use their observations to draw a model that explained what was happening to the water in each bottle. Mitch then asked some groups to suggest ways they could test their model for a second round of data collection. These suggestions were made during a whole-class discussion and the class then voted on what test would be conducted next so they could further refine their models. After the revision to their models, Mitch selected some groups’ models to hold up and explain to the class in the same way he maintained responsibility for explaining the tanker truck models in the earlier lesson.

In the video club following this lesson, Mitch mentioned the difficulty he experienced facilitating rich discussion with his students:

> You know, I gotta say, when I was walking around looking at their drawings and asking them questions, it was, this is maybe the hardest. It was hard to judge the depth of their explanation because it's so easy to corner them into something they haven't even thought about . . . and then you've got nothing because you've started talking and they've stopped talking.

This difficulty may be why he made the decision to report out on the models rather than asking the students to do so at that point in the semester.

By the last classroom observation, Mitch transferred responsibility to the groups to explain their data and interpretations to the class. Students were told to collect data about the period of a pendulum using 10 different pendulum lengths, graph the data, and explain the relationship between the period and pendulum length. These reporting out sessions were brief, and did not involve the presenters fielding questions from their classmates, but it did mark a shift in responsibility compared to the previous two lessons.

Mitch attributed some of the difficulty he had had with facilitating the discussion to the design of the prompt. He raised this issue several times during the last two video club meetings. He wondered aloud after one extended period of analyzing and interpreting student work, "I don't know what the right prompt is to get an answer where the kid really stretches out and starts to talk about things like applying the big idea." Mitch continued to think about this problem of practice in his post interview. He remarked that although he felt that he had made some progress, he still had room for growth, saying that the work was "very tricky," and that he "may not know the correct probing question yet to get them to talk." He added that "if I see it enough, I can do it." He mentioned that he was looking forward to an upcoming month-long professional development series he was helping to organize that he thought would help him "craft an experience" that would stimulate discussions in which he could "stop giving answers" and "get out of the way."

Laurel – "It was about putting that type of activity on my radar." Laurel, an Earth Science and AP Environmental Science teacher with 15 years of experience, elected to participate in the video club based on her experience as a National Board candidate and assessor: "I learned so much from the video portion. It is like having another pair of eyes. There is a lot of science going on that I can't see because I can't be everywhere at once." She was also looking forward to getting feedback to improve her instruction, in particular on having students look at "real data" to form conclusions about environmental phenomena.

Although I was not able to make any observations of her classroom practice, Laurels' comments in both the video clubs and pre and post interviews suggest that she was experimenting with practice as well. She attended the first and last video club meetings. During these meetings, Laurel commented most often on student motivation. She was largely silent during the analysis of student thinking in Meetings 1 and 5 except to praise students' efforts. In Meeting 1, she commented on students' models of the tanker truck collapse:

> I'd just be happy that they are A, engaged, and B, they're grasping but they're drawing and like trying to figure things out. Like the fact that she was like I think it's weakened

> the metal. She's probably seen that before. Where metal got hot and bends a little bit better? And, yeah, that's totally way off of what happened, but at the same time like she's scaffolding and stuff like she knows.

Laurel made a similar comment in Meeting 5, commenting on Mitch's students' work saying "the fact that they are coming to a conclusion is a win." In this same meeting, she reacted to a students' four word answer to a prompt about the relationship between pendulum period and length saying that her students lack the "academic resilience" to push through hard tasks. "Academic resilience" was something she mentioned in her pre-interview. She wondered how to increase their "academic resilience" noting "that is a big question – something I want to figure out."

Although I was unable to conduct any observations of Laurel's classroom during the study semester, Laurel's comments in her post-interview about her practice over the study semester also reflected her continued concerns with motivation and providing opportunities for students to work with data. In her post interview, she described attempts she made to "provide opportunities" for her students to reason through data. One opportunity she provided was a case study on the Salton Sea. This was an assignment Laurel reported that students were "energized" by. Students read an article, identified the pros and cons for refilling the sea, then took a position on the issue. She explained:

> I really had to be a huge cheerleader. The reading part itself was probably the hardest for them – the discipline it took to read 25 paragraphs . . . I can barely get them to read four. But they were interested in it. They got to choose what to do. It was relevant. I

taught them how to mark up the text. I gave them to tools they needed, they got to work as a team.

She reported taking a similar to a project she designed in which students researched the pros and cons of a controversial issue in California. She also described working with colleagues to design a performance task for her Earth Science students. Students had to read five articles about climate change and identify talking points for the President of the United States about a policy position. She mentioned that she wasn't entirely satisfied with how students did on this task but saw it as an important step in improving their critical thinking skills. She attributed their struggles with making clear claims and leveraging relevant evidence to lack of practice and modeling, a more nuanced position than what she expressed during the video club meetings:

> The truth is the reason they couldn't do it was because they'd never been taught how . . . It's not that they didn't want to do what I asked them to do. There was no rebellion there. It wasn't like that. It was just that they, honestly, many of them just did not know where to start . . . They really just need more practice.

She expressed interest in continuing to refine these tasks, mentioning that the development of the evidence-based reasoning rubric revealed shortcomings of the prompt. She explained, "You make this great question you think is awesome, then you write the rubric and you realize your rubric isn't awesome." She also noted that making the prompt relevant was critical for engagement saying, "if you choose your article poorly, they're not going to be interested in it."

Reflecting back on the video club itself, she said participating put evidence-based reasoning tasks "on the radar" for her. To her, that meant looking for more tasks of that type, and being “more attentive to asking the students to do that and really try to hone that so that they’ll become more of an anchor in my classroom.” Continuing to refine and focus on evidence-based tasks was something she saw as a continued focus for her professional growth.

Ron and Vince – “I still have to figure out how to make this work.” Although Ron and Vince noticed details of students’ thinking in the video club, observations of their classrooms did not reveal changes to practice over the course of the video club. In their post interviews, both acknowledged that they did not feel that they changed much and were dissatisfied with their current instructional practice. Interestingly, both described their current practice similarly as being too “cookbook” (Ron) and “cookie-cutter” (Vince). That said, they both also shared a desire to change to more student-centered instruction.

The question this raises is, if both were dissatisfied with their practice and wanted to change, why did they not experiment? I identify two explanations based on their comments in interviews and video club meetings: goal misalignment and curricular constraints.

Ron’s and Vincent’s goals differed from the other participants’ in two ways. First, William, Mitch, and Laurel’s goals were centered on students thinking and experiences. Participants’ goals and beliefs frame what they notice in artifacts (Hammer & Schifter, 2001; Levin et al., 2009). William’s frame involved getting more information about what students understand, so he viewed the video club artifact examples as additional sources of data about their thinking. Mitch’s goal was to “make conversations happen,” so he viewed the video club artifact examples as ways to promote and sustain discussion about science ideas. Their classroom experimentation aligned with their personal, specific, student-centered goals for participation in the video club as well as with the articulated goals of the video club.

A second way in which Ron's and Vincent's goals differed was a lack of specificity in purpose. Vincent mentioned that he was "curious" about himself as a teacher and wondered what he could change. Ron was similarly vague, stating that he "just wanted to be better." This lack of specificity may have not provided the framing needed to take action on the elements of the instructional triangle being discussed in the video club meetings (Gallimore et al., 2009).

Vince and Ron also mentioned particular constraints in their teaching contexts. Vincent, in both interviews and discussions following his observations, expressed concern with preparing his students for the AP physics exam. The exam defined both the types of lab activities and the way in which those lab experiences were structured for Vincent. Labs were always preceded by a lecture and questioning focused on correctness of calculations and verifying the setup of equipment. Ron occasionally posed a question during the lab debrief about conceptual understanding, but often ended up answering his own question. During the video club semester, he experimented with using iPads and probeware to collect and graph data. This particular change *was* in alignment with his goal of preparing students for the exam because it did not alter the type of lab he ran and made the task of data collection and analysis "easier" for students by providing more data points and more accurate measurement.

Ron mentioned a different constraint. Like Mitch and William, he expressed relief at not being held to the pacing guide driven by the CST, but acknowledged that he "did not change much" in the way of his instructional approach over the semester. He explained that he already wrote his lesson plans for the semester prior to the start of the study. In the observed lessons, activities were frontloaded by a lecture the previous day. Ron would ask students to explain their answers, but would not press them to elaborate or use them to launch further discussion.

He also mentioned, both in post interviews and during video club meetings, that he "didn't know how to use drawings in Biology." Although he saw merits in their use, he struggled to find scenarios in which a drawing would be a helpful to understand what students knew about concepts addressed in the second semester of his biology course.

Interestingly, both revealed that they wished either the timing or their choice of class to feature in the video club was different. Vincent said that he wished he had used his earth science class as part of the study because he had more freedom with that curriculum. Ron indicated that he wished that the study had taken place during first semester because "the topics were better." Both felt these curricular constraints curtailed their ability to experiment.

This is not to say that Vincent and Ron did not perceive that they benefited as instructors through participation in the video club. Both expressed dissatisfaction with their "cookbook" approach and mentioned their need to give more responsibility for thinking and more opportunity for struggle over to their students. Previous work shows that changing practice is an incremental process in which teachers often make small changes then observe the results before undertaking more (Reiser, 2013; Star, 2015; Timperley, 2008). It may be that for these two teachers the video club did not provide enough opportunity for these teachers to feel empowered to experiment in ways that were workable for their practice.

Discussion

The work of participants in this study both in the video club and in their classrooms during the study semester reveals two key issues. First, teachers can recognize the value of making student thinking more visible and want more access to student's reasoning, but may perceive themselves and be ineffective at eliciting student thinking. This particular professional development design was effective at helping participants to know *about* student thinking. All participants demonstrated sustained attention to the content of students' ideas during the video club. All expressed the value and desire to design instruction to reveal more of students' ideas in their post interviews. This particular video club design appears to have been less effective at helping participants know *how* to act on their instructional goals to make student thinking more visible.

Additionally, the instructional moves needed to elicit student thinking are different than the instructional moves needed to leverage these ideas to sustain discussion about disciplinary core ideas and cross cutting concepts in real time (Windschitl et al., 2012). This would require a different phase of professional development, one in which participants would continue to collaboratively engage in puzzling about practice through the examination of artifacts from their own classrooms. Analyzing artifacts in collaboration with those who share similar instructional contexts reaps the benefits of increased attention to the instructional triangle as well as constructive critique from colleagues when compared to working in isolation (Seidel et al., 2011). We know that teachers require more than just an opportunity to "try out" solutions to problems of practice; they need sustained time and support until they "figure out" problems of practice (Gallimore et al., 2009).

Given the time constraints of the video club, this second phase of support was not feasible in a professional development that only spanned one semester. However, reducing the amount of time devoted to honing participants' noticing to attend to student thinking would likely have resulted in less conviction on the part of the participants to change instruction to make student thinking more visible. Change that is dictated to employees is rarely sustained or implemented with fidelity (Wakamatsu, 2009). Securing the “buy-in” and understanding of participants in the value of increasing windows into student thinking through their own experience was a critical component of the video club design. Developing this particular type of noticing and the component skills takes time (van Es & Sherin, 2009). The three skills of describing, analyzing, and responding to student thinking are linked in such a way that they build on each other; one cannot effectively respond to student thinking without first demonstrating skill in both describing and analyzing the substance of student thinking (Barnhart & van Es, 2015). Developing the ability to learn from students’ thinking extends professional learning and improvement of practice beyond the end of formal professional development (Jacobs et al., 2007). Shifting the focus of the video club to changing practice prior to mastering the component skills of reflection would therefore likely be unsuccessful. What is required, then, is an extension of the video club rather than a re-allocation of existing time.

Second, lack of clarity and alignment between the goals of the individual participant, the professional development designer, and the school and district may have also limited the effectiveness of professional development. All the participants in this study expressed a desire to improve and voluntarily gave of their time to participate in after-school video club sessions. Despite this commitment to professional learning, only two of the five participants experimented with explicit instructional changes during the study semester. The personal goals of three teachers who experimented were specific to gaining insight into and responding to students’ ideas or building more opportunities to develop students’ reasoning. Two other participants’ goals — the postponers — were very general and not specifically tied to students’ ideas or reasoning. It is perhaps not surprising, then, that the experimenters responded differently than the postponers given the difference in their goals. Experimenters likely found the activity in the video club highly relevant and tightly aligned with their personal learning goals while the others, less so (Hammer & Schifter, 2001).

Organizational change literature identifies the importance of SMART goals, those that are specific, measurable, achievable, results-oriented, and time-bound (O'Neill, 2000). Much of the literature on school improvement emphasizes setting SMART goals for organizations or even departments, and the importance of aligning professional development goals with institutional goals (Desimone, 2009; DuFour & Eaker, 2005). Ironically, the teacher professional development literature appears to largely neglect the importance of teachers' *personal and individual* goals for learning during the design phase of the professional development model — despite overt calls in the literature for teachers to attend to the personal and individual needs of their students as learners and differentiate instruction as appropriate (Wigfield & Eccles, 2000; Gay, 2002). It seems advisable then for professional developers to take the time to not only account for the *institutional* goals of the sites in which their participants work, but also the personal goals of the participants during the initial design phase; the designer must also build in ways to challenge and refine participants' goals that are not initially focused on the capacity for all students to learn (Timperley, 2008).

Achieving this alignment would require working with individual participants to clearly define and refine their learning goals, but it would be time and effort well spent. Rodgers (2002), in her review of Dewey's explanation of disciplined reflection, identified critical attitudes for productive reflection as whole-heartedness, directness, open-mindedness, and responsibility. Similarly, Shulman and Shulman (2004) identified clarity of vision and motivation for improvement as key elements of learning from teaching. Phelps and Spitzer (2015) reported that what teachers value about learning from teaching influences what they actually learn from studying teaching. Taking the time to gain clarity on one's personal professional goals may activate and bring to the fore these important attitudes to maximize participants' learning from professional development. Further, Borko and colleagues (2011) described a continuum of more specified to more adaptive professional development models. Although it has the benefit of a clear, targeted, and cohesive experience, highly specified professional development suffers from potentially not appearing relevant or relatable to participants (Borko et al., 2011). Clarity of the experience may not be worth the tradeoff if participants choose not to experiment with the professional development ideas the design intends to provoke due to lack of perceived relevance or coherence with individual goals. This avenue is certainly worth further exploration.

Limitations

This examination of the influence on a video club on secondary science teachers' learning and practice has several limitations. First, the video club was restricted to five meetings with five participants over the course of one semester. Not every participant was able to attend each meeting, and I was not able to observe each participant in his or her classroom on a regular basis. I also asked to view a particular type of lesson, so it is unclear how reflective the observations that were made accurately reflect the participants' practice. This limited the data and therefore the opportunity to understand each participant's experience with the video club and the influence on their practice.

Additionally, this group was composed of a particular set of individuals teaching a particular discipline in a particular district with a particular facilitator. Each of these elements greatly influenced the activity and participation in this video club (Borko, 2004). The generalizability of findings from this video club to other video club settings is, therefore, limited.

An additional limitation is that the artifacts the group examined during the video club offered varying levels of complexity and windows into student thinking. The windows and depth of the student thinking in the artifacts influences the type of discourse in a video club setting (Sherin et al., 2009). Although I aspired to select artifacts featuring high windows and depth of student thinking to promote rich discussion, this effort was sometimes at odds with the desire of the participants to examine artifacts from their own practice and with the need to provide artifacts with disciplinary core ideas with which at least some of the participants were familiar. The level of critical discourse in each meeting was influenced not only by the development of the participants’ noticing but also by the quality of the artifact under investigation.

CHAPTER 4 – Professional Development Design and Design Tensions

Introduction

The third research question addresses the process of designing, implementing, and revising a professional development program to address a local problem. More specifically, how did the design elements of a video club focused on developing teacher noticing of students' disciplinary thinking influence the participant's experimentation with ambitious science teaching practices. In this study, the problem was the instructional challenges associated with addressing the new NGSS and CCSS standards. I will first elaborate on the initial problem and the proposed design solution to address the problem. I will then discuss how the design elements interacted to influence the video club meeting outcomes.

The goal of design research is to create learning environments to address a complex educational problem, to understand how those designed environments work in particular settings, and also to develop some broader understanding about teaching and learning (Edelson, 2002; Plomp, 2013; Sandoval, 2014). This particular study is a validation study, one in which the researcher studies attempts to better understand a particular learning ecology, namely a video club for teaching. This approach treats the learning environment as a complex system of interacting elements, with the research focus not just on the elements of the design, but how tasks, tools, and talk work together to support learning (Cobb, et al., 2003; Sandoval, 2014).

Testing the Conjectures

A particular affordance of conjecture mapping is that it allows the designer to make explicit the ideas about how the elements of the proposed design are intended to interact to make learning happen so they can be tested (Sandoval, 2014). Conjecture maps contain two sets of testable conjectures: Theoretical conjectures that connect mediating processes to outcomes and design conjectures that connect the embodied design to mediating processes. I will first discuss the testing of the theoretical conjectures, and then I will discuss testing of the design conjectures displayed by the video club conjecture map in Figure 4.1.

Theoretical Conjectures

This design was built on two theoretical conjectures represented by the arrows between the mediating processes and the video club design outcome: Conjecture 1. If participants notice students' ideas and evidence-based reasoning about scientific phenomenon, then they will experiment with elements of ambitious science teaching in which teachers elicit and work on students' ideas about science phenomena; and Conjecture 2. If participants engage in critical discourses around the instructional triangle, then they will experiment with elements of ambitious science teaching in which teachers elicit and work on students' ideas about science phenomena. Because this method treats the design as a system, both mediating processes are hypothesized to jointly produce the outcome and so will be addressed together (Cobb et al.,2003; Sandoval, 2014).

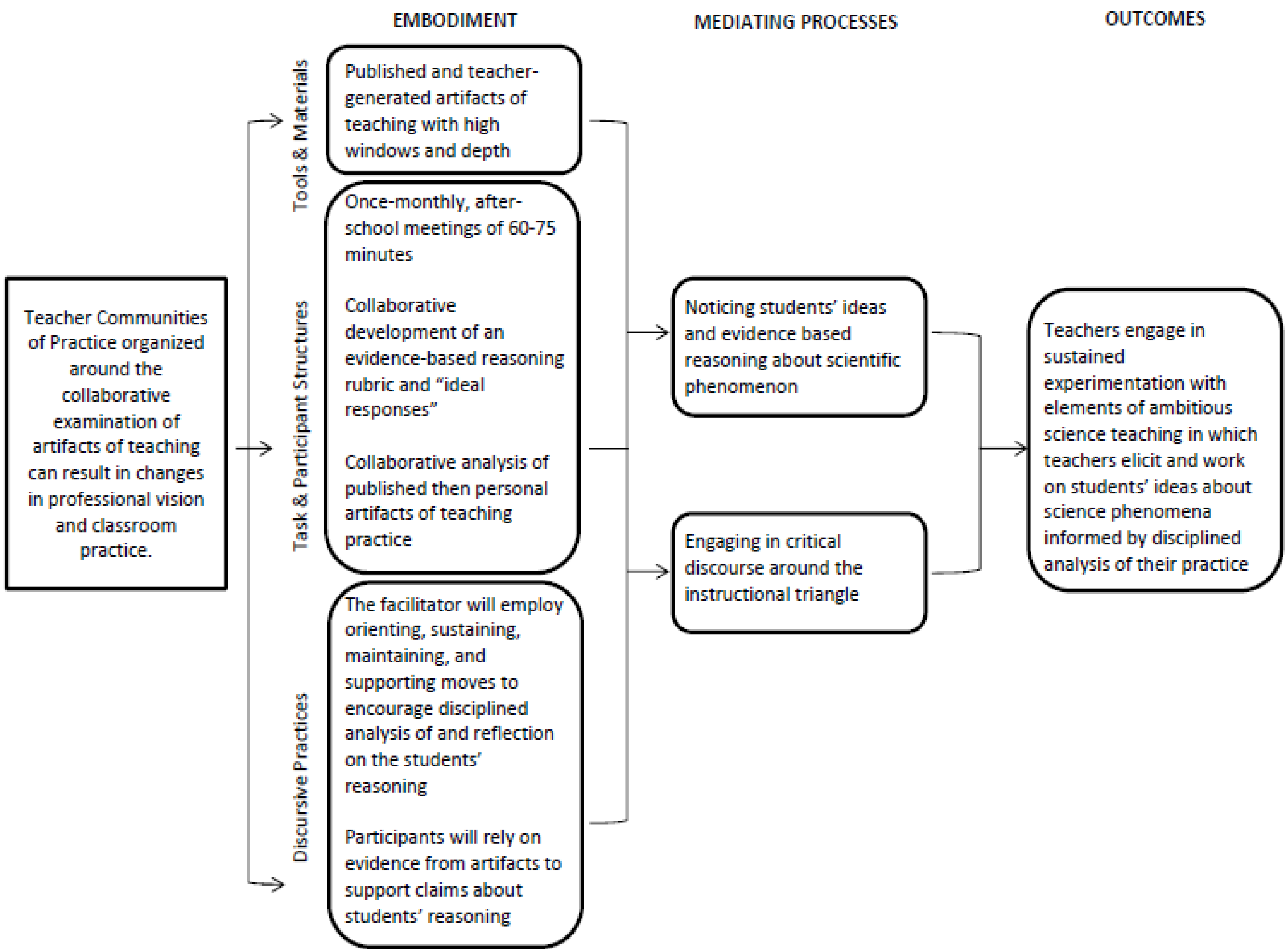


Figure 4.1. Design principles and conjecture map for a video club promoting ambitious science teaching.

Both mediating processes — teacher noticing of ambitious science teaching and engagement in critical discourses around the instructional triangle — were tested by research questions 1 and 2. The findings, based on analyses of video club transcripts, participants' interviews, and videos and field notes of their recorded lessons are discussed in detail Chapter 3. The results indicate that participants did demonstrate noticing of students' disciplinary thinking throughout the video club. The evolution of what participants noticed is represented in Figure 4.2. Participants' noticing of student thinking became more interpretive over time and grounded in specific evidence of student thinking about core disciplinary ideas from the artifacts. Video club discussions around artifacts started with descriptive and interpretive sequences about student thinking of core disciplinary ideas, then transitioned to include related instructional issues. Often these instructional issues involved how the prompts students responded to either opened up or limited the opportunity to make student thinking and reasoning visible. Participants came to use evidence from the artifacts as well as anecdotes from their professional experience to problematize issues around the instructional triangle in later meetings when investigating artifacts from their own classrooms.

<table>
<tr><td>Meeting 1</td><td colspan="2">Highly descriptive and interpretive, collaborative focus on student thinking about the DCI in the artifact.</td><td colspan="4">Evaluative, sometimes collaborative, sometimes individual focus on correctness/incorrectness of student thinking about the DCI, effectiveness of the instructional moves in the clip and general teaching scenarios to elicit student thinking about DCI.</td></tr>
<tr><td>Meeting 2</td><td>Interpretive and collaborative focus on the DCI featured in the artifact.</td><td colspan="5">Evaluative and collaborative focus on generic instructional principles for DCI, cross cutting concepts and practices in science. Mixed use of the artifact and professional experiences.</td></tr>
<tr><td>Meeting 3</td><td colspan="6">Highly descriptive and interpretive, collaborative focus on the student thinking about the DCI in the artifact. Some collaborative exploration of specific questioning moves to gain more insight into students' thinking about the DCI.</td></tr>
<tr><td>Meeting 4</td><td colspan="3">Highly descriptive and interpretive, collaborative focus on the student thinking about the DCI in the artifact.</td><td colspan="2">Interpretive and collaborative problematizing prompt design and questioning to gain more insight into student thinking about DCI.</td><td>Collaborative expressions of concerns about student motivation and persistence when engaging in inquiry based on professional experiences.</td></tr>
<tr><td>Meeting 5</td><td colspan="3">Highly descriptive and interpretive, collaborative focus on the student thinking about the DCI in the artifact, with some discussion about the affordances of the task design to elicit student thinking about the DCI.</td><td>Expressing collaborative and individual concerns about student motivation and different expectations when engaging in inquiry based on professional experiences.</td><td>Interpretive, collaborative focus on student thinking about the DCI in the artifact and the affordances of the task design to elicit student thinking.</td><td>Expressing collaborative and individual concerns about student motivation and different expectations when engaging in inquiry based on professional experiences.</td></tr>
</table>

Figure 4.2. Evolution of critical discourses across a five-meeting sequence. This figure is described in further detail in Chapter 3.

However, noticing of student thinking of core disciplinary ideas using critical discourses did not always translate to participants' experimentation with elements of ambitious science teaching to make student thinking more visible in their own classrooms. The analysis described in Chapter 3 found that two participants attempted adjustments to instruction to make student thinking more visible but did not shift teacher-student discourse to press and probe students about the disciplinary thinking elicited by the changes in instruction. The previous analysis showed that the other two participants cited constraints with work flow, timing of the study, and perceived curricular constraints as reasons for not acting on their desire to make student thinking more visible. The three participants who experimented stated professional goals related to eliciting and working with student ideas, and the two participants who did not experiment communicated much vaguer professional goals for engaging in the video club. All participants acknowledged wanting greater access to student thinking during instruction, but expressed concerns about their efficacy in doing so. These results indicated mixed success at achieving the design outcome. An exploration of how the elements of the embodied design interacted with each other will help elucidate this result.

Design Conjectures

Elements of the tools, task, and talk were designed to result in the mediating processes of teacher noticing of students' disciplinary thinking and critical discourse around the instructional triangle. Four conjectures addressed the relationship between these elements and learning processes: Conjecture 1. If participants examine artifacts with high windows and depth, they will notice students' evidence-based reasoning and use critical discourse to analyze the instructional triangle; Conjecture 2. If participants engage in constructing an evidence-based explanation rubric and ideal responses, they will notice students' evidence-based reasoning and use critical discourses to analyze the instructional triangle; Conjecture 3. If participants examine published and personal artifacts of science teaching, they will notice students' evidence-based reasoning and use critical discourses to analyze the instructional triangle; and Conjecture 4. If the facilitator employs moves to prime, focus, and maintain participants' attention on student thinking, promote collaborative participation and the use of evidence to support their interpretations, and challenge existing ideas, participants will notice students' evidence-based reasoning and use critical discourse to analyze the instructional triangle.

These embodied elements do not function as discrete parts of the design, but as interconnected elements of a learning ecology (Cobb, Confrey, diSessa, & Schauble, 2003). To understand how these elements "function together to support learning" (Cobb, Confrey, diSessa, & Schauble, 2003, p. 9), one should be explicit about how the theorized elements interact (Sandoval, 2014). The theorized interactions between embodied elements to produce the learning results described above are displayed in Figure 4.3.

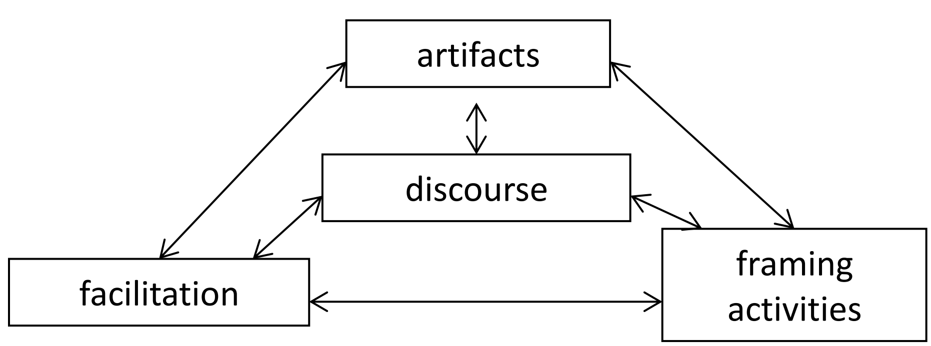


Figure 4.3. Theorized interactions between elements of embodied design structures and elements in the video club design's context.

I conjectured that three design elements — the artifacts used, the framing activities employed prior to working with the artifacts, and the facilitation moves — would all interact to influence discourse in the video club and each other. Artifacts with high windows and depth provide greater affordances for interpretive, evidence-based examinations of students' disciplinary thinking as compared to artifacts with low windows and low depth (Sherin et al., 2009). Because Sherin and colleagues (2009) found that artifacts with high and low clarity both had affordances for productive discussion, clarity was not used as a selection criterion for artifacts used in the video club meetings.

How participants' frame their analysis of artifacts also influences what they notice (Levin et al., 2009). Activities that frame participants' analysis of the artifacts to focus on understanding how students are thinking about disciplinary core ideas and using evidence-based reasoning should result in richer, more interpretive discussions than alternate frames that may encourage participants to focus on other aspects of teaching and learning (Borko et al., 2011). Doing so involves taking the time to think through the disciplinary core ideas in the artifact, what participants' expectations were for students' disciplinary reasoning, and understanding the context of the artifact in the larger instructional sequence.

In addition to highlighting artifacts and activities, researchers have identified several facilitation moves that contribute to high-quality discussion— maintaining a focus on the student thinking, pressing participants to focus on evidence, probing to elaborate on their reasoning, confronting assumptions about practice, pursuing productive lines of inquiry about practice, as well as maintaining a degree of trust and intellectual safety (Coles, 2013; Gröschner et al., 2014; van Es et al., 2014; Zhang, Lundeberg, Koehler, & Eberhardt, 2011). Additionally, the facilitator needs an awareness of participants' expectations for learning, as well as how each participant explores ideas raised during the professional development in his or her own practice over time (Gregoire, 2003; Kazemi & Hubbard, 2008).

I now turn to an analysis of how artifacts, framing activities, and facilitation were used with participants across the meetings and how their interactions related to how they noticed students' evidence-based, disciplinary reasoning about science, and use of critical discourses referenced in Chapter 3.

Overview of design elements and meeting productivity. An overview of the design elements in all meeting phases is represented in Table 4.1. With regard to the influence of artifacts, the proportion of highly productive idea units was not related to the quality of artifacts, though artifacts of different qualities served different purposes in each phase. High quality artifacts were used because of the ample student reasoning on display in Meetings 1 and 3. Meeting 2 featured a medium-quality life science artifact to increase participation of everyone in the group, and a low-quality artifact as an example of how task design limits access to student thinking. Medium and low-quality artifacts were used in Meetings 4 and 5 to feature participants' own work. With respect to framing activities, participants came to draw on the both the ideal response discussions and evidence-based reasoning rubric more frequently in later phases. With respect to facilitation, promoting a focus on the artifact and supporting participation were the dominant moves throughout the video club, with shifts in the frequency of different types of promoting moves over time. Pressing, revoicing, and offering alternative explanations were more frequent in Phases 2 and 3 than in Phase 1. In the following sections, I will discuss each meeting and the various design elements in detail then describe the interactions between the elements of the design.

Table 4.1

Overview of Design Elements across Three Meeting Phases

Discourse	Descriptive and interpretive analysis of students’ thinking using evidence from the artifact followed by evaluations of teaching and correctness of students’ ideas	Sustained descriptive and interpretive analysis of students’ thinking and affordances of instructional moves using evidence from the artifact	Descriptive and interpretive analysis of students’ thinking using evidence from the artifact followed by problematizing of their own instruction
Artifact	Meeting 1: High windows & depth Students discussing drawn models about relationships between pressure, temperature, and volume of gas (selected to model evidence-based analysis of student thinking) Meeting 2: 1. Medium windows & depth Students discussing relationships between respiration & reproduction in yeast (selected to increase participation) 2. Low windows & depth Students collecting data on mechanical advantage (selected as a non-example)	Meeting 3: 1. High windows, medium depth Students drew and explained drawn models of sound waves from two tuning forks of differing pitch (selected to model evidence-based analysis of student thinking) 2. High windows, high depth Students drew models of sound waves of different instruments in the front and back rows at a concert (selected to model evidence-based analysis of student thinking)	Meeting 4: Medium windows & depth Students wrote and drew explanations about relationships between pressure, temperature, and volume of gas (selected to feature participants’ experimentation) Meeting 5: 1. Medium windows & depth Students explain graph of results showing the relationship between pendulum length and period (selected to feature participants’ experimentation) 2. Low windows, medium depth Students write explanation between the relationship between pendulum length and period and identify the matching mathematical function for their data (selected to feature participants’ experimentation)
Priming Activity	Initial generating of the rubric – defining indicators of high and low quality evidence-based reasoning	Refining and the rubric (modifying and adding new indicators) and leveraging it to maintain focus on the artifacts	Leveraging the rubric to analyze artifacts & problematize instruction
Facilitation	***Supporting*** participation and **highlighting** of evidence of students’ disciplinary thinking	**Highlighting**, **pressing** for, and **revoicing** participants’ use of evidence of students’ disciplinary thinking	**Supporting** participation and **highlighting** of evidence of students’ evidence based reasoning and **offering alterative** interpretations of evidence
Participants	Meeting 1: Ron, Laurel, Mitch, William, & Vincent Meeting 2: Ron & Mitch	Meeting 3: Ron, William, & Vincent	Meeting 4: Mitch, William, & Vincent Meeting 5: Ron, Laurel, & Mitch

Phase 1 discourse: Meetings 1 and 2. Recall that analysis of Meetings 1 and 2 revealed two different discourse patterns. On the one hand, the participants demonstrated some attention to students' disciplinary thinking and evidence-based reasoning. As a group, they started both meetings by describing and interpreting the student thinking in the high and medium quality published artifacts. However, their discourse then turned toward evaluating the correctness of the student answers and the effectiveness of the instructional moves in the video clips. Their evaluations were often grounded in references to general teaching practices they employed in their own practice, such as "not giving too much away," giving clearer directions, and having only one student speak at a time to keep discussions organized. Facilitation moves focused on supporting participation. Neither the participants nor the facilitator relied heavily on the framing activities to support analysis of the high-quality artifacts. Here, I examine in more detail how the three design features – framing activities, video artifacts, and facilitation – interacted to promote the discourse that emerged.

Artifacts. I hypothesized that artifacts featuring high windows into and depth of student thinking about science would enable participants to notice students' disciplinary thinking and therefore afford critical, evidence-based examinations of the instructional triangle. The artifacts featured in Meetings 1 and 2 were of high, medium, and low quality. Meeting 1 featured video clips of students working on an explanation of how a railroad tanker container that had been steam cleaned then sealed shut collapsed. The video featured students drawing a before and after sketch of the tanker container and discussing their explanation with each other and the teacher as she circulated from group to group. The first clip showed one group of students and the second clip showed a different group of students from the same class. The clips granted the viewer access to their written and spoken reasoning about a non-routine, substantive science idea and were therefore considered to have high windows and depth of student thinking. These high-quality artifacts afforded one highly productive idea unit each out of 10 total idea units. During these highly productive and interpretive idea units, participants described then interpreted details in the ways students were thinking about the gas laws. For example, William noted, “I see they’re starting to, if you look at the bottom ones, right now there’s more big arrows in the bottom one like there’s more pressure on that side.” Later, Mitch observed, “Well [on] the inside of the drawing they’re using arrows and dots and they’re trying to represent the air trying to get out.” Both were typical examples of productive discussion.

The first of the two video clips analyzed in Meeting 2 featured students exploring the relationship between cellular respiration and reproduction in flasks with yeast, warm water, and sugar. Because I noticed that Ron, the sole biology teacher in the group, was limited in his participation when analyzing the physical science clip in Meeting 1, I selected a life science clip for Meeting 2. The clip showed one lab group of students finishing data collection and answering their teacher’s questions about their lab observations. This clip did not feature any written or drawn explanations of the students’ thinking but did allow the viewer to hear their responses to the teacher’s attempts to press for elaboration on the classroom-based task about a substantive science idea. For this reason, it was coded as having medium windows and depth of student thinking. It did not result in any highly productive idea units.

The second clip from Meeting 2 was intentionally selected as an example of how the structure of a task could *limit* windows into student thinking. This clip featured students working in lab groups to collect data using pulleys and masses to calculate mechanical advantage. Most of the teacher and student interaction in the video involved the teacher correcting students on how to accurately collect data and set up the apparatus rather than exploring their conceptual understanding of mechanical advantage. For this reason, it was coded as having low windows and depth of student thinking. This artifact did not result in any highly productive idea units but given its selection as a non-example, I did not anticipate that it would generate rich discussion of students' thinking because student thinking was not readily visible in the clip.

For example, unlike the interpretive and descriptive idea units generated by other clips in Phase 1, the low affordance clip in Meeting 2 was consistently evaluative:

Facilitator	All right so you get the idea. So what's happening here?
Ron	Chaos.
Mitch	Yeah, he's not able to get to any concepts, he's just giving directions.
Ron	Yeah he's trying to help too many, well he's trying to help all the kids that have all these questions. It almost seems like, uh maybe he didn't give enough direction prior to the experiment? Maybe he should have put it up on the board so the kids have something to refer to but, they're asking a lot of very, I don't know, maybe simple questions that should have almost kinda been explained right from the begin, before the begin, before the lab even started. I don't know.
Mitch	Yeah at least at this point in the lesson he's swamped with the logistics of what they're going to do and he's not able to get to even figure out what their experience is with the ideas.

Because this clip did not feature student reasoning about mechanical advantage, there was no "figuring out" to do. As a result, discussion turned immediately to what was visible in the clip – how the task design and implementation resulted in student confusion about the simple logistics of the lab procedure. I later directed the group to discuss how a different framing of the same pulley task could have led to students asking conceptual questions about the lab procedure ("why would we want to use a spring scale to measure force here?") or about the concept of mechanical advantage ("why would adding a pulley reduce the effort force needed to lift the mass?") to drive home the idea that tasks can set up or shut down one's access to students' ideas. Mitch, in his last comment in the example above, demonstrates some understanding of the desired connection between tasks and talk when he expresses his dissatisfaction that the teacher is "not able to get to even figure out what their [students'] experience is with the ideas."

In summary, there was a relationship between the number of productive idea units and artifact quality: Artifacts with high windows and depth generated more highly productive idea units than the artifact with medium windows and depth. However, it was expected that the artifacts with high windows and depth would generate more than one productive idea unit each. Discussions started out highly interpretive, collaborative, and grounded in the artifact but were not sustained beyond the first idea unit of each artifact.

Framing activity 1: Evidence-based reasoning rubric. One of the framing activities I hypothesized to be important for focusing participants' noticing on student thinking was the development of an evidence-based reasoning rubric. Prior to examining the artifact in Meeting 1, I asked the group to brainstorm characteristics of high-quality evidence-based explanations. I informed the group that we would use these ideas to develop a rubric that they could use to inform their interactions with students as they engaged in evidence-based modeling or argumentation. These included ideas such as "students comprehend the evidence," "students use appropriate vocabulary," "students have a thesis or make a claim about a relationship," "students apply knowledge to a new situation," and "students are engaged." I identified three dimensions in the ideas they provided: use of evidence, depth of explanation, and use of scientific vocabulary. In the second meeting, I shared these dimensions with the group, and the participants used their statements from Meeting 1 to collectively identify indicators for high and low quality for these dimensions. The group also added a new dimension we called "claims." The group struggled to articulate indicators for medium quality, so I informed them that this middle area might become clearer as they looked at more student explanations. This first iteration of the evidence-based reasoning rubric is shown in Table 4.2.

Table 4.2

Students' Evidence-Based Explanations in Science Version 1

Dimension	Low quality	Medium quality	High quality
Use of evidence	Evidence used by unrelated and poorly chosen		Evidence is relevant and accurate
Depth of explanation	"fragile" – does not stand up to questioning Not well thought out		"toughness" survives scientific criticism Student can respond/defend with scientific argument
Use of scientific vocabulary	Vague language, not connected to the scientific concept		Specific and academic Clear Correct Well chosen
Claims	No, irrelevant, or unclear claim made		

Though the rubric was developed in part to help participants make sense of the students' evidence-based reasoning in the artifacts, participants nonetheless made few references to the ideas raised in the evidence-based rubric discussions in Meetings 1 and 2 (see Table 4.3). One reference to vocabulary occurred during the first interpretive idea unit in Meeting 1, and two references to evidence in Meeting 2. At this point, neither the facilitator nor participants actively leveraged the rubric during the collaborative analysis of artifacts.

Table 4.3

References to Framing Activities in Phase 1

	Meeting 1										Meeting 2								
	Clip 1					Clip 2					Clip 1						Clip 2		
	Idea Unit 1*	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 5	**Idea Unit 1***	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 5	Idea Unit 1	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 5	Idea Unit 6	Idea Unit 1	Idea Unit 2	Idea Unit 3
rubric	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
ideal response	10	0	0	0	0	2	0	0	0	0	0	4	0	2	1	0	0	0	1
turns of talk	55	38	9	6	17	49	14	16	15	30	68	21	16	23	52	43	51	20	71

Note. Highly productive idea units are indicated by *and boldface type.

Framing activity 2: Ideal response. I refer to a second framing activity that I designed as the "ideal response" discussion. This framing activity involved participants in writing and sharing their response to the prompt given to students in the artifact. The purpose of this activity was to develop clarity on the disciplinary core ideas that the prompt should elicit and provide insight into ways students might approach the prompt. Analysis reveals that this activity informed participants' interpretation of the artifacts (see Table 4.3). Participants referenced the ideal response 19 times across 19 total idea units, 12 times in two idea units in Meeting 1, and eight times in three idea units in Meeting 2.

In Meeting 1, for example, I facilitated a discussion about what students should be able to understand about the relationship between temperature, pressure, kinetic activity of molecules, and volume to explain the collapse of a tanker truck container. The participants, some of whom taught physics, some of whom taught chemistry, and one of whom taught biology, identified that students should know that the gas molecules in the container would be moving rapidly due to the steam cleaning of the interior of the container. This movement would result in forceful collisions between the molecules themselves and the molecules and the inside of the container. These collisions would generate sufficient pressure equal to the pressure the atmosphere exerted on the outside of the container. However, as the gas cooled overnight, the molecules would slow down, collide with less force, and exert less pressure on the inside of the container. This would cause an imbalance of pressure on the inside and outside of the container, resulting in the buckling inward of its walls. Participants expected students to show molecular movement of gas with dots and arrows to indicate direction and magnitude.

This "ideal response" discussion was referenced 10 times during the first idea unit of artifact one and two times during the first idea unit of artifact two. These references occurred *exclusively* during the interpretive discussions focused on students' disciplinary thinking. Other idea units that were evaluative or not focused on student's disciplinary thinking did not include references to the "ideal response" discussion.

In Meeting 2, the "ideal response" discussions appeared to be slightly less effective at supporting artifact-based analysis of students' disciplinary thinking. There were two different artifacts featured in this meeting. One featured students collecting and interpreting data from an investigation involving yeast respiration and reproduction. The other featured students collecting data using pulleys, masses, and spring scales to study mechanical advantage.

The core disciplinary idea in the yeast video involved understanding that model organisms digest food to obtain molecules that can be handled by the process of cellular respiration to generate useable energy. Organisms use this energy to do the work required to stay alive. In yeasts, a relatively simple organism, much of this energy is directed to reproduction. Participants referenced this discussion six times across six idea units. Unlike Meeting 1, these references did not exclusively occur during interpretive idea units focused on students' disciplinary thinking. Three references occurred during evaluative idea units focused on instruction. In one case, Mitch noted that students were attempting to make the connection between reproduction and respiration but that the way the instructor organized the lab groups' discussion prevented this from happening.

Mitch made a similar critique of the instruction in the second clip. In this artifact, the "ideal response" was referenced only once when Mitch critiqued the instructor for not focusing students on how different pulley configurations would result in different amounts of force. In this case, the “ideal response” discussion informed a different part of the instructional triangle: instruction as it related to the disciplinary core idea rather than just student thinking.

***Facilitation*.** My goal for facilitation in Meetings 1 and 2 was to model the type of critical discourse for analyzing artifacts by *promoting* and *maintaining* participants’ attention to the student thinking in the artifacts, and to establish a sense of trust among the participants by *supporting* productive participation. Table 4.4 provides an overview of the five main facilitation moves in Phase 1. Sixteen percent of the total facilitation moves in Meetings 1 and 2 were used to promote an inquiry stance by *highlighting* evidence of student thinking in the artifact and modeling artifact-based *interpretations* of the student thinking in the artifacts. *Highlighting* and *interpreting* evidence were the dominant moves in both of the highly productive idea units from each artifact, accounting for 45% of the total moves made in the highly productive idea units from Meeting 1. *Highlighting* and *interpreting* were used in less productive Idea units, but less frequently (17%) and instead were replaced by *supporting* moves (56%). I referred to evidence in the clips less often in Meeting 2, seven moves in six idea units from the first artifact, and only once in three idea units from the second artifact. Meeting 2 did not include any idea units that were considered highly productive.

Table 4.4

Facilitation Moves in Phase 1

	Meeting 1										Meeting 2								
	Clip 1					Clip 2					Clip 1						Clip 2		
facilitation moves	**Idea Unit 1***	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 5	**Idea Unit 1***	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 5	Idea Unit 1	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 5	Idea Unit 6	Idea Unit 1	Idea Unit 2	Idea Unit 3
orienting	6	0	0	0	0	7	0	0	0	0	3	0	1	0	0	0	1	4	0
promoting	12	0	3	0	0	10	5	4	0	1	7	5	0	5	8	5	8	0	9
maintaining	0	0	1	0	0	0	1	0	0	1	1	1	0	1	0	1	0	0	0
supporting	6	7	1	0	3	4	2	3	10	3	15	4	3	4	15	13	11	0	23
other	0	6	1	0	0	0	0	0	0	0	0	0	0	0	1	0	6	5	0
total moves	24	13	6	0	3	21	8	7	10	5	26	10	4	10	24	19	26	9	32
turns of talk	55	38	9	6	17	49	14	16	15	30	68	21	16	23	52	43	51	20	71

Note. Highly productive idea units are indicated by *and boldface type.

Nearly half of the facilitation moves in Meetings 1 and 2 served to *support* and encourage participants to continue to talk. These moves typically took the form of *minimal responses* (99 uses across 10 of the 11 idea units) and *affirming* statements (21 uses across eight of 11 idea units). These moves were equally distributed throughout all the idea units in both meetings, both highly productive and less productive. There were few instances when I *pressed* participants to elaborate on their claims in these early meetings; two of the three of these came during highly productive idea units in Meeting 1 and an additional two during one of the few interpretive idea units during Meeting 2. Facilitation moves that *promoted* attention to artifacts were used half as often as *supporting* moves in Meeting 2; *supporting* and *promoting* moves were roughly equal in Meeting 1.

Much of the remaining quarter of the facilitation moves in Meetings 1 and 2 involved highlighting evidence about student thinking or instruction in parts of the artifact videos the group did not watch together. These were video segments that I was familiar with from prepping for the video club meetings but elected not to show the group. On two occasions in one idea unit from Meeting 1, I described examples of students' reasoning about the gas laws in an attempt to build on a participant's interpretation about students' misconceptions. On four occasions in two idea units from Meeting 1, I used evidence from the non-shared part of the artifact to challenge particular assumptions made by two participants; they suggested that the clips I selected for us to view together were examples of the "good" groups or that the groups were only productive while the camera or teacher was with them. An example of this is an interaction I had with Ron toward the end of Meeting 1. He initiated the interaction with a question:

Ron	Were all groups video taped or not?
Facilitator	Um. I don't know. They end up showing four different groups.
Ron	Because one thing I don't think that has been said is if, the groups that are video taping, the ones being video taped, are they doing it just because the camera is there and they're forced to be thinking? Like, we really don't know how much effort is being put by the groups that aren't.

Although I was concerned that challenging a participant in an early meeting could potentially discourage further participation, I felt it important to establish these clips as realistic and relatable examples of the type of intellectual work their own students could accomplish. Viewers who do not see students similar to their own in artifacts are less likely to find the artifacts compelling and relevant to their own practice (Brophy, 2004). I therefore decided to challenge Ron's assertion by informing him that the full video actually included all the groups and that one camera was left with each group and an additional camera followed the teacher around. I also *highlighted* evidence from the video by noting that although not all groups were equally focused on the task, each group had interesting ideas about pressure, volume, and temperature:

Facilitator	So, um, but I think you got and some groups, there's another group, the one that we skipped over, they were less, like tuned in the entire time. There was-
Ron	-yeah, these two groups that you highlighted were, I would say, would be very high-achieving students. Making an effort [inaudible]. Trying to come up with a solution.
Facilitator	but even the ones that were kinda like, one of the groups that tended to have a lot of screwing around behavior, was the one with the tornado and the invisible foot of air.

The "invisible foot of air" and "tornado" ideas were highlighted earlier as an interesting example of how students were attempting to explain why the tanker container collapsed. To allow the notion that only "high-achieving" students had interesting and complex ideas about science to go unchallenged would undermine the perceived relevance of the meeting artifacts and therefore limit their ability to act as a stimulus to potentially question their own teaching practice. Tensions between encouraging participation and modeling critical discourse was one example of an interaction between design elements that I discuss further later in the chapter.

Participants. All five participants, Laurel, Mitch, William, Ron, and Vincent, were present for Meeting 1. Most participants knew each other well either because they worked at the same site or from frequent course-alike meetings at the district. Ron and William were probably the least familiar to the group in general because they were the only teachers of biology and chemistry and had not been course leads or department chairs.

Mitch, William, and Vincent were the most active in Meeting 1, commenting frequently on the substance of students' science ideas and referencing moments from their teaching of gas laws. Ron and Laurel, whose courses did not specifically address gas laws, were less active. Both commented on concerns with the classroom management impact of the teacher spending as much time as she did with each group.

Only Mitch and Ron attended Meeting 2. Having noted in my design log that Ron appeared to struggle with the physical science concepts in Meeting 1, I specifically chose an artifact from a biology course for Meeting 2. However, the approach the teacher in the video clip took to teaching the relationship between cellular respiration and reproduction was not one Ron was familiar with. However, Ron noted a confusing detail in the students' data that I had missed when preparing to facilitate discussion of the clip. Ron, Mitch, and I spent nearly eight minutes attempting to puzzle out what happened with the students' data. This was at the expense of analyzing the students' explanations of the relationship between cellular respiration and reproduction in their flask. Mitch, who taught physics for part of the day, viewed the yeast activity as an energy flow problem. Despite having never taught biology, he was able to use his knowledge to analyze the clip. Both Ron and Mitch participated equally in the analysis of the "non-example" mechanical advantage clip. Ron, whose participation was limited when analyzing the physical science artifacts in Meeting 1, contributed several ideas to this clip – most likely because there were few student ideas about mechanical advantage on display in the clip, leading to issues such as task design and delivery of instructions dominating the discourse in this meeting.

Phase 2 discourse. In Meeting 3, the participants sustained a descriptive and interpretive stance throughout and remained focused on students' disciplinary thinking using evidence from the artifact. When participants attended to the instruction in the artifacts, the discussion typically followed an interpretive sequence that left the group with questions about the students' understanding. Frequently, talk about instruction involved ways to make student thinking more visible or proposing a question one could ask the student to gain further insight into students' reasoning. For example, after identifying a puzzling difference between the sound waves one student drew on the left and right sides of two tuning forks, Vince mentioned, "I would actually point to both right sides and ask him you know, can you tell me a little about the lines here, and kinda, what the difference is there." Facilitation moves continued to *promote* the use of evidence and included some *pressing* for elaboration and *revoicing* of participants' ideas. Framing activities were referenced more often in this meeting phase to analyze artifacts of good quality.

I now examine how the design features interacted to promote the descriptive and interpretive discourse in this meeting.

***Artifacts*.** Two types of artifacts were examined in this meeting; three video clips and three student work samples. The video clip featured students explaining their drawings of how sound waves would emanate from two different-sized tuning forks. The viewer had access to the students' drawings, their verbal explanation, and responses to teacher and classmates' questions about the drawing. For this reason, all three clips were rated as having high windows. The prompt asked students to explain a scenario they had worked on in class with tuning forks. Because all three students used evidence from their in-class experiences in their tuning fork drawings, these clips were rated as having medium depth. Of the 11 idea units about these three artifacts, seven were considered highly productive.

The other artifacts examined in this meeting were student work samples of a final assessment from a unit on sound. This work sample was from the next phase of the lesson that featured the tuning fork clip and drew on the same disciplinary core ideas. Because this would reduce the amount of time the group would have to spend on the "ideal response " discussion and because participants had demonstrated interest in still shots of students' work in previous video clips, I elected to feature a student work sample rather than video clip from a different lesson. In the student work samples from Meeting 3, students were asked to explain how a girl sitting in the front row and a girl sitting in the back row at a concert would experience the sound of drums, bass guitar, and lead guitar. The student responses included a drawing of the different sound waves produced by the three different instruments accompanied by a written explanation. Because all three students used evidence from various experiences to explain a non-routine situation, all were considered high in depth. The first student work sample lacked the detail both in the drawing and the written explanation of the other two work samples, so the first sample was rated as medium and the other two work samples were rated as high in windows into student thinking. The first work sample rated as medium windows, high depth generated three idea units, all of which were highly productive. The other two idea units, both rated high windows and high depth, generated six total idea units, two of which were considered highly productive.

As in Meeting 1, I expected the artifacts with high windows and depth to yield the most productive idea units; however, like in Meeting 1, these artifacts did not promote as many productive idea units as anticipated. The artifacts that did produce the highest proportion of productive idea units were those that were a mixture of high and medium windows and depth. The two artifacts of this type generated eight idea units, seven of which were highly productive.

Framing activity 1: Evidence-based reasoning rubric. In Meeting 3, participants continued to refine the evidence-based reasoning rubric. Unlike Meetings 1 and 2, in which the rubric was discussed at the beginning or end of the meeting, the rubric was discussed briefly at the start of Meeting 3, twice during the examination of artifacts in the middle of the meeting, and again at the end of the meeting. The group used their experience referencing the rubric during artifact analysis to offer recommendations to refine it. After examining the six artifacts in this meeting, the group decided to add another dimension, titled "making connections" to the rubric (see Table 4.5). This dimension addressed the ability of students to extend their conceptual understanding beyond the particular example in the task.

Table 4.5

Third Iteration of the Evidence-Based Reasoning Rubric

Dimension	Low quality	Medium quality	High quality
Use of evidence	Evidence used is unrelated and poorly chosen		Evidence is relevant and accurate
Depth of explanation	“fragile” – does not stand up to questioning Not well thought out		“toughness” survives scientific criticism Student can respond/defend with scientific argument
Use of scientific vocabulary	Vague language, not connected to the scientific concept		Specific and academic Clear Correct Well chosen Precision of language
Claims	No, irrelevant, or unclear claim made		Clear and relevant claim made
Making connections	No connections	Makes connections but does not move beyond example at hand	Explanation connects evidence to “big idea” and moves beyond the specific example at hand

Participants referenced the rubric 49 times across 20 idea units (see Table 4.6). Highly productive idea units included 39 of the 49 references to the rubric. Only three of the 20 total idea units included no references to the rubric; two of these three were less productive idea units. The third was a relatively short idea unit (17 turns at talk compared to an average of 30 turns at talk across all idea units) focused on describing the student thinking in the artifact. Most of the references to the rubric involved the clarity of the student’s explanation dimension (12 of 49 references), the correctness of the student’s explanation dimension (seven of 49 references), and student’s use of vocabulary dimension (seven of 49 references). These references typically occurred while describing and interpreting students' work. For example, "She's using correct vocabulary, she actually built a correct model from close to far away" (Mitch), and "He talks about 'long sound and loud too,' but it's unclear what, which one is the long sound, what a long sound is" (William).

Participants referenced the rubric more often in the second half of the meeting, when the artifacts changed from clips featuring a formative assessment of their understanding of tuning forks to a summative assessment involving students' understanding of many aspects of sound. Analysis of the three video clips revealed 17 references across 11 idea units to the rubric (mostly about the clarity dimension), and analysis of the three student work samples showed 39 references across nine idea units to the rubric (mostly about the correctness, vocabulary, and clarity dimensions). It is unclear if participants utilized the rubric more often in the second half of the meeting because they interacted more with it by revising it multiple times during the meeting or if it was because they felt issues of correctness and use of vocabulary were more important on a summative assessment than a formative one.

In summary, participants worked with and referenced the rubric more in Meeting 3 than in Meetings 1 and 2. Participants leveraged the rubric more during highly productive idea units as compared to less productive idea units.

Table 4.6

References to Framing Activities in Phase 2

	Meeting 3																			
	Clip 1					Clip 2	Clip 3					Student Work 1			Student Work 2					SW 3
	Idea Unit 1*	**Idea Unit 2***	**Idea Unit 3***	Idea Unit 4	**Idea Unit 5***	Idea Unit 1	**Idea Unit 1***	Idea Unit 2	**Idea Unit 3***	Idea Unit 4	Idea Unit 5	**Idea Unit 1***	**Idea Unit 2***	**Idea Unit 3***	Idea Unit 1	Idea Unit 2	**Idea Unit 3***	Idea Unit 4	Idea Unit 5	**Idea Unit 1***
rubric	1	3	2	3	2	0	1	3	0	0	2	8	2	5	0	0	12	0	4	15
ideal response	8	2	5	0	7	0	10	0	3	11	1	7	2	15	0	0	4	4	0	4
turns of talk	32	14	22	4	18	9	32	4	17	33	18	65	8	49	14	18	70	36	17	42

Note. Highly productive idea units are indicated by *and boldface type.

Framing activity 2: Ideal response. Two different artifacts were analyzed in Meeting 3, both involving sound: the tuning fork explanation and the sound at a concert explanation. Participants referenced the ideal response discussions 78 times across the 20 total idea units for this meeting (see Table 4.6). This is a marked increase from Meetings 1 and 2. Every idea unit that was characterized as highly productive referenced the "ideal response" discussions. The six idea units that contained zero references to the "ideal response" discussion were all considered less productive. Furthermore, four of these less productive idea units lacking reference to the "ideal response" discussion were coded as evaluative in stance. Participants referenced the ideal response discussion 47 times in eight of the 11 idea units devoted to the tuning fork artifact. Participants made 46 references to the "ideal response" of sound at a concert discussion in six of the nine idea units. Unlike references to the evidence-based rubric, which increased when analyzing the student work samples relative to the clip, the references to the ideal response were roughly equal between the video clip artifacts and the student work artifacts.

Discussions about the topic of sound ended up uncovering some misconceptions among the participants who did not teach physics. One participant, Ron, thought that the tone would be lower and the wavelength would be longer with the shorter tuning fork. He also drew sinusoidal waves to represent sound. William had the idea that the shorter tuning fork would generate smaller wavelengths and a higher pitch and drew lines to represent compression waves. Vince, the only physics teacher present at this meeting, informed the group that because the shorter tines could vibrate faster, they generated shorter compression waves and a higher pitch sound. He represented the compression waves not as simple compression lines but as clumps of dots because it was the transference of energy from one vibrating neighbor to the next that was important for him. The group agreed that in response to the prompt, students should be able to show different patterns of compression and rarefication from the two forks with the compressions more spaced out in the longer, low-pitched tuning fork compared to the shorter, high-pitched tuning fork.

In the “ideal response” discussion to the sound at a concert prompt, the new conceptual idea added to the tuning fork artifact was how sound dissipated over distance. Participants agreed that the lead guitar would produce compression waves with short wavelengths and higher pitched sounds while the bass guitar would produce long wavelengths and lower pitched sounds. The group all agreed that there would be a degradation in sound from the front row to the back row, but Ron, William, and I were not quite sure how this would be represented using Vince’s dot representation of compression waves. This idea continued to be refined as we looked at the student work. When describing ones student’s work, William said, “I see there’s a gap in between there’s some gaps now between uh, the answer. Yeah, I can’t tell the difference, man. I’m not the physics guy or whatever.” This was an indication that even after the ideal response discussion, some confusion remained about the physics concept featured in the student work.

Overall, the numerous references to the “ideal response” discussions and the high number of highly productive idea units focused on interpreting the students’ thinking about the disciplinary core idea indicated that despite initial unfamiliarity with the concept, the “ideal response” discussion had sufficient affordances to allow non physics teachers to participate in the analysis of students’ work. However, the fact that the group continued to work through their understanding during artifact analysis led me to question if all participants were equally supported.

In summary, participant usage of the “ideal response” discussion was similar to that of the evidence-based reasoning rubric in that more references were made in Meeting 3 than in Meetings 1 and 2. Also like the rubric, participants’ references to this framing activity coincided with highly productive idea units.

Facilitation. Facilitation in Meeting 3 changed to include *pressing* (6% of total moves) and *revoicing* (4% of total moves). I continued to *highlight* and *interpret* evidence in the artifacts (21% of total moves) and *support* participant participation through the use of *minimal responses* (42% of total moves) and *affirmations* (7% of total moves) but to a lesser degree as compared to Meetings 1 and 2. A summary of facilitation for this meeting is displayed in Table 4.7.

Table 4.7

Facilitation Moves in Phase 2

	Meeting 3																			
	Clip 1					Clip 2	Clip 3					Student Work 1			Student Work 2					SW 3
facilitation moves	**Idea Unit 1***	**Idea Unit 2***	**Idea Unit 3***	Idea Unit 4	**Idea Unit 5***	Idea Unit 1	**Idea Unit 1***	Idea Unit 2	**Idea Unit 3***	Idea Unit 4	Idea Unit 5	**Idea Unit 1***	**Idea Unit 2***	**Idea Unit 3***	Idea Unit 1	Idea Unit 2	**Idea Unit 3***	Idea Unit 4	Idea Unit 5	**Idea Unit 1***
orienting	1	1	0	2	0	1	1	1	0	0	1	3	1	0	3	4	2	0	2	0
promoting	3	2	7	0	3	0	13	1	3	3	3	2	1	10	0	0	16	0	5	5
maintaining	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
supporting	7	4	3	0	4	0	12	0	6	11	1	19	2	9	2	4	11	11	1	11
other	0	0	0	0	0	4	2	0	1	0	2	0	0	1	0	0	0	1	0	0
total moves	11	7	10	2	7	5	29	2	10	14	7	24	4	20	5	8	29	12	8	16
turns of talk	32	14	22	4	18	9	32	4	17	33	18	65	8	49	14	18	70	36	17	42

Note. Highly productive idea units are indicated by *and boldface type.

Meeting 3 included increases in participants' reliance on evidence as well as changes in facilitation moves. By Meeting 3, participants had analyzed four different artifacts. Because participants used artifact-based evidence to describe and interpret student thinking *throughout* Meeting 3, there was a greater proportion of highly productive idea units in this meeting (20% in Meeting 1, none in Meeting 2, and 60% in Meeting 3). Relatedly, even the less productive idea units included many facilitation moves to *promote* a focus on evidence, meaning highly productive and less productive idea units were more similar to each other in Phase 2 than they were in Phase 1. In Meeting 3, 24% of the facilitation moves in highly productive idea units referenced evidence from the artifact, compared to 13% of the moves in less productive idea units, a difference of 11%. In Meetings 1 and 2, 44% of the facilitation moves in productive idea units *highlighted* and *interpreted* evidence from the artifact, compared to 17% of the facilitation moves in other idea units, a difference of 27%.

Because participants had taken up the role of *highlighting* evidence, facilitation shifted from modeling how to ground analyses in the evidence of the artifact to another aspect of critical discourse – that of *pressing* on each other's interpretations of the student learning in the artifacts. This move typically involved requests for them to elaborate on their initial interpretations. For example, Vince explained his impressions of one student's tuning fork explanation:

> He's somewhat on the right track. I'm wondering if it's just, you know, I see his writing and maybe he just doesn't draw very well? I think, my impression is he's on the right track and maybe he just needs a little more to be higher quality.

I replied with, “Uh huh. So what, say a little bit more, like what specifically?” Vince then elaborated with, “For example if he was consistent like, uh, in the fork on the right,” referring to the spacing between the lines on both forks. *Pressing* moves used in this way prompted participants to further clarify their thinking and share more details about their interpretations of student thinking.

Pressing served to promote attention to the student thinking; however, at least in this meeting, I did not see evidence of participants *pressing* each other the same way they consistently *highlighted* evidence from the artifact to describe and *interpret* student thinking. Taking up this particular aspect of critical discourse would be necessary if the group were to continue to develop professionally, particularly when we began to engage with problems in their own practice in coming meetings or past the end of the video club in their own professional learning community work.

Participants. Ron, Vincent, and William attended Meeting 3. Vincent and William attended closely to the details in students’ drawings. Vincent mentioned students’ misconceptions about how compression waves moved through air and William attempted to make sense of students’ representations of pitch and volume. Ron attended to other details in the drawings, such as why one student added a particular color to his drawing of tuning forks and remarks that another student clearly labeled and included a lot of detail her drawing. Because William and Ron, despite their lack of experience teaching about sound in their science courses, found aspects of the artifacts to raise for discussion, I pressed all three to elaborate on their contributions and encouraged them to make connections to the evidence-based reasoning rubric.

Phase 3 discourse: Meetings 4 and 5. In Meetings 4 and 5, participants continued to employ an interpretive stance to analyze artifacts from their own classrooms. However, interpretive segments were followed by segments in which participants problematized aspects of practice they found challenging. Concerns with how to design tasks that elicited students' disciplinary thinking, as well as issues of student motivation and persistence were common topics in Meetings 4 and 5. Facilitation continued to support participation and promote a focus on the artifacts while also introducing some alternate interpretations of evidence from the artifacts. The framing activities were used to analyze the student thinking and launch discussions about the instruction featured in the lower quality artifacts in this phase. Below I examine how the design elements contributed to the shifts in the last phase of the video club.

Artifacts. These meetings were the first time that participants analyzed artifacts from their own classrooms rather than from published sources. In Meeting 4, the group looked at work samples from William's chemistry class. The artifact was drawn from a lesson on gas laws. It was similar to the artifact from Meeting 1 because the goal was for students to understand the relationship between temperature, pressure, volume, and molecular movement. In William's lesson, students boiled a small amount of water in a soda can then quickly inverted it in a room temperature water bath. Students were prompted to explain what they observed then used kinetic theory to explain their observations. They were reminded to "think about the movement of gases inside as compared to the outside of the system," and to "include before and after pictures depicting movement of gases." Because these responses included brief written explanations accompanied by drawn representations of students' ideas about an important science concept that didn’t require them to generalize outside of the lab, they were considered to have medium windows into and depth of student thinking.

These artifacts, being of lower quality than several of the published artifacts the group previously examined, were not anticipated to afford highly productive evidence-based discussion. However, each of the two student work samples in Meeting 4 resulted in one highly productive idea unit each. This is similar to the productivity of discussions featuring the high-quality artifacts during Meeting 1 and better than the discussions of artifacts of similar quality in Meeting 2.

In Meeting 5, the group examined one video clip and three student work samples from a lesson Mitch taught on pendulums. Students were tasked with collecting data about the period of 10 different pendulum lengths and graphing their results. The video clip from this lesson included one lab group presenting its data to the class. The presentation consisted of stating what they thought the relationship between pendulum length and period was, sharing something they felt was a success, and sharing something they struggled with in the lab. The video clip featured students explaining and answering brief questions about their data on their large whiteboard, so this artifact was rated as having medium windows into student thinking. Also, the task involved manipulation of data that students had some choice about selecting, but did not require them to elaborate beyond their lab experience, so this artifact was rated as being medium in depth of student thinking. In addition, the audio quality of the clip was poor, and this was compounded by a failure to successfully connect my computer to the external speakers in the meeting room. An on-the-spot decision was made to move immediately to examining the work samples rather than watch another video clip.

The student work samples prompted students to write the observations about the pendulum, specifically what they noticed about the period and the length. Students were also asked to circle one of 11 mathematical functions that “looked like a match” to what they observed. Students’ written observations about the pendulum length and period were typically only one or two sentences. Students circled a function, but did not elaborate on what the function meant about pendulums. For this reason, these artifacts were all rated as low in windows and medium in depth of student thinking.

The video clip did not result in highly productive discussion (another reason I decided to move to the student work samples). Two of the three work samples, despite being low in windows, did generate highly productive idea units. The first generated one long, productive idea unit (56 turns at talk). The second, in a similar pattern to what was seen in Meeting 1 and Meeting 4, generated an initial productive, descriptive, and interpretive idea unit followed by subsequent evaluative idea units.

In summary, productive discussions occurred even when artifact quality was not optimal. The pattern of initially descriptive and interpretive idea units followed by less productive idea units when examining participants’ artifacts was the same pattern observed for published artifacts of varying quality. This suggests that other factors contributed to the productivity of the groups’ discussions. I now turn to examine the influence of framing activities in Phase 3.

Framing activity 1: Evidence-based reasoning rubric. Participants continued to discuss the rubric in Meetings 4 and 5, however no changes were made to the rubric language. In Meeting 4, the group briefly discussed if the rubric adequately addressed students contradicting themselves in their answer and then went on to discuss how this type of expectation of students' explanations using evidence-based reasoning required different types of prompts. Mitch explained:

> I agree that once you get your rubric set, you have to now be ambitious with your prompt so that kids know what's expected. 'Cause there's no way that somebody would know to make connections to a big idea beyond the specific example at hand based on this prompt.

Mitch used the rubric to launch a discussion about the instructional triangle; in this particular case, how the prompt design limited the evidence-based reasoning available to examine during instruction.

References to the rubric in this phase were equally frequent between highly productive and less productive idea units (see Table 4.8). Every reference to the rubric corresponded with discussion about student thinking and/or instruction in Phase 3. With one exception, idea units focused on student motivation did not reference the rubric. Participants referenced the rubric 15 times across three of the six idea units in Meeting 4. Participants referenced the rubric more often and more consistently in Meeting 5. There were 39 references across eight of the nine idea units. Most references were about the use of evidence, vocabulary, clarity, and making a connection between their drawing and their written explanation dimensions of the rubric. This use was consistent with Phase 2 use. Despite not explicitly discussing the rubric in Meeting 5, the consistent references indicated that it had become a tool participants used to examine students' disciplinary reasoning, particularly during interpretive sequences.

Table 4.8

References to Framing Activities in Phase 3

	Meeting 4						Meeting 5								
	Student Work 1					Student Work 2	Clip 1	Student Work 1	Student Work 2				Student Work 3		
	Idea Unit 1*	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 5	**Idea Unit 1***	Idea Unit 1	**Idea Unit 1***	**Idea Unit 1***	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 1	Idea Unit 2	Idea Unit 3
rubric	3	9	0	0	0	3	8	11	5	0	3	4	4	3	1
ideal response	18	5	0	2	0	5	0	0	6	0	2	0	4	0	3
turns of talk	77	77	18	6	21	20	22	53	24	7	16	54	22	9	24

Note. Highly productive idea units are indicated by *and boldface type.

Framing activity 2: Ideal response. There was one "ideal response" discussion in Meetings 4 and 5. Because the artifact in Meeting 4 involved the same concepts as did the tanker container collapse, participants were only reminded of the similarity between the can and tanker container scenarios. In Meeting 5, Martin informed the group of what he hoped to elicit from students with his pendulum exploration – specifically, students should understand that as pendulum length increases, period duration also increases at a logrhythmic rate. This was different than the ideal response discussions in other meetings in which participants actually attempted to address the prompt given to students. In order for participants to respond to the prompt in this artifact, they would have needed to have the pendulum apparatus and photogates. I determined that the benefit of engaging in the same activity as the students did not justify the amount of time it would take to complete, therefore, Mitch's explanation served as a substitute.

Despite the changes in this framing activity, participants continued to reference criteria identified in the "ideal response" in both meetings. There were 30 references across four of the six idea units in Meeting 4, and 15 references across four of the nine idea units in Meeting 5. Like the other meetings, most references occurred during highly productive idea units, peaking during the first idea unit for each artifact. It should be noted that the number of references was substantially less than in Meeting 3, but more than in Meetings 1 and 2, indicating that participants continued to utilize the "ideal response" to analyze student thinking as well as when problematizing instruction.

Facilitation. As in Phase 1, there were multiple facilitation goals in this phase of the video club. Because participants examined artifacts from their own classrooms for the first time in this phase, increased attention was paid to *supporting* participation while also continuing to *press* participants to *highlight and interpret* evidence and challenge each other's interpretations. Sixty-six percent of the moves in Meeting 4 *supported* participation, while 8% *promoted* a focus on evidence in the artifacts (see Table 4.9). Because Meeting 4 was the first occasion on which a participant's work was featured, establishing a supportive environment was privileged over other goals. However, once support was re-established, supporting moves dropped to 38% in Meeting 5 and moves that promoted focus on evidence in the artifacts increased to 48%.

Table 4.9

Facilitation Moves in Phase 3

	Meeting 4						Meeting 5								
	Student Work 1					Student Work 2	Clip 1	Student Work 1	Student Work 2				Student Work 3		
facilitation moves	**Idea Unit 1***	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 5	**Idea Unit 1***	Idea Unit 1	**Idea Unit 1***	**Idea Unit 1***	Idea Unit 2	Idea Unit 3	Idea Unit 4	Idea Unit 1	Idea Unit 2	Idea Unit 3
orienting	4	0	0	0	0	2	1	3	3	0	0	0	2	0	0
promoting	6	10	1	0	0	3	5	9	5	0	6	3	5	3	8
maintaining	0	0	0	1	0	0	0	0	0	0	1	0	2	0	0
supporting	13	22	7	2	5	4	4	8	2	2	2	11	2	1	3
other	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
total moves	23	32	8	3	5	9	11	20	10	2	9	14	11	4	11
turns of talk	77	77	18	6	21	20	22	53	24	7	16	54	22	9	24

Note. Highly productive idea units are indicated by *and boldface type.

Moves to provide alternative interpretations to participants' contributions increased in Meetings 4 and 5 relative to other meetings, accounting for 12% of the total facilitation moves in Phase 3 (compared to 8% in Phases 1 and 2 combined). Unlike participants' references to evidence that tended to occur most often in the first idea units for each artifact, alternative interpretations tended to occur in subsequent idea units after participants completed their initial descriptive and interpretive analysis. Participants expressed ideas in these two meetings — like the idea in Meeting 1 that only "high-achieving students" were capable of having complex explanations of science phenomenon — that I determined, if left unchallenged, would inhibit future change in practice. Concerns about leaving these ideas unchallenged overrode concerns about building trust. Two such related ideas were that students must be explicitly taught how to represent their ideas using scientific notation and that students cannot be left to discuss each other's ideas about science phenomena without first being told the answer by their teacher. Both ideas stem from a belief that students do not bring worthwhile ideas into the science classroom. This idea is antithetical to the goal of the video club of increasing teacher noticing of student thinking; if student ideas are not seen as resources teachers can work with, then increasing attention to them is moot. These ideas and ideas about students' lack of motivation were challenged in in two of the six idea units in Meeting 4 and three of the nine idea units in Meeting 5.

For example, when Ron mentioned the tendency of his students to "shorthand" their answers to "just get it done," I countered that I did not think that we, as teachers, always made our expectations clear to students. Lack of clarity about expectations could also explain students' brief responses. When Laurel complained that her students often found it "just easier to quit" rather than persist through challenging work, I reminded the group that persistence is a skill that can be developed with practice. Unlike challenges in Phase 1, these did not rely on highlighting evidence from the artifacts, because appropriate counter-examples were not available in the Phase 3 artifacts.

Participants. Vincent, Mitch, and William attended Meeting 4. This meeting featured student work from William's class. All three attended to how students were representing gas movement and pressure using arrows. Mitch attended the most to students' use of evidence from the lab to back up their claims in their written answers. All three expressed dissatisfaction with students' lack of elaboration in their answers and blamed the design of the prompt and task. In Meeting 5, which was attended by Mitch, Laurel, and Ron, the same concern about student answers was raised. This time, however, Ron and Laurel attributed the brevity of student answers to students' lack of resilience. When Ron and Laurel were together, both in Meeting 1 and Meeting 5, students' deficits were raised more often. This could be because the science featured in the artifacts had the least amount of overlap with their instructional experience as teachers of earth science and biology.

I now turn to discuss how each of the embodied elements of the design – the artifacts, the framing activities, and facilitation – interacted to influence meeting discourse.

Interactions between design elements. Analysis revealed that different design elements played more or less prominent roles in influencing discourse during the course of the five meeting sequence. The prominent design element in each phase of the video club is shown in Figure 4.4.

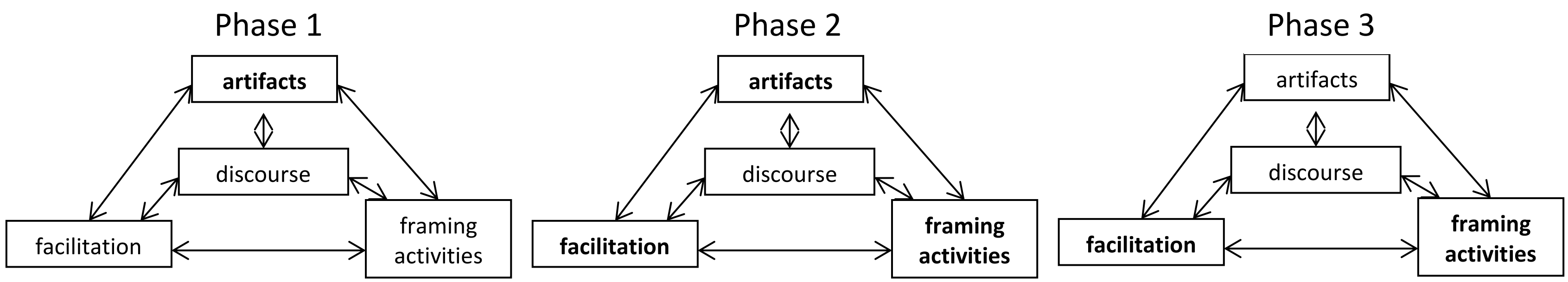


Figure 4.4. Changing prominence of design elements across three video club phases. The most prominent feature(s) of each phase are noted in bold type.

The element that most influenced discourse in Phase 1 was artifact quality. Phase 1 Meetings featured an initial descriptive and interpretive stance focused on students' disciplinary thinking in the artifacts followed by evaluations of teaching moves and the correctness of student ideas. A few design elements appear to have interacted to produce this result. One goal throughout the meetings was to model and promote the use of evidence to inform collaborative critique. The high-quality artifacts chosen for this meeting provided ample opportunity for participants and me, as the facilitator, to highlight evidence of student thinking. However, this way of working requires building trust and a feeling of intellectual safety among participants (Little et al., 2003). Facilitation moves that encourage critique can make participants uncomfortable, and electing not to take up ideas participants raise and redirecting discussion can also have the effect of reducing participants' willingness to contribute ideas (Curry, 2008; Borko et al., 2011; Horn & Little, 2010). The decision not to press or redirect more forcefully stemmed from a tension to "balance comfort and challenge" and was evident in the limited use of these moves in Phase 1 Meetings. The affordances of the evidence-rich artifact compensated for the lack of press in facilitation and resulted in some discourse that examined students' disciplinary thinking.

In Phase 2, all three elements combined to influence discourse. Discourse in Phase 2 was characterized by sustained description and interpretation of students' disciplinary thinking based on evidence from the artifacts. Because participants were familiar with the norms and expectations of analyzing student thinking, encouraging participation ceased to be a major facilitation concern in this phase. Facilitation in Phase 2 focused on modeling and developing aspects of critical discourse that involved pressing for evidence-based interpretations. Because the facilitation goals were no longer in conflict, I was able to provide more press and more effectively redirect discussion. The high quality artifacts featured in Phase 2 again afforded ample opportunities for participants to highlight evidence of students' disciplinary thinking when pressed.

The evidence-based rubric played an important role in Phase 2. At this point in the video club, the rubric was now in a form with several identified dimensions and some indicators of different levels of quality. I used it as a reference to *revoice* participants' observations about the artifacts using the language of the rubric. My intention in using the rubric this way was to provide a frame for participants' noticing — specifically by asking if students made progress on the dimensions the participants deemed important, such as use of evidence to support claims and precision of academic language. Additionally, I was able to use it to redirect participants back to the artifact and so maintain interpretive discussions about the students' disciplinary thinking. As a result of high quality artifacts, focused facilitation, and availability of the rubric as tool to frame and redirect discussion, Phase 2 yielded the most productive idea units of the video club.

In Phase 3, facilitation and framing activities were the most influential features. Participants in this phase described and interpreted students' disciplinary thinking using evidence from artifacts, then turned to problematizing aspects of their instruction. The artifacts featured in Phase 3 were from participants' own classrooms and offered fewer windows into students' thinking relative to artifacts in previous phases. Despite the lower affordances of the artifacts in this phase, discussion was just as productive as the discussion around higher quality artifacts in Phase 1. Interactions between the rubric and facilitation contributed to this productivity.

As in Phase 2, facilitation moves in Phase 3 attempted to leverage the more fully developed rubric to *maintain* a focus on student thinking. The rubric also became a launching point to explore an aspect of practice participants struggled with as they experimented with practice. However, because the group was now analyzing artifacts from their own practice, facilitation moves were also employed to re-establish *support.* As in Phase 1, a balance had to be struck between maintaining intellectual safety while also *promoting* and *maintaining* a focus on students' disciplinary thinking. As in Phase 1, the tension created between these two facilitation goals limited the potential productivity of this phase despite the increased affordances of the rubric. Although discourse in Phase 3 was more productive than Phase 1, it did not maintain the level of productivity established in Phase 2. Tensions between and within design elements have implications for facilitation of other video clubs and similar efforts to collaboratively examine artifacts of practice. I now turn to discuss these findings.

Discussion

The research literature has documented elements of effective facilitation (Coles, 2013; Gregoire, 2003; Gröschner et al., 2014; Kazemi & Hubbard, 2008; van Es et al., 2014), effective artifacts (Le Fevre, 2004; Seidel et al., 2011; Sherin et al., 2009), and effective artifact discussion structures (Borko et al., 2008; Santagata, 2009; Zhang et al., 2011). Less work has looked at how these elements work in relation to each other in situ – in particular, how facilitation moves are used in differing proportions in response to tensions that arise in the professional development design ecosystem. Three types of tensions arose in this study: Professional development goals in opposition to teach other, professional development goals in opposition to participants' goals and interests, and best practices in professional development in opposition to school structures and logistics. I will discuss each in turn.

This professional development design, like many, was informed by best practices. Research on artifact-rich professional development encourages maintaining a focus on student thinking and reasoning as well as productive critique. It is also important for the facilitator to establish a sense of safety among participants to make public one's practice and reduce participant concerns about "offending" colleagues (Borko, et al., 2011; van Es 2012). In this study, goals informed by best practices led to a privileging of certain facilitation moves over others in each phase of the video club. Facilitation that *supported* participation in Phase 1 shifted toward *promoting* focus on interpreting students' disciplinary thinking and reasoning in Phase 2. Pressing participants to elaborate on their interpretations and introducing alternative interpretations to challenge existing ideas was privileged in Phase 3. This is to say that facilitation in Meeting 1 did not look the same as facilitation in Meeting 5, nor should it have; facilitation should shift in response to participant progress and his/her willingness to take risks. Adjustments to facilitation moves requires a facilitator who is responsive to how participants are engaging in the work and a sense of the designed trajectory of the professional development (Schifter & Lester, 2005).

Facilitation must also be responsive to the tools that are available to support productive analysis. Best practices indicate that teachers should have a hand in tool development (Brown, 2009). However, tool development takes time. As a result, tools that are to be developed with participants in professional development — like the evidence-based reasoning rubric —will not have the same utility for analyzing artifacts in early phases as they will in late phases. In this video club, the evidence-based rubric consisted of a few dimensions with limited descriptions in Phase 1. As a result, the rubric was not often leveraged by the facilitator or participants to understand student reasoning. In later meetings, particularly in Phase 3, when it reflected the participants' more fully realized vision of student reasoning, the rubric was leveraged by both participants and the facilitator to interpret students' reasoning, redirect attention back to student thinking, and open up problems of practice. A fully developed rubric given to participants in Phase 1 might have provided clear descriptions of students' reasoning, but participants' lack of ownership of the tool might not have resulted in the same type of utility in later meeting phases. It is through the making of the tool that understanding of its intended purposes takes place (Brown, 2009; Cohen, 1990). This means that the need to have high-quality tools must sometimes be delayed to privilege the teacher learning that comes through developing the tool themselves.

The selection of artifacts was another way design elements were in tension. Research indicates that artifacts with particular qualities have greater affordances for supporting productive talk (Borko et al., 2011; Sherin et al.,2009). However, participants are more focused and motivated when examining their own artifacts (Seidel et al., 2011). In this study, when the professional learning that is to take place involves experimenting with new instruction, early attempts to enact new instruction might not meet the "high quality" criteria documented in the literature — as was the case in this video club; artifacts created by William and Mitch were of lower quality than the published artifacts. Fortunately, other aspects of the design (having already established a supportive environment and a developed evidence-based reasoning rubric) usually mitigated any lack of affordances from the artifacts. Further evidence of how affordances of some design elements mitigate the lack of affordances in others is my selection of a lower-quality biology artifact to support Ron's participation in Meeting 2. This selection occurred in Phase 1 when other design supports were not as robust and, consequently, discussion around this artifact was less productive than anticipated. Both instances of Phase 1 and Phase 3 discussions around lower quality artifacts serve as examples of how design elements interact to help resolve design tensions. As with the need to adjust facilitation based on participants' engagement, a facilitator must also be aware of how resources in the form of tools change over the course of professional development.

Another type of tension revealed in this analysis was that of professional design objectives and participants' goals and interests. Schifter and Lester (2005) explained that skilled facilitation is particularly demanding because it requires deep understanding of the content, the goals of the professional development design, as well as the perspectives of the participants. Different participant groups might bring experience and pre-existing dynamics that can influence the readiness with which they take on the changing roles in their learning community (Kazemi & Hubbard, 2008). Variation in participants means that while there is likely a desired direction for the professional development design, there can be no hard and fast, pre-defined timeline to shift from the promotion of one facilitation goal (supporting participation) to another (promoting an inquiry stance).

Additionally, participants might have learning goals that differ from that of the professional development designer, a situation that leads to what Richardson (1992) defined as the "agenda setting dilemma" – how does one balance the intended direction of the professional development with participant choice in the process of change? In some cases, these dilemmas are not apparent until one is in midstream of the professional development. In these cases, decisions must be made on the fly to determine what participant interests and/or problems of practice will "open up possibilities" and which will not (Coles, 2013). Facilitation moves can set up discourse that either promotes the problematizing of practice or normalizes problems of practice (Horn & Little, 2010). Normalizing may "smooth over" immediate design tensions, but if the problem is rooted in teacher practices or beliefs incongruent with the goals of the professional development, it will likely act as a barrier for professional learning. Such was the dilemma that arose in this video club. Participants who located problems with motivation in students and who believed authority of science thinking resided in the teacher and the text might eventually change instruction to make student thinking more visible, but would do so only superficially and be unlikely to leverage student ideas as resources for learning in the classroom (Cohen, 1990; Planning for engagement with important science ideas, 2014). How best to resolve issues of this type is unclear given the limited time provided for most professional development projects and the resistance of beliefs to change, but it seems clear that skilled facilitation that recognizes and responds to participant issues is a critical component.

Another tension raised by this study is the logistics of artifact-based professional development for secondary science teachers. Although site-based professional development is important, it raised challenges for a secondary science department. The literature has documented artifact-rich professional development with multiple subject, mathematics, and language arts teachers. All these teachers share the same credential. This study with high school science teachers involved five teachers with *four different credentials*. Close analysis of student thinking requires familiarity with the disciplinary thinking involved as well as insights into how students typically think about the concept (Cartier, et al., 2013; Windschitl et al., 2012). The facilitator must also have strong content knowledge as well as pedagogical content knowledge and community knowledge to effectively guide professional learners (Borko et al., 2011). The design attempted to mitigate some of the issues with differences in content knowledge for teaching with the "ideal response" discussions and a focus on evidence-based reasoning, a practice that cuts across disciplines (NRC, 2012). Results showed mixed success. Participants were able to leverage one or both of the framing activities to engage with artifact analysis but it was not clear that all participants leveraged the tools equally. Additionally, a video club that privileges deep understanding of a disciplinary core idea of physical science rather than a cross cutting concept or disciplinary practice would require a facilitator more skilled in that particular discipline. A sustainability model of professional development hinges on developing a teacher leader in each department to do this work, which poses potential problems (Borko et al., 2011; Wilkinson, Akiba, Farfan, Howard, & Kuleshova, 2016). One 10–15 minute conversation is not the equivalent of 10–15 years of practice. More work is needed to explore how artifact-rich professional development is to be effective for high school groups.

The three tensions identified in this study — tensions within design, tension between design and participants, and tensions between design and school structures — illuminate the critical importance of a skilled facilitator to negotiate decision points as participants and tools change over time across different school contexts. Numerous authors have recognized the importance of facilitation on the group (Borko et al., 2011; Coles, 2015; van Es & Sherin, 2006) with Gröscher and colleagues (2014) even characterizing the role of the facilitator as "pivotal." Further exploration of how facilitators navigate tensions that arise during professional development would greatly benefit the field of professional development and more clearly explain why some professional development designs fall short of expectations for teacher learning while others meet and exceed them.

Limitations

There are several limitations to this analysis. One, this is a study of one design, in one context, over a relatively short period of time, which limits the generalizability of the particular findings of the study as they relate to the design and theoretical conjectures. An additional limitation is that I was the designer, facilitator, and researcher in this particular professional development context. I also was a close colleague of four of the five study participants for several years. This familiarity afforded some deep understanding of the context of the school sites (Anderson & Shattuck, 2012), but also potentially limited my objectivity as both a facilitator and a researcher.

CHAPTER 5 – Summary and Conclusions

The purpose of this study was to attempt to address a problem in science education, specifically addressing obstacles to implementing ambitious science instruction that promotes students' evidence-based reasoning and explanation building. The design solution used a video club model (Sherin & Han, 2004; van Es & Sherin, 2008) to structure secondary science teachers' collaborative analysis of artifacts of science teaching that featured students' evidence-based reasoning. The design involved engaging participants in particular tools, tasks, and talk to promote the development of teachers' noticing of students' disciplinary thinking and exploring the instructional triangle using critical discourse.

The design featured in this study differed from previous video clubs that primarily focused on noticing students' disciplinary thinking (Sherin & Han, 2004; van Es & Sherin, 2008). This video club design had an explicit goal to change participants' instruction and featured elements to frame discussion not just on student thinking but also on the instructional triangle. Although research indicates that participants who develop sophisticated noticing of students' disciplinary thinking enact more student-centered instruction (Levin, Hammer, Elby, & Coffey, 2013; Richards & Elby, 2014; Sherin & van Es, 2009; Sun & van Es, 2015; van Es & Sherin, 2010), instructional change was not the focus of previous video club designs. The video club design in this study also included a blend of published and participant videos and student work samples. Previous research indicates some differences in teachers' focus when looking at own versus other's artifacts, but overall, structured, collaborative examination of artifacts from either source can influence instruction (Dunne, Nave, & Lewis, 2000; Little et al., 2003; Seidel et al., 2011; Thompson et al., 2009). It was therefore anticipated that participants would begin to experiment with the types of instruction featured in the video club artifacts.

With respect to research question one, results indicate that, consistent with previous video club studies (Sherin & Han, 2004; van Es & Sherin, 2002, 2008), participants can hone attention to students and their thinking. In this study, participants' noticing moved through three phases over the course of the video club. In Phase 1, participants started out with a pattern of initially describing and interpreting, then shifted to a predominantly evaluative stance and drew on personal experience to suggest simple recommendations to "fix" the instructional problems they identified in the clips. In Phase 2, participants sustained an interpretive stance, grounded in artifact-based evidence. In Phase 3, participants initially described and interpreted evidence from artifacts from their own teaching, then shifted to discussions of problems in their own practice.

A noteworthy distinction in this study was that participants were able to demonstrate sustained noticing of student's disciplinary thinking in a relatively short period of time – nearly half that of previous studies. Using clips with high affordances in the early phases of the meetings, tools like the evidence-based reasoning rubric to focus and frame attention to students' thinking, and facilitation moves that model how to use evidence to support interpretations of students' thinking and associated teaching moves contributed to participant's rapid development of student-centered noticing. Given limitations of time and resources to provide effective professional development for teachers (Gulamhussein, 2013) and the importance of noticing students' ideas and responsive teaching (Levin, Hammer, Elby, & Coffey, 2013; Schoenfeld, 2011), and stimulating instructional change (Santagata & Yeh, 2013; Sherin, Jacobs, & Phillipp, 2011) this finding is encouraging.

With respect to research question two, results indicate that participation in video-based professional development can promote experimentation with classroom practice. In this study, two participants explored ways to make their students' thinking more visible by encouraging students to draw explanatory models based on their data and observations and another included more opportunities for her students to develop evidence-based claims. These modest changes are not only typical of how teachers appropriate new knowledge into their existing practice (Timperley, 2008), but are what instructional reformers now advocate (Bybee, 2014; Reiser, 2013; Star, 2015). Not only are small changes implemented relatively easily and are therefore more likely to be implemented, but they also set up more ambitious changes in the future because there is some indication that small changes in practice to incorporate more student-centered instruction can change teacher beliefs about what ideas students can contribute (Luft, 2001; van Es & Sherin, 2010). By becoming a student of one's students (McDonald et al., 2014), teacher learning becomes generative (Franke, Carpenter, Levi, Fennema, 2001).

However, not all participants in professional development focused on noticing and framing instruction in terms of students' thinking and reasoning will change quickly (or at all) without supportive opportunities to work on and through challenges that arise with implementation (Gallimore et al., 2009). In this study, we observed that in just five meetings, three teachers began to experiment with instructional changes and two came to perceive the value of a more student-centered approach to instruction. It may be the case that with additional cycles of bringing artifacts of participants' own practice to the video club, that teachers in this setting will come to develop a spirit of experimentation to their teaching. Having already established norms and routines for evidence-based analysis of students' disciplinary thinking, the work of the group could then pick up where video clubs similar to Sherin and Han (2004) and van Es and Sherin (2008) but with a more rapid progression to a "high functioning" community (van Es, 2012).

With respect to the research question three, results indicate that individual components of the video club – artifacts, framing activities, and facilitation – worked in concert to support critical discourse. While previous work has examined the individual influence of artifacts, or facilitation, or specific discussion structures on teacher learning (Borko et al., 2008; Gallimore et al., 2009; Levin et al., 2009; Seidel et al., 2011; Sherin et al., 2009; van Es et al., 2012), this study examined how these elements interacted in a learning ecology. This research and design approach afforded insights into how teacher learning changed over time in relation to the professional development design. Knowing not just that participants change, or even how participants change over the course of the professional development, but how design elements contribute and change in response to participant learning is important information that can inform future designs.

Artifacts, facilitation, and framing activities were of differing quality across the five meeting sequence. The most productive discussion resulted when all three elements were at their highest quality. However, the realities of working with practicing teachers in real classrooms with varying goals and contexts can make achieving high quality in artifact selection, facilitation, and tools difficult. It is important to note that highly productive discourse still occurred when the high affordances of some elements compensated for the low affordances of others. Skilled facilitation supported by high quality artifacts compensated for an underdeveloped framing tool (in this case, the evidence-based rubric). Skilled facilitation and a more developed framing tool later compensated for artifacts of lower quality. However, when multiple elements lack affordances, productivity of discussion suffered. Facilitation on its own, for example, cannot compensate for artifacts *and* tools with low affordances. Similarly, high quality artifacts cannot sustain productive discussion if they are poorly facilitated and lack supporting tools. Balancing the affordances of artifacts, facilitation, and tools in artifact-rich professional development is an important consideration for designers and facilitators.

More broadly, this work contributes to a growing understanding that teacher learning outcomes are not a result of a single professional development element, such as curricular tools, or collaborative meeting structures. Increasingly, policy-makers and school administrators rely on scripted curriculum (Ede, 2006), or simply instituting “Professional Learning Community” time (Vescio et al., 2009) to stimulate rapid changes in teacher practice without accounting for other elements of professional development. An awareness that teacher learning is best achieved when tools, tasks, and talk are integrated and responsive to the varying contexts in which they are embedded is critically important to achieving the ambitious instructional goals defined by the new Common Core State Standards and Next Generation Science Standards. It is also timely as the adoption of new standards triggers the design and adoption of new curricula from publishers. What this study makes clear is that teacher learning that results in meaningful changes in practice requires more than just a new set of textbooks, workbooks, and ancillary website. Professional development involves more than training teachers how to use the new materials – it requires the design of a long-term system of tools, tasks, and support in a collaborative environment in which teachers can work through multiple cycles of problem solving.

One limitation of this work is the influence teachers' content knowledge and content knowledge for teaching influenced discourse. The teachers in this particular group held four different types of credentials, which presented a challenge in selecting artifacts that were appropriately relevant and accessible to everyone in the group. Interpreting the ways students reason about disciplinary core ideas requires a requisite amount of content knowledge for teaching (Ball et al., 2008). Activities such as the "ideal response" discussion can help bridge *some* of the potential gap in content knowledge for teaching among participants who teach different subjects or grade levels, but this becomes more challenging as the content becomes more advanced and specific in high school level courses. Designing for a diverse group of teachers who do not share a common course assignment requires attention to artifact selection as well as scaffolds to support content-rich discussions of student thinking in artifacts. A potential solution would be to organize discussion groups online, but this format presents additional challenges. Participants might teach student populations that differ so greatly from each other that colleagues might not see the artifacts as relevant to their teaching contexts (Brophy, 2004). Establishing and maintaining a sense of community is more difficult in online formats (Palloff & Pratt, 2010). It also makes monitoring instructional changes in the participants' classrooms in between video club meetings particularly difficult if the group spans a large geographic area. Further exploration into the affordances of assembling a group of class-alike teachers to analyze artifacts versus the challenges associated with facilitating online professional development is needed.

This study was also limited to studying how design elements change in relation to participants in a particular context. Specifically, more study is needed to explore the *tensions* between design elements (tools, tasks, talk) in a variety professional development settings and the facilitator's role in negotiating them. The literature has documented best practice for tools, tasks, and talk, so the professional development community would benefit from moving to a disciplined and rigorous exploration of these elements together in a learning ecosystem. Some questions worth exploring include: Are some artifacts more advantageous for some professional development phases than others? Do artifacts and tools function differently in different phases, for example, drawing attention to student thinking versus drawing attention to models of instruction versus providing disconfirming evidence of beliefs that are barriers for instructional change? Rather than thinking about a set of "effective" facilitation moves, research that explores the use of those moves in relation to participants and tools would be helpful. Understanding the relation of elements of design ecology is an important next step in designing effective professional development of any form.

REFERENCES

Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., & Tuan, H. L. (2004). Inquiry in science education: International perspectives. *Science Education*, *88*(3), 397–419.

Alozie, N. M., Moje, E. B., & Krajcik, J. S. (2010). An analysis of the supports and constraints for scientific discussion in high school project-based science. *Science Education*, *94*(3), 395–427.

American Association for the Advancement of Science. (2009). *Benchmarks for scientific literacy*. New York, NY: Oxford University Press.

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, *13*(1), 1–12.

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research? *Educational Researcher, 41*,16–25.

Anelli, C. (2011). Scientific literacy: What is it, are we teaching it, and does it matter? *American Entomologist*, *57*(4), 235–244.

Ball, D. L., Thames, M. H., Phelps, G., Loewenberg Ball, D., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389–407.

Barnhart, T., & van Es, E. (2015). Studying teacher noticing: EXAMINING the relationship among pre-service science teachers' ability to attend, analyze and respond to student thinking. *Teaching and Teacher Education*, *45*, 83–93.

Basu, S. J., & Barton, A. C. (2007). Developing a sustained interest in science among urban minority youth. *Journal of Research in Science Teaching*, *44*(3), 466–489.

Bauer, M. W., Allum, N., & Miller, S. (2007). What can we learn from 25 years of PUS survey research? Liberating and expanding the agenda. *Public understanding of Science*, *16*(1), 79–95.

Berliner, D. C. (2001). Learning about and learning from expert teachers. *International Journal of Educational Research*, *35*(5), 463–482.

Berliner, D. C. (2004). Describing the behavior and documenting the accomplishments of expert teachers. *Bulletin of Science, Technology & Society*, *24*(3), 200–212.

Bolam, R., Mcmahon, A., Stoll, L., Thomas, S., Wallace, M., Greenwood, A., . . . Smith, M. (2005). Creating and sustaining effective professional learning communities. *Education*, 210. Retrieved from www.dfes.go.uk/research.

Borko, H. (2004, November). Professional development and teacher learning. *Educational Researcher*, *8*, 3–15.

Borko, H., Jacobs, J., Eiteljorg, E., & Pittman, M. E. (2008). Video as a tool for fostering productive discussions in mathematics professional development. *Teaching and Teacher Education*, *24*(2), 417–436.

Borko, H., Koellner, K., & Jacobs, J. (2014, June). Examining novice teacher leaders' facilitation of mathematics professional development. *The Journal of Mathematical Behavior*, *33*, 149–167.

Borko, H., Koellner, K., Jacobs, J., & Seago, N. (2011). Using video representations of teaching in practice-based professional development programs. *ZDM - International Journal on Mathematics Education*, *43*(1), 175–187.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education*, *95*(4), 639–669.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience and school.* Washington, DC: National Academy Press.

Brantlinger, A. & Sherin, M. G. (2006, April). *Discussing discussion: A video club in the service of National Board preparation.* Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA.

Brophy, J. (2004). *Using video in teacher education.* Amsterdam, Netherlands: Elsevier.

Brown, A. L., Ash, D., Rutherford, M., Nakagawa, K., Gordon, A., & Campione, J. C. (1993). Distributed expertise in the classroom. In G. Salomon (publ.): *Distributed cognitions: psychological and educational considerations* (pp. 188–228). Cambridge, UK: Cambridge University Press.

Brown, A. L. & Campione, J. C. (1996). Psychological theory and the design of innovative learning environments: on procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.): *Innovations in learning: New environments for education* (pp. 289-325). Mahwah, NJ: Lawrence Erlbaum Associates.

Brown, M. W. (2009). The teacher–tool relationship: Theorizing the design and use of curriculum materials. In J. T. Remillard, B. A. Herbel-Eisenmann, and G. M. Lloyd (Eds.): *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 17—36). New York, NY: Routledge.

Bybee, R. W. (2014). NGSS and the next generation of science teachers. Journal of Science Teacher Education, (25), 211-221.

Carlsen, W. S. (1992). Closing down the conversation: Discouraging student talk on unfamiliar science content. *Journal of Classroom Interaction; Journal of Classroom Interaction*, *27*(2), 15–21.

Cartier, J. L., Smith, M. S., Stein, M. K., & Ross, D. (2013). *Five practices for orchestrating taskbased discussions in science.* Reston, VA: National Council of Teachers of Mathematics.

Cazden, C. B. (2001). The language of teaching and learning. *The language of teaching and learning*. Portsmouth, NH; Heinemann.

Chin, C. (2007). Classroom Interaction in Science: Teacher questioning and feedback to students' responses. *International Journal of Science Education, 28*(11), 1315—1346.

Cobb, P., Confrey, J., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher*, *32*(1), 9–13.

Cochran-Smith, M., & Lytle, S. L. (1999). Relationships of knowledge and practice: Teacher learning in communities. *Review of Research in Education*, *24*, 249–305.

Cochran-Smith, M., & Lytle, S.L. (2009). *Inquiry as stance: Practioner research in the next generation.* New York, NY: Teachers College Press.

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of Research in Science Teaching*, *48*(10), 1109–1136.

Cohen, D. K. (1990). A revolution in one classroom: The case of Mrs. Oublier. *Educational Evaluation and Policy Analysis*, *12*(3), 311–329.

Cohen, D. K., & Ball, D. L. (1999). Teaching as the learning profession: Handbook of policy and practice. *Teaching as the Learning Profession: Handbook of Policy and Practice*. San Francisco, CA: Jossey Bass.

Coles, A. (2013). Using video for professional development: the role of the discussion facilitator. *Journal of Mathematics Teacher Education*, *16*(3), 165–184.

Curry, M. (2008). Critical friends groups: The possibilities and limitations embedded in teacher professional communities aimed at instructional improvement and school reform. *Teachers and Teaching: Theory and Practice*, *110*(4), 733–774.

Darling-Hammond, L. (2008). Teacher learning that supports student learning. In B. Presseisen (Ed.) *Teaching for intelligence,* (pp. 91–100). Thousand Oaks, CA: Corwin.

Davis, E. A. (2006). Characterizing productive reflection among preservice elementary teachers: Seeing what matters. *Teaching and Teacher Education*, *22*(3), 281–301.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriuculm materials to promote teacher learning. *Educational Researcher, 34*(3), 3–14.

Davis, E. A., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. *Review of Educational Research*, *76*(4), 607–651.

Dede, C., Honan, J. P., & Peters, L. C. (2005). *Scaling up success: Lessons learned from technology-based educational improvement*. Indianapolis, IN: Jossey-Bass.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181–199.

Dewey, J. (1927). *The public and its problems*. New York, NY: Holt.

Dillon, J. T. (1988). *Questioning and discussion: A multidisciplinary study*. Norwood, NJ: Greenwood Publishing Group.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational researcher*, *23*(7), 5–12.

DuFour, R., & Eaker, R. (2005). *Professional learning communities at work TM: Best practices for enhancing students achievement*. Alexandria, VA: Solution Tree Press.

Dunne, F., Nave, B., & Lewis, A. (2000). Critical friends groups: Teachers helping teachers to improve student learning. *Phi Delta Kappan*, (28), 1–9.

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education*, *32*(1), 268–291.

Duschl, R. A., & Gitomer, D. H. (1997). Strategies and challenges to changing the focus of assessment and instruction in science classrooms. *Educational Assessment*, *4*(1), 37–73.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.) (2007). *Taking science to school: Learning and teaching science in grades K–8*. Washington, DC: National Academies Press.

Dyer, E. (2013). *Teacher noticing to support collaboration among teachers.* Unpublished manuscript.

Eaker, R., & DuFour, R. (2015). *Getting started: Reculturing schools to become professional learning communities*. Alexandria, VA: Solution Tree Press.

Eccles, J. S. (2004). Schools, academic motivation, and stage-environment fit. *Handbook of Adolescent Psychology*, *2*, 125–153.

Ede, A. (2006). Scripted curriculum: Is it a prescription for success? *Childhood Education*, *83*, 29–32.

Edelson, D. C. (2002). design research: What we learn when we engage in design. *Journal of the Learning Sciences*, *11*(1), 105–121.

Erduan, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education*, *88(6)*, 915– 933.

Feinstein, N. (2011). Salvaging science literacy. *Science education*, *95*(1), 168–185.

Flinchbaugh, J., & Carlino, A. (2006). *The hitchhiker's guide to lean: Lessons from the road.* Dearborn, MI: Society of Manufacturing Engineers.

Franke, M. L., Carpenter, T. P., Levi, L., & Fennema, E. (2001). Capturing teachers' generative change: A follow-up study of professional development in mathematics. *American Educational Research Journal*, *38*(3), 653–689.

Furtak, E. M. (2006). The problem with answers: An exploration of guided scientific inquiry teaching. *Science Education*, *90*(3), 453–467.

Furtak, E. M., & Ruiz-Primo, M. A. (2008). Making students' thinking explicit in writing and discussion: An analysis of formative assessment prompts. *Science Education*, *92*(5), 799–824.

Gallimore, R., Ermeling, B. A., Saunders, W. M., & Goldenberg, C. (2009). Moving the learning of teaching closer to practice: Teacher education implications of school-based inquiry teams. *The Elementary School Journal*, *109*(5), 537–553.

Galton, M. (2009). Moving to secondary school: Initial encounters and their effects. *Perspectives on Education*, *2*(2009), 5–21.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915–945.

Gay, G. (2002). Preparing for culturally responsive teaching. *Journal of Teacher Education, 53*(2), 106–116.

Gleick, J. (2011). *The information: A history, a theory, a flood* [HarperCollins: Kindle version].

Goodwin, C. (1994). Professional vision. *American anthropologist*, *96*(3), 606–633.

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (2009). Effects of inquiry-based learning on students' science literacy skills and confidence. *International journal for the Scholarship of Teaching and Learning*, *3*(2), 16.

Greeno, J. G., Collins, A. & Resnick, L. B. (1996) Cognition and learning (Ch 2). In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of Educational Psychology.* New York: Macmillan, 15-46.

Gregoire, M. (2003). Is it a challenge or a threat? A dual-process model of teachers' cognition and appraisal processes during conceptual change. *Educational Pyschology Review, 15*(2), 147–179.

Gröschner, A., Seidel, T., Pehmer, A.-K., & Kiemer, K. (2014). Facilitating collaborative teacher learning: The role of "mindfulness" in video-based teacher professional development programs. *Gruppendynamik Und Organisationsberatung*, *45*(3), 273–290.

Grossman, P., & McDonald, M. (2008). Back to the future: Directions for research in teaching and teacher education. *American Educational Research Journal*, *45*(1), 184–205.

Grossman, P. L., Smagorinsky, P., & Valencia, S. (1999). *Appropriating conceptual and pedagogical tools for teaching English: A conceptual framework for studying professional development.* National Research Center on English Learning & Achievement, University at Albany, State University of New York. Retrieved from http://www.albany.edu/cela/reports/grossmanappropriating12011.pdf.

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *Teachers College Record, 103*(6), 942–1012.

Gulamhussein, A. (2013). *Teaching the teachers: Effective professional development in an era of high stakes accountability.* The Center for Public Education. Retrieved from http://www.centerforpubliceducation.org/teachingtheteachers.

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

Guskey, T. R. (2002). Professional development and teacher change. *Teachers and Teaching: Theory and Practice*, *8*(3), 381–391.

Hatch, J. A. (2002). *Doing qualitative research in education settings*. New York, NY: Suny Press.

Hammer, D. (2000). Student resources for learning introductory physics. *American Journal of Physics*, *68*(S1), S52–S59.

Hammer, D., & Schifter, D. (2001). Practices of inquiry in teaching and reserach. *Cognition and Instruction*, *19*(4), 441–478.

Hawley, W. D., & Valli, L. (1999). The essentials of effective professional development: A new consensus. In L. Darling-Hammond, and G. Sykes (Eds.). *Teaching as the learning profession: Handbook of policy and practice* (pp 127–150). San Francisco, CA: Jossey-Bass.

Horn, I. S., & Little, J. W. (2010). Attending to problems of practice: Routines and resources for professional learning in teachers' workplace interactions. *American Educational Research Journal*, *47*(1), 181–217.

Hurd, P. D. (2000). Science education for the 21st century. *School Science and Mathematics*, *100*(6), 282–288.

Kang, E. J., Bianchini, J. A., & Kelly, G. J. (2013). Crossing the border from science student to science teacher: Preservice teachers' views and experiences learning to teach inquiry. *Journal of Science Teacher Education*, *24*(3), 427–447.

Kazemi, E., & Franke, M. L. (2004). Teacher learning in mathematics: Using student work to promote collective inquiry. *Journal of Mathematics Teacher Education*, *7*, 203–235.

Kazemi, E., & Hubbard, A. (2008). New directions for the design and study of professional development. *Journal of Teacher Education*, *59*(5), 428–441.

Kazemi, E., & Stipek, D. (2001). Promoting conceptual thinking in four upper-elementary mathematics classrooms. *The Elementary School Journal*, *102*(1), 59.

Kelly, A. (2004). Design research in education: Yes, but is it methodological? *Journal of the Learning Sciences*, *13*(1), 115–128.

Kennedy, M. (1999). The role of preservice teacher education. In L. Darling-Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp 54–85). San Francisco, CA: Jossey-Bass.

Kersting, N. B., Givvin, K. B., Sotelo, F. L., & Stigler, J. W. (2010). Teachers' analyses of classroom video predict student learning of mathematics: Further explorations of a novel measure of teacher knowledge. *Journal of Teacher Education*, *61*(1–2), 172–181.

Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. *Journal of Research in Science Teaching*, *39*(6), 522–549.

Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-goals-driven design model: Developing curriculum materials that align with national standards and incorporate project-based pedagogy. *Science Education*, *92*(1), 1–32.

Lau, M. (2010). *Understanding the dynamics of teacher attention: Case studies of how high school physics and physical science teachers attend to student ideas.* (Unpublished doctoral dissertation). University of Maryland, College Park.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge University Press.

Le Fevre, D. M. (2004). Designing for teacher learning: Video-based curriculum design. In J. Brophy (Ed.), *Using video in teacher education* (pp. 235–258). New York, NY: Elsevier.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex Publishing Corporation.

Levin, D. M. (2008). What secondary science teachers pay attention to in the classroom: Situating teaching in institutional and social systems. (Doctoral dissertation). University of Maryland, College Park.

Levin, D. M., Hammer, D., & Coffey, J. E. (2009). Novice teachers' attention to student thinking. *Journal of Teacher Education*, *60*(2), 142–154.

Levin, D. M., Hammer, D., Elby, A., & Coffey, J. E., (2013). *Becoming a responsive science teacher*. Arlington, VA, NSTA Press.

Lewis, C. (2000). *Lesson study: The core of Japanese professional development.* Retrieved from http://eric.ed.gov/?id=ED444972

Lewis, C., Perry, R., & Murata, A. (2006). How should research contribute to instructional improvement? The case of lesson study. *Educational researcher*, *35*(3), 3–14.

Lincoln, Y., & Guba, E (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage.

Little, J. W. (1993). Teachers' professional development in a climate of educational reform. *Educational Evaluation and Policy Analysis*, *15*(2), 129–151.

Little, J. W. (2002). Locating learning in teachers' communities of practice: Opening up problems of analysis in records of everyday work. *Teaching and Teacher Education*, *18*(8), 917–946.

Little, J. W. (2006). *Professional development and professional community in the learner-centered school.* Arlington, VA: National Education Association.

Little, J. W., Gearhart, M., Curry, M., & Kafka, J. (2003). Looking at student work for teacher learning, teacher community, and school reform. *Phi Delta Kappan, 85*(3), 184—192.

Lord, B. (1994). Teachers' professional development: Critical colleagueship and the role of professional communities. In N. Cobb (Ed.) *The future of education: Perspectives on national standards in education* (pp.175–204). New York, NY: College Entrance Exam Board.

Loughran, J. J. (2002). Effective reflective practice in search of meaning in learning about teaching. *Journal of Teacher Education*, *53*(1), 33–43.

Luft, J. A., (2001). Changing inquiry practices and beliefs: The impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education, 23*(5), 517-534.

Marshall, J. C., Smart, J., & Horton, R. M. (2010). The design and validation of EQUIP: An instrument to assess inquiry-based instruction. *International Journal of Science and Mathematics Education*, *8*(2), 299–321.

McDonald, M., Kazemi, E., Kelley-Petersen, M., Mikolasey, K., Thompson, J., Valencia, S. W., & Windschitl, M. (2014). Practice makes practice: Learning to teach in teacher education. *Peabody Journal of Education, 89*(4), 500-515.

McLaughlin, M. W., & Talbert, J. E. (2006). *Building school-based teacher learning communities: Professional strategies to improve student achievement* (Vol. 45). New York, NY: Teachers College Press.

McNeill, K. L. & Krajcik, J. (2007). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In M. Lovett, & P. Shah (Eds.), *Thinking with data* (pp. 233-265). New York, NY: Taylor & Francis Group, LLC.

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education*, *94*(2), 203–229.

McWhorter, R. R., Delello, J. A., Roberts, P. B., Raisor, C. M., & Fowler, D. A. (2013). A cross-case analysis of the use of web-based eportfolios in higher education. *Journal of Information Technology Education*, *12*.

Mehan, H. (1979). “What time is it, Denise?”: Asking known information questions in classroom discourse. *Theory into Practice*, *18*(4), 285–294.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage.

Miller, K., & Zhou, X. (2007). Learning from classroom video: What makes it compelling and what makes it hard. In R. Goldman, R Pea, B. Barron, & S. Derry (Eds.), *Video research in the learning sciences* (pp. 321–334). New York, NY: Routledge.

Minstrell, J. (2000). Implications for teaching and learning inquiry: A summary. In J. Minstrell & E. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 471–496). Washington, DC: American Association for the Advancement of Science.

Minstrell J., & van Zee, E. (2000). *Inquiring into inquiry learning and teaching in science.* Washington, DC: American Association for the Advancement of Science.

Morris, A. K., Hiebert, J., & Spitzer, S. M. (2009). Mathematical knowledge for teaching in planning and evaluating instruction: What can preservice teachers learn?. *Journal for Research in Mathematics Education*, 491–529.

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. Maidenhead, UK: Open University Press.

National Governors Association Center for Best Practices, Council of Chief State School Officers (2010). *Common Core State Standards.* Washington, DC: National Governors Association Center for Best Practices, Council of Chief State School Officers.

National Research Council. (2012). *A framework for k–12 science education: Practices, crosscutting concepts, and core ideas*. Committee on a Conceptual Framework for New K–12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. National Academies Press. Retrieved from http://www.nap.edu/download.php?record_id=13165.

National Staff Development Council. (2001). *Standards for staff development.* Retrieved from learningforward.org.

Nemirovsky, R., & Galvis, A. (2004). Facilitating grounded online interactions in video-case-based teacher professional development. *Journal of Science Education and Technology*, *13*(1), 67–79.

Nystrand, M., & Gamoran, A. (1991). Instructional discourse, student engagement, and literature achievement. *Research in the Teaching of English*, *25*(3), 261–290.

Nystrand, M., Wu. L., Gamoran, A., Zeiser, S., & Long D. (2003). Questions in time: Investigating the structure and dynamics of unfolding classroom discourse. *Discourse Processes 35*(2), 135–198.

Olitsky, S. (2006). Structure, agency, and the development of students' identities as learners. *Cultural Studies of Science Education*, *1*(4), 745–766.

O'Neill, J. (2000). SMART goals, SMART schools. *Educational Leadership*,*57*(5), 46–50.

Opfer, V. D., & Pedder, D. (2011). Conceptualizing Teacher Professional Learning. *Review of Educational Research*, *81*(3), 376–407.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994–1020.

Ottenbreit-Leftwich, A. T., Glazewski, K. D., Newby, T. J., & Ertmer, P. A. (2010). Teacher value beliefs associated with using technology: Addressing professional and student needs. *Computers and Education*, *55*(3), 1321–1335.

Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching*, *46*(2), 147–165.

Palloff, R. M., & Pratt, K. (2010). *Collaborating online: Learning together in community* (Vol. 32). San Francisco, CA: John Wiley & Sons.

Park, S., Jang, J. Y., Chen, Y. C., & Jung, J. (2011). Is pedagogical content knowledge (PCK) necessary for reformed science teaching?: Evidence from an empirical study. *Research in Science Education*, *41*(2), 245–260.

Penuel, W. R., Fishman, B. J., Cheng, B. H., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher*, *40*(7), 331–337.

Phelps, C. M. & Spitzer, S. M. (2015). Propsepctive teachers' conceptions and values about learning from teaching. *Teachers and Teaching: Theory and Practice, 21*(1), 61-73.

Pimentel, D. S., & McNeill, K. L. (2013). Conducting talk in secondary science classrooms: Investigating instructional moves and teachers' beliefs. *Science Education*, *97*(3), 367–394.

Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology*, *95*(4), 667.

Planning for engagement with important science ideas. (2014). Retrieved from ambitiousscienceteaching.org.

Plomp, T. (2013). Educational design research: An introduction. In T. Plomp & N. Nieveen (Eds.), *Educational design research – part A: An introduction* (pp. 10–51). Enschede, the Netherlands: SLO.

Pluta, W. J., Chinn, C. A., & Duncan, R. G. (2011). Learners' epistemic criteria for good scientific models. *Journal of Research in Science Teaching*, *48*(5), 486–511.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher*, *29*(1), 4–15.

Reiser, B. J. (2013). What professional development strategies are needed for successful implementation of the Next Generation Science Standards? Paper written for the Invitational Research Symposium on Science Assessment, Washington, D.C.

Remillard J. T., & Geist, P. K. (2002). Supporting teachers' professional learning by navigating openings in the curriculum. *Journal of Mathematics Teacher Education, 5*(1), 7–34.

Richards, J., & Elby, A. (2014). Incorporating disciplinary practices into characterizations of progress in responsive teaching. *Journal of Learning Sciences*, 1–29.

Richardson, V. (1992). The agenda-setting dilemma in a constructivist staff development process. *Teaching and Teacher Education*, *8*(3), 287–300.

Rodgers, C. (2002). Defining reflection: Another look at John Dewey and reflective thinking. *The Teachers College Record*, *104*(4), 842–866.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. New York, NY: Oxford University Press.

Roth, W. M., & Lee, S. (2002). Scientific literacy as collective praxis. *Public Understanding of Science*, *11*(1), 33–56.

Rothwell, J. (2013, June). *The hidden STEM economy.* Metropolitan Policy Program at Brookings. Retrieved from http://www.brookings.edu/~/media/research/files/reports/2013/06/10%20stem%20economy%20rothwell/thehiddenstemeconomy610.pdf.

Ruiz-Primo, M. A., & Furtak, E. M. (2006). Informal formative assessment and scientific inquiry: Exploring teachers' practices and student learning. *Educational Assessment*, *11*(3 & 4), 205–235.

Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *Journal of Research in Science Teaching*, *50*(3), 284–314.

Russ, R. S., & Sherin, M. (2013, April). *Modeling the relationship between teacher noticing and student learning.* Paper presented at the American Educational Research Association annual meeting, San Francisco, CA.

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences, 23*(1), 18—36.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, *89*(4), 634–656.

Sandoval, W. A., Deneroff, V., & Franke, M. L. (2002). *Teaching, as learning, as inquiry: moving beyond activity in the analysis of teaching practice*. Paper presented at the American Educational Research Association annual meeting, New Orleans, LA.

Sandoval, W. A., & Harven, A. M. (2011). Urban middle school students' perceptions of the value and difficulty of inquiry. *Journal of Science Education and Technology*, *20*(1), 95–109.

Santagata, R. (2009). Designing video-based professional development for mathematics teachers in low-performing schools. *Journal of teacher education*, *60*(1), 38–51.

Santagata, R., & Angelici, G. (2010). Studying the impact of the lesson analysis framework on preservice teachers' abilities to reflect on videos of classroom teaching. *Journal of Teacher Education*, *61*(4), 339–349.

Santagata, R., Gallimore, R., & Stigler, J. W. (2005). The use of videos for teacher education and professional development: past experiences and future directions. In C. Vrasidas & G. V.Glass (Eds.), *Current perspectives on applied information technologies: Preparing teachers to teach with technology* (Vol. 2, pp. 151–167).Greenwich, CT: Information Age Publishing.

Santagata, R., & van Es, E. (2010). Disciplined analysis of mathematics teaching as a routine of practice. *AMTE Monograph*, *7*, 109–123.

Santagata, R., & Yeh, C. (2013). Learning to teach mathematics and to analyze teaching effectiveness: evidence from a video-and practice-based approach. *Journal of Mathematics Teacher Education*, December, 1-24.

Schoenfeld, A. H. (2011). Noticing matters. A lot. Now what? In M. Sherin, V. Jacobs, & R. Phillips (Eds.) *Mathematics teacher noticing: Seeing through teachers' eyes* (pp.223–238). [Routledge: Kindle version.]

Schwartz, M. S., Sonnert, G., & Tai, R. H. (2008). Depth versus breadth: How content coverage in high school science courses relates to later success in college science coursework. *Science Education*, 93(5), 798–826.

Seago, N. M. (2000). Using video of classroom practice as a tool to study and improve teaching. In *teaching to meet the needs of middle grades learners and to maintain high expectations*: *Proceedings of a national convocation and action conferences* (pp. 63–75). Washington, DC: National Academy Press.

Sebring, P. B., Allensworth, E., Bryk, A. S., Easton, J. Q., & Luppescu, S. (2006). the essential supports for school improvement. Research Report. *Consortium on Chicago School Research*. Retrieved from http://files.eric.ed.gov/fulltext/ED498342.pdf.

Seidel, T., Sturmer, K., Blomberg, G., Kobarg, M., & Schwindt, K (2011). Teacher learning from analysis of videotaped classroom situations: Does it make a difference whether teachers observe their own teaching or that of others? *Teaching and Teacher Education, 27*(2), 259–267.

Sherin, M. (2004). New perspectives on the role of video in teacher education. In J. Brophy (Ed.), *Using video in teacher education* (pp. 1–27). New York, NY: Elsevier.

Sherin, M. G., & Han, S. Y. (2004). Teacher learning in the context of a video club. *Teaching and Teacher Education*, *20*(2), 163–183.

Sherin, M.G., Jacobs, V., & Phillips R. (2011). *Mathematics teacher noticing: Seeing through teachers' eyes*. [Routledge: Kindle version.]

Sherin, M. G., & Linsenmeier, K. A. (2011). Pause, rewind, reflect. *Journal of Staff Development*, *32*(5), 38–41.

Sherin, M. G., Linsenmeier, K. A., & van Es, E. A. (2009). Selecting video clips to promote mathematics teachers' discussion of student thinking. *Journal of Teacher Education*, *60*(3), 213–230.

Sherin, M. G., Russ, R. S., & Colestock, A. A. (2011). Accessing mathematics teachers' in-the-moment noticing. In M. Sherin, V. Jacobs, & R. Phillips (Eds.) *Mathematics teacher noticing: Seeing through teachers' eyes* (pp.79–94). [Routledge: Kindle version.]

Sherin, M., & van Es, E. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education*, *13*(3), 475–491.

Sherin, M. G., & van Es, E. A. (2009). Effects of video club participation on teachers' professional vision. *Journal of Teacher Education*, *60*(1), 20–37.

Shifter, D., & Lester, J. (2005). Active facilitation: What do mathematics specialists need to know and how might they learn it? *Journal of Mathematics and Science, 8*, 97-118.

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

Shulman, L. S., & Shulman, J. H. (2004). How and what teachers learn: A shifting perspective. *Journal of Curriculum Studies*, *36*(2), 257–271.

Sinatra, G. M., & Chinn, C. A. (2012). Thinking and reasoning in science: Promoting epistemic conceptual change. In K. Harris, S. Graham, T. Urdan, A. Bus, S. Major, & H. Swanson (Eds.), *APA educational psychology handbook, Vol 3: Application to learning and teaching* (pp. 257–282). Washington, DC, US: American Psychological Association.

Star, J. R. (2015). *Improve math teaching with incremental improvements.* Retrieved from http://www.kappancommoncore.org/improve-math-teaching-with-incremental-improvements/.

Star, J. R., & Strickland, S. K. (2008). Learning to observe: Using video to improve preservice mathematics teachers' ability to notice. *Journal of Mathematics Teacher Education*, *11*(2), 107–125.

Stipek, D. J. (1996). Motivation and instruction. In P. Alexander & P. H. Vinne (Eds.) *Handbook of educational psychology* (pp.85–113). New York, NY: Routledge.

Stroupe, D. (2014). Beginning science teachers' use of tools to learn ambitious instruction. *LEARNing Landscapes, 8*(1), 269–285.

Sun, J., & van Es, E. A. (2015, March). An exploratory study of the influence that analyzing teaching has on preservice teachers' classroom practice. *Journal of Teacher Education*, 1–15.

Tannen, D. (1990). *You just don't understand: Men and women in conversation.* New York, NY: Harper Collins.

Tannen, D. (1993). *Framing in discourse*. New York, NY: Oxford University Press.

Thompson, J., Windschitl, M., & Braaten, M. (2010). *Developing a theory of teacher practice.* Paper presented at the National Association for Research in Science Teaching Annual Conference, Philadelphia, PA.

Thompson, J., Braaten, M., Windschitl, M., Sjoberg, B., Jones, M., & Martinez, K. (2009, November). Collaborative inquiry into students' evidence-based explanations: How groups of science teachers can improve teaching and learning. *The Science Teacher,* 48–52.

Thompson, C. L., & Zeuli, J. S. (1999). The frame and the tapestry: Standards-based reform and professional development. In L. Darling-Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 341–375). San Francisco, CA: Jossey Bass.

Timperley, H. (2008). *Teacher professional learning and development.* Retrieved February 20, 2016, from http://edu.aru.ac.th/childedu/images/PDF/benjamaporn/EdPractices_18.pdf

Toulmin, S. E. (2003). *The uses of argument*. New York, NY: Cambridge University Press.

Tripp, T., & Rich, P. (2012). Using video to analyze one's own teaching. *British Journal of Educational Technology*, *43*(4), 678–704.

Turner, J. C., Midgley, C., Meyer, D. K., Gheen, M., Anderman, E. M., Kang, Y., & Patrick, H. (2002). The classroom environment and students' reports of avoidance strategies in mathematics: A multimethod study. *Journal of Educational Psychology*, *94*(1), 88.

van Es, E. A. (2012). Examining the development of a teacher learning community: The case of a video club. *Teaching and Teacher Education*, *28*(2), 182–192.

van Es, E. A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Journal of Technology and Teacher Education*, *10*(4), 571–596.

van Es, E. A., & Sherin, M. G. (2006). How different video club designs support teachers in" learning to notice. *Journal of Computing in Teacher Education*, *22*(4), 125.

van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Education*, *24*(2), 244–276.

van Es, E. A., & Sherin, M. G. (2010). The influence of video clubs on teachers' thinking and practice. *Journal of Mathematics Teacher Education*, *13*(2), 155–176.

van Es, E. A., Tunney, J., Seago, N., & Goldsmith, L. (2014). *A framework for the facilitation of teachers' analysis of video.* Symposium paper presented at the American Educational Research Association annual meeting, Vancouver, B.C.

van Zee, E. H., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. *Journal of Research in Science Teaching*, *38*(2), 159–190.

van Zee, E., & Minstrell, J. (1997). Using questioning to guide student thinking. *The Journal of the Learning Sciences*, *6*(2), 227–269.

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education*, *24*(1), 80–91.

Wakamatsu, Y. (2009*). The Toyota mindset: The ten commandments of Taiichi Ohno.* Bellingham, WA: Enna Products Corporation.

Weinbaum, A., Allen, D., Blythe, T., Simon, K., Seidel, S., & Rubin, C. (2004). *Teaching as inquiry.* New York, NY: Teachers College Press.

Wenger, E. (2011). *Communities of practice: A brief introduction.* National Science Foundation (U.S.). Retrieved from http://scholarsbank.uoregon.edu/xmlui/handle/1794/11736.

Wigfield, A., & Eccles, J. S. (2000). Expectancy–value theory of achievement motivation. *Contemporary educational psychology*, *25*(1), 68–81.

Wilkinson, B., Akiba, M., Farfan, G., Howard, C. & Kuleshova, A. (2016, April). *Lesson study in Florida*. Paper presented at the Annual Meeting of the American Educational Research Association, Washington, DC.

Windschitl, M., & Thompson, J. (2006). Transcending simple forms of school science investigation: The impact of preservice instruction on teachers' understandings of model-based inquiry. *American Educational Research Journal*, *43*(4), 783–835.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941–967.

Windschitl, M., Thompson, J., & Braaten, M. (2011). Ambitious pedagogy by novice teachers: Who benefits from tool-supported collaborative inquiry into practice and why. *Teachers College Record*, *113*(7), 1311–1360.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for science teachers. *Science Education, 96*(5), 878–903.

Xie, Y., & Killewald, A. A. (2012). *Is American science in decline?* Boston, MA: Harvard University Press.

Zhang, M., Lundeberg, M., Koehler, M. J., & Eberhardt, J. (2011). Understanding affordances and challenges of three types of video for teacher professional development. *Teaching and Teacher Education*, *27*(2), 454–462.

APPENDIX A

Teacher Interview Protocol

This interview is being conducted during your video club participation to help me understand the impact you perceive this professional development has on you and the group as well as on student reasoning and interest in science. The interview will be audio and video recorded, but anything you say in this interview will remain confidential. You have the right to refuse to answer any questions or stop the interview at any time. I have some questions to get us started, but I may also ask you some other questions as we proceed.

First participant interview (November, 2013)

1. First, I'm interested in learning more about your teaching background.
    a. For how many years have you been teaching?
    b. How long have you taught at your current school?
    c. What is your current teaching assignment at your school?

2. Now that you've made the decision to participate in the video club, what are your expectations?
    a. What do you hope to get out of the experience?
    b. What types of work do you anticipate doing?
    c. What difficulties or challenges are you concerned about?

3. Finally, I'd like to learn about how you approach teaching science.
    a. How important is developing students' ability to use evidence to reason about science concepts?
    b. How would you describe your role as a teacher in teaching students how to use evidence to reason about science concepts?
    c. How do you monitor student development of reasoning skill in your class? How do you know they are learning and improving?
    d. How do you feel about student errors in science? For example, are errors to be avoided or ignored or are errors seen as opportunities for individuals or the class to learn? How would you characterize how you treat errors in your classroom?
    e. How important is it to develop student interest in science?
    f. What is your role in promoting student interest in science?

4. Are there other thoughts or ideas you'd like to share with me?

Thank you so much for your time. This has been very helpful for me. If you have any questions, please feel free to contact me.

End of year interview (June, 2014)

This interview is being conducted during your video club participation to help me understand the impact you perceive this professional development has on you and the group as well as on student reasoning and interest in science. The interview will be audio and video recorded, but anything you say in this interview will remain confidential. You have the right to refuse to answer any questions or stop the interview at any time. Again, these questions are used to get us started. Do you have any questions before we begin?

1. Looking back on your video club experience, I'd like to learn about the types of work you did over the past several months.
    a. At our first interview, I asked you about your expectations for the process. How did your actual experience compare to your expectations?
    b. What types of work did you engage in through this process?
    c. What role did your colleagues play in this work?
    d. Can you describe a specific interaction you had with colleagues that was particularly salient to you?

2. Finally, I'd like to know about the impact you feel this process may have had on your practice.
    a. What kind of changes in yourself do you see or feel as a result of this process?
    b. How would you describe your role as a teacher of student reasoning using evidence now?
    c. In your opinion, are your students making better use of evidence in reasoning about science concepts? How do you know?
    d. How would you describe your role as promoting student interest in science now?
    e. In your opinion, are your students developing more interest in science? How do you know?
    f. How would you describe the way you treat student errors now?

3. You've been really helpful. Is there anything else you'd like to share with me about your experience?

APPENDIX B

Frequency of Topic Clusters by Idea Unit

Topic	Meeting 1		Meeting 2		Meeting 3						Meeting 4		Meeting 5			
	C1	C2	C1	C2	C1	C2	C3	SW1	SW2	SW3	SW1	SW2	C1	SW1	SW2	SW3
DCI/ST	1 (55)	1 (49)	1 (21)		2 (50)		4 (100)	1 (65)	2 (77)	1 (42)	2 (83)	1 (20)			1 (24)	
DCI/INST/ST	3 (53)	2 (30)			1 (22)			1 (8)							1 (16)	1 (22)
INST/ST			1 (52)													
DCI/INST/ST/ ASSESS					1 (14)			1 (49)			1 (77)			1 (53)		1 (24)
INST			1 (16)	2 (71)		1 (9)										
DCI/INST		1 (30)	1 (23)													
DCI			1 (68)						1 (18)							
Other ST combo			1 (43)						1 (36)		1 (21)		1 (22)		1 (7)	1 (9)
Other (not ST)	1 (17)	1 (15)		1 (71)	1 (4)		1 (4)		1 (14)		1 (18)				1 (54)	

Note. Total turns of talk for each topic cluster is noted in parenthesis.

APPENDIX C

Topic, Stance, Use of Evidence, and Participation by Idea Unit

Meeting, Artifact, Idea Unit	topic	stance	evidence	participation	#participants	turns of talk
M1C1#1	DCI/ST	INT	ART	MH	5/6	55
M1C1#2	INST/ST	EVAL	ANEC	MH	5/6	38
M1C1#3	INST/ST	DESC	ART	L	4/6	9
M1C1#4	INST/ST	EVAL	ANEC	MH	3/6	6
M1C1#5	ClassMang	EVAL	ANEC/ART	L	5/6	17
M1C2#1	DCI/ST	INT	ART	MH	6/6	49
M1C2#2	DCI/ST/INST	EVAL	ANEC/ART	ML	4/6	14
M1C2#3	DCI/ST/INST	EVAL	ART	H	3/6	16
M1C2#4	DCI/OTHER	INT	ART/SCI	ML	4/6	15
M1C2#5	DCI/INST	EVAL	ANEC/ART	MH	5/6	30
M2C1#1	DCI	INT	ANEC/ART/SCI	H	3/3	68
M2C1#2	DCI/ST	EVAL	ART/SCI	MH	3/3	21
M2C1#3	INST	EVAL	ART	H	3/3	16
M2C1#4	DCI/INST	INT	ART/SCI	H	3/3	23
M2C1#5	INST/ST	EVAL	ANEC/ART	H	3/3	52
M2C1#6	INST/ST/BEH	EVAL	ART	MH	3/3	43
M2C2#1	INST	EVAL	ART	MH	3/3	51
M2C2#2	INST	EVAL	ANEC/ART	H	3/3	20
M2C2#3	INST/MOT	EVAL	ANEC	H	3/3	71
M3C1#1	DCI/ST	INT	ART	MH	4/4	32
M3C1#2	DCI/ST/ASSESS	INT	ART	MH	3/4	14
M3C1#3	DCI/ST/INST	INT	ART	MH	4/4	22
M3C1#4	ASSESS/VOCAB	EVAL	ART	MH	3/4	4
M3C1#5	DCI/ST	INT	ART	MH	4/4	18
M3C2#1	INST	EVAL	ART	L	3/4	9
M3C3#1	DCI/ST	INT	ART	MH	4/4	32
M3C3#2	ASSESS	EVAL	ART	MH	3/4	4
M3C3#3	DCI/ST	INT	ART	MH	3/4	17
M3C3#4	DCI/ST	DESC	SCI	MH	3/4	33
M3C3#5	DCI/ST	INT	ART	MH	4/4	18
M3SW1#1	DCI/ST	INT	ART	MH	4/4	65
M3SW1#2	DCI/ST/INST	INT	ART	MH	2/4	8
M3SW1#3	DCI/ST/INST/ASSESS	INT	ART	MH	4/4	49
M3SW2#1	OTHER	EVAL	ART	MH	4/4	14
M3SW2#2	DCI	DESC	ANEC/SCI	MH	3/4	18
M3SW2#3	DCI/ST	INT	ART	H	4/4	70
M3SW2#4	ST/VOCAB	INT	ANEC/ART	H	4/4	36
M3SW2#5	DCI/ST	EVAL	ART	MH	3/4	17

M3SW3#1	DCI/ST	INT	ART	MH	4/4	42
M4SW1#1	DCI/ST	INT	ART	MH	4/4	77
M4SW1#2	DCI/ST/INST/ASSESS	INT	ANEC	H	4/4	77
M4SW1#3	MOT	EVAL	ANEC	H	4/4	18
M4SW1#4	DCI/ST	EVAL	ART	L	2/4	6
M4SW1#5	INST/ST/MOT	EVAL	ANEC	MH	3/4	21
M4SW2#1	DCI/ST	INT	ART	MH	4/4	20
M5C1#1	DCI/INST/ST/VOCAB	EVAL	ANEC/ART	ML	4/4	22
M5SW1#1	DCI/ST/INST/ASSESS	INT	ART	H	4/4	53
M5SW2#1	DCI/ST	INT	ART	MH	3/4	24
M5SW2#2	INST/ST/CLIMATE	EVAL	ANEC	L	2/4	7
M5SW2#3	DCI/ST/INST	INT	ANEC/ART	MH	3/4	16
M5SW2#4	INST/ASSESS/MOT	EVAL	ANEC	MH	4/4	54
M5SW3#1	DCI/ST/INST	INT	ANEC/ART	H	3/4	22
M5SW3#2	ST	EVAL	ANEC/ART	L	3/4	9
M5SW3#3	DCI/ST/INST/ASSESS	INT	ANEC/ART	MH	3/4	24

Note. DCI = disciplinary core idea; ST = student thinking; INST = instruction; CM = classroom management; BEH = behavior; MOT = motivation, ASSESS = assessment, INT = interpretive, EVAL = evaluative, DESC = descriptive, ART = artifact, ANEC = anecdotal, SCI = scientific theory, L = low, ML = medium low, MH = medium high, H – high.

APPENDIX D

Lesson graph with notes and analytic memo as informed by EQUIP

Time (minutes)	Phase	Observations
0-56	Data collection (cont.) in lab groups	V explaining agenda for the day, sts get in lab groups to continue lab V looks at data already collected - do you notice, what do you think that tells you? Well, so if you had a marble instead of a ball bearing, what would happen? V asks group, can I see your math? On this one, see if you can get good timing - I notice your rotational energy is a little low. I think your timing may have been a little fast sts discuss calc - what they are using to solve for variables sts work on calcs and data collection sts adjusting the ramp sts ask for confirmation on calculation Sts “we are a little confused about what to do now”, V explains to get this, it is this divided by this, so then you did it correctly, this should be a little slower because you have friction, can I see the equation you guys are using for your radius? So take this divide by radius...talks through the calc. V writes on sts paper V continues to talk through calc, it should be around 34, 35 - what happened was (explains to other student in the group) some sts make calc, some play with ramp V with group - ask yourselves some questions - is it going to be harder to rotate? Easier? There's a reason I chose a ball bearing. It's heavy right? So rotational energy is more… so shorter roll, shorter ramp, less energy… V asks another group what their k was, so what does that tell you about what's going on? V asks which factor influences more? This is same as regular kinetic but instead of v you have omega so it is the same… V walks a student through a calc - this is your k, you are going to use this and this. Did you use that for the first one? We can check the math, go ahead and do this one first V this is when we had the ball bearing here (points to the ramp) then this one is the bottom of the ramp,

		V points out - you'll notice here was the taller block and this was the shorter one, so I'm wondering, but that's your data. Something to talk about later, maybe it was a timing error V checking another group's data - checking time - I think that group just mis-timed it. I was going to assign this for hw but you can do it now. This lab was full of potential errors, make sure you include that. I want to read that. V - I wish I had the ipads because then we'd have more data points sts working on calc V - finish calc then I want to start the debrief
56-66	whole class debrief	V- at the top all the energy is, potential right, and what is happening here, rotational, right… how did we calculate what the rotation was? What did we do? How'd you guys get it? Stu answer, then what, ok then what (writing on board) V continues to walk through calculation, so we had to get omega, and how'd you guys get that? You had this energy, you know some of that was this energy. Now you have this, you can get this. How'd you get your percent? You guys got 16, you guys got 48,… now here's what I want to get out of it. is it significant? you did high and low, what was the difference? you'll notice a lot of the energy is going into what? when it is lower, is it going to rotate faster or slower, so then it will go into what? V continues I used the ball bearing so you can see the rotation. So that's the big picture, so now you can write the discussion. I'm curious to hear what you guys think about using the ipad or the vernier what would be different, V continues what I want you to work on next, this is essentially a position time graph, what does that show? Velocity. So do that. Then to wrap it up do the venn diagram. If you guys want some structure for the conclusion, look at the objectives. For each one of those you have a result, mention those results. Was it experimentally significant? That's the main point. sts work on conclusion at desks. V asks What did you think of the lab? I thought the beginning was a little tricky. I needed to redesign it so it flows a bit better. You guys are my guinea pigs. You are probably tired of

		hearing me say that.
66-84	Writing lab conclusion	sts work on conclusion at desks
84-86	packing up	

Memo: Students engaged in data collection most of the period. Procedures and needed equipment defined for them. Content was frontloaded by lecture on a previous day (confirmation lab). V circulates to provide assistance and check in (mostly about calculations, apparatus set up). V makes statements like "your rotational energy seems to be low" like he is noticing that the data is not reasonable and concludes measurement error, but he does not ask sts, does this make sense to you? Does it seem reasonable based on what you know? Asks some questions like, why did I choose a ball bearing instead of something else? Prompts students to ask, what if you did this with a marble instead? Attempting to get students thinking about what the calculations really mean, but these discussions are not sustained. He often jumps in and answers his own question after students offer initial (usually short) answer. Sts ask each other questions when stuck doing calculations in lab groups. Focus during debrief seemed to be more on correctness of calculations rather than understanding friction. But, does talk about how this problem differs from previous ones from honors physics (rotational energy versus simple inclined plane problem). Does ask sts to complete a Venn diagram to compare and contrast. Asks more conceptual questions (compared to last time) but often modifies the original question (to make it a more refined question) then answers his own question maybe after the student gives a partial answer to first question. V seems to provide a lot of help with calculations (use this to get that then divide by this to get that). V in charge of explaining during the debrief. IRE pattern in the debrief.

APPENDIX E

EQUIP Coding for all participants

Participant	w	w	w	w	w	w	r	r	v	v	v	m	m
Observation date	8-Jan	14-Jan	6 Feb p2	6 Feb p4	1-May	15-May	15-Feb	6-Mar	13-Jan	12-Feb	30-Apr	22-Apr	20-May
Instructional factors													
Instructional strategies	3	2	4	4	2	2	2	3	2	2	3	4	4
Order of instruction	1	1	1	1	1	1	1	1	2	1	2	3	3
Teacher role	3	3	3	3	3	3	2	3	3	3	3	3	3
Student role	4	3	4	4	2	3	3	4	3	3	4	3	4
Knowledge acquisition	3	2	3	3	2	2	2	3	2	2	3	3	3
Discourse factors													
Questioning Level	3	2	3	3	2	2	2	3	2	2	1	4	4
Complexity of Questioning	3	1	3	3	2	3	2	3	1	2	1	3	3
Questioning Ecology	1	1	2	2	2	2	2	2	1	2	1	3	3
Communication Pattern	2	2	2	2	2	2	2	2	2	2	1	2	2
Classroom Interactions	2	1	3	3	3	3	2	2	2	2	1	3	3

APPENDIX F

Participant Case Display

Ron	pre-interview	vc1 Jan	vc2 Feb	lesson 2/15	lesson 3/6	vc3 Mar	vc5 June	post-interview
Professional development goals	“I want to be better, I want to see what others are doing.” “I look at what my daughter is expected to do and think my students should be able to do the same. I want to teach like I would want my daughter taught.”							“I want to be less cookbook, incorporate more written explanations but I worry about the time needed to grade them.”

Role of the teacher	Hands-on, consistency, study habits are almost as important as the content, vocab quizzes. “The standards keep me focused.” – job is to teach the standards, get through pacing guide.							“Be a facilitator not a dictator, let them find the answers.” “I still have to figure out how to make this work.” “I’ve tried to slow down and listen to their ideas, see where they are.” “Their ideas can drive me in a certain direction. I’m hoping that this next year I can take advantage of it.”

Struggles/ obstacles	No CST now so “that gives me freedom.” “I was hesitant to participate – I am a little bit intimidated.” “Not looking forward to watching myself on video – I remember what it was like in my credential program and I was so critical of myself.”	Concerned about students off task when T not there. Classroom management . Spending too much time with one group. Unsure of content (physics). “ I can’t figure out what happened.”	Hadn’t thought about teaching cell processes in this way. "I guess I'm not a very good teacher" “But how can students press each other when they don’t know what the final result or the final discussion point should be?”			R unfamiliar with content again (sound) we don’t use much in biology. Attends to different things than the others, again, maybe because of content. Attends to color on the drawing, attends to speaker placement at a concert (that was not really what the question was about) but trying to find a way to make sense of the problem. R continues to engage and ask questions even when out of his area. “You know what I’m looking for? A rubric, Is there one? , I mean I’m	Worried about students quitting. “They try to shorthand everything.” “Very few students go that extra mile.” “Writing is hard for them. They know what’s going on but have difficulty spitting it out in a correct manner.”	“Wished I had done this first semester – I would have had more lessons like you were looking for.” More inquiry opportunitie s in that content. "I didn't change too much this semester, I'm sorry to say. I mean, I already had the lesson plans. But at least next year I can try to make a concerted effort." Making labs less cookbook will require more time “because if they mess up they have to start over. They are going to be all over the place but I

Areas of interest	“I want to see how others teach.”	Student use of vocab	Student use of vocab	Groups were communicating with each other "I was happy with it, every group was communicating." changed from 2 years ago when no questions, just cards and Venn diagram	Student language acquisition mentioned as a possible reason students confuse longer versus faster period. Mentions not using complete sentences as a problem with student's incomplete answer	“I was glad W added connecting drawing and explanation to rubric - writing must explain the drawing (model).” R raises Jack's answer for discussion because of the detail and labeled drawings.	R presses M on longer versus larger period – language use. “Is this a vocab issue or a language issue?” “Is the problem that they didn’t put it into sentence form?”	“I saw ways to approach future activities or labs, ways to make it less cookbook, ways to let them explore.” “Good timing because the standards have changed so we are redoing the curriculum.”

Memo: Ron mentions that he wants to get better by participating in the video club and wants to see how others teach, but says he feels nervous and intimidated. He is unsure about the content in a few video clubs (physical science), but attempts to participate. Notes classroom management (too much time spent with one group) and expresses concern that the students are off task when the camera is not on them. He focuses on student's use of academic vocabulary and using complete sentences in multiple meetings. Ron is the only biologist. Does he comment on these issues because he does not have enough knowledge to comment on the science content in a public space like this? He seems a bit pessimistic about students again in Meeting 4 when he mentions that "few students will go the extra mile" and again in the post-interview when he states that "learning is not as important to them." Skeptical. In the end, Ron mentions that he did not change much, but wants to be "less cookbook" and let the students "explore more" in the future. He said he already had his lesson plans written. Even without the CST, Ron seems to feel pressure to move lessons along. He mentioned in his pre-interview that his job was to get through the pacing guide so he taught all the standards. He was concerned about how much more time "exploring" will take and how much time grading students' writing will take. During both observation lessons, he would ask students to share answers, but not to elaborate. He did not explore "wrong" answers. He seems very concerned about leaving students with "wrong ideas." Ron remains very much in charge of the learning and flow of the lesson. Activity is frontloaded by direct instruction. Mixture of independent work and group work. Short IRE sequences dominant. Students were asked to write explanations, but not share them.

APPENDIX G

Design Elements and Meeting Characteristics

Meeting, artifact, idea unit	topic	stance	evidence	participation	turns of talk	windows	depth	clarity	ideal answer	rubric
M1C1#1*	DCI/ST	INT	ART	MH	55	H	H	M	10	1
M1C1#2	INST/ST	EVAL	ANEC	MH	38				0	0
M1C1#3	INST/ST	DESC	ART	L	9				0	0
M1C1#4	INST/ST	EVAL	ANEC	MH	6				0	0
M1C1#5	CM	EVAL	ANEC/ART	L	17				0	0
M1C2#1*	DCI/ST	INT	ART	MH	49	H	H	H	2	0
M1C2#2	DCI/ST/INST	EVAL	ANEC/ART	ML	14				0	0
M1C2#3	DCI/ST/INST	EVAL	ART	H	16				0	0
M1C2#4	DCI/OTHER	INT	ART/SCI	ML	15				0	0
M1C2#5	DCI/INST	EVAL	ANEC/ART	MH	30				0	0
M2C1#1	DCI	INT	ANEC/ART/ SCI	H	68	M	M	L	0	1
M2C1#2	DCI/ST	EVAL	ART/SCI	MH	21				4	1
M2C1#3	INST	EVAL	ART	H	16				0	0
M2C1#4	DCI/INST	INT	ART/SCI	H	23				2	0
M2C1#5	INST/ST	EVAL	ANEC/ART	H	52				1	0
M2C1#6	INST/ST/BEH	EVAL	ART	MH	43				0	0
M2C2#1	INST	EVAL	ART	MH	51	L	L	H	0	0
M2C2#2	INST	EVAL	ANEC/ART	H	20				0	0
M2C2#3	INST/MOT	EVAL	ANEC	H	71				1	0
M3C1#1*	DCI/ST	INT	ART	MH	32	H	M	M	8	1
M3C1#2*	DCI/ST/ASSESS	INT	ART	MH	14				2	3
M3C1#3*	DCI/ST/INST	INT	ART	MH	22				5	2
M3C1#4	ASSESS/VOCAB	EVAL	ART	MH	4				0	3
M3C1#5*	DCI/ST	INT	ART	MH	18				7	2
M3C2#1	INST	EVAL	ART	L	9	H	M	M	0	0

Meeting, artifact, idea unit	topic	stance	evidence	participation	turns of talk	windows	depth	clarity	ideal answer	rubric
M3C3#1*	DCI/ST	INT	ART	MH	32	H	M	M	10	1
M3C3#2	ASSESS	EVAL	ART	MH	4				0	3
M3C3#3*	DCI/ST	INT	ART	MH	17				3	0
M3C3#4	DCI/ST	DESC	SCI	MH	33				11	0
M3C3#5*	DCI/ST	INT	ART	MH	18				1	2
M3SW1#1*	DCI/ST	INT	ART	MH	65	M	H	M	8	7
M3SW1#2*	DCI/ST/INST	INT	ART	MH	8				2	2
M3SW1#3*	DCI/ST/INST/ASSESS	INT	ART	MH	49				5	15
M3SW2#1	OTHER	EVAL	ART	MH	14	H	H	M	0	0
M3SW2#2	DCI	DESC	ANEC/SCI	MH	18				0	0
M3SW2#3*	DCI/ST	INT	ART	H	70				12	4
M3SW2#4	ST/VOCAB	INT	ANEC/ART	H	36				0	4
M3SW2#5	DCI/ST	EVAL	ART	MH	17				4	0
M3SW3#1*	DCI/ST	INT	ART	MH	42	H	H	H	15	4
M4SW1#1*	DCI/ST	INT	ART	MH	77	M	M	M	18	3
M4SW1#2	DCI/ST/INST/ASSESS	INT	ANEC	H	77				5	9
M4SW1#3	MOT	EVAL	ANEC	H	18				0	0
M4SW1#4	DCI/ST	EVAL	ART	L	6				2	0
M4SW1#5	INST/ST/MOT	EVAL	ANEC	MH	21				0	0
M4SW2#1*	DCI/ST	INT	ART	MH	20	M	M	L	5	3
M5C1#1	DCI/INST/ST/VOCAB	EVAL	ANEC/ART	ML	22	M	M	M	0	8
M5SW1#1*	DCI/ST/INST/ASSESS	INT	ART	H	53	L	M	L	0	11
M5SW2#1*	DCI/ST	INT	ART	MH	24	L	M	L	6	5
M5SW2#2	INST/ST/ CLIMATE	EVAL	ANEC	L	7				0	0
M5SW2#3	DCI/ST/INST	INT	ANEC/ART	MH	16				2	3

Meeting, artifact, idea unit	topic	stance	evidence	participation	turns of talk	windows	depth	clarity	ideal answer	rubric
M5SW2#4	INST/ASSESS/MOT	EVAL	ANEC	MH	54				0	4
M5SW3#1	DCI/ST/INST	INT	ANEC/ART	H	22	L	M	L	4	4
Meeting, artifact, idea unit	topic	stanc e	evidence	participatio n	turns of talk	window s	dept h	clarit y	ideal answer	rubri c
M5SW3#2	ST	EVAL	ANEC/ART	L	9				0	3
M5SW3#3	DCI/ST/INST/ ASSESS	INT	ANEC/ART	MH	24				3	1

*Note. Highly productive idea units are denoted with a *.*

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Frequency of Facilitation Moves by Idea Unit

Meeting, artifact, idea unit	**orienting**	launching	situating	answering question	**promoting**	highlighting	pressing	offering alt	revoicing	interpreting	questioning	**maintaining**	**supporting**	affirming	distributing	using humor	minimal	**other**
M1C1#1*	6	1	2	3	12	9	1			2			6	1			5	
M1C1#2	0				0								7			1	6	6
M1C1#3	0				3	3						1	1				1	1
M1C1#4	0				0								0					
M1C1#5	0				0								3			1	2	
M1C2#1*	7	1	3	3	10	9	1						4	2			2	
M1C2#2	0				5	2		3				1	2				2	
M1C2#3	0				4	3		1					3				3	
M1C2#4	0				0								10	4			6	
M1C2#5	0				1	1						1	3				3	
M2C1#1	3	1		2	7	2		5				1	15	3	3		9	
M2C1#2	0				5			5				1	4			1	3	
M2C1#3	1	1			0								3				3	
M2C1#4	0				5	3	2					1	4	1			3	
M2C1#5	0				8			3		5			15	3		1	11	1
M2C1#6	0				5	2		3				1	13	2			11	
M2C2#1	1	1			8	1		7					11				11	6
M2C2#2	4			4	0								0					5
M2C2#3	0				9			9					23	5			18	
M3C1#1*	1	1			3	1	2						7	1			6	
M3C1#2*	1	1			2		2						4				4	
M3C1#3*	0				7	2	2		2	1			3	2			1	

Meeting, artifact, idea unit	**orienting**	launching	situating	answering question	**promoting**	highlighting	pressing	offering alt	revoicing	interpreting	questioning	**maintaining**	**supporting**	affirming	distributing	using humor	minimal	**other**
M3C1#4	2	2			0								0					
M3C1#5*	0				3	3							4	1			3	
M3C2#1	1	1			0								0					4
M3C3#1*	1	1			13	6				6	1	1	12	2		1	9	2
M3C3#2	1	1			1		1						0					
M3C3#3*	0				3	1	2						6				6	1
M3C3#4	0				3					3			11	3			8	
M3C3#5	1			1	3				1	2			1	1				2
M3SW1#1*	3	1		2	2		1		1				19	1	1		17	
M3SW1#2*	1	1			1		1						2				2	
M3SW1#3*	0				10	3	3		1	2	1		9		1		8	1
M3SW2#1	3	3			0								2	2				
M3SW2#2	4			4	0								4			1	3	
M3SW2#3*	2	2			16	4	1		4	5	2		11	2		1	8	
M3SW2#4	0				0								11	1			10	1
M3SW2#5	2			2	5			1		4			1				1	
M3SW3#1*	0				5	3				2			11	1			10	
M4SW1#1*	4	2		2	6	2					4		13	3			10	
M4SW1#2	0				10			8		2			22	7			15	
M4SW1#3	0				1			1					7	1			6	
M4SW1#4	0				0							1	2				2	
M4SW1#5	0				0								5				5	
M4SW2#1*	2	2			3	1	2						4				4	
M5C1#1	1	1			5	2		2			1		4	1			3	1
M5SW1#1*	3	3			9	2		1		5	1		8	1			7	

Meeting, artifact, idea unit	**orienting**	launching	situating	answering question	**promoting**	highlighting	pressing	offering alt	revoicing	interpreting	questioning	**maintaining**	**supporting**	affirming	distributing	using humor	minimal	**other**
M5SW2#1*	3	2		1	5	1				3	1		2				2	
M5SW2#2	0				0								2				2	
M5SW2#3	0				6	3		1			2	1	2				2	
M5SW2#4	0				3			3					11	2			9	
M5SW3#1	2	2			5	2				3		2	2	1			1	
M5SW3#2	0				3	1				1	1		1				1	
M5SW3#3	0				8	2		4		1	1		3	3				

*Note. Highly productive idea units are denoted with a *.*