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Leveraging Analysis of Students' Disciplinary Thinking in a Video Club to Promote Student-Centered Science Instruction

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Recent policy reports and standards documents advocate for science teachers to adopt more student-centered instructional practices. Four secondary science teachers from one school district participated in a semester-long video club focused on honing attention to students' evidence-based reasoning and creating opportunities to make students' reasoning visible in practice. Although all participants expressed value in attending to students' ideas and shifting autonomy to students in the classroom, they experienced varying levels and types of integration in their practice. Analysis revealed that teachers' goals and commitments influenced the incremental ways in which participants integrated learning from the video club. Sustained and substantial changes to practice likely require support through multiple cycles of shifting visions of what is possible, coupled with collaborative attempts to work through challenges of implementation.

A scientifically literate populace is essential for the well-being of a nation (Anelli, 2011). Science "permeates nearly every facet of modern life" (National Research Council [NRC], 2007, p. 1) and is critical to meeting current and future social challenges (American Association for the Advancement of Science [AAAS], 2009; Duschl, 2008; NRC, 2012). In response, several national documents offer recommendations and standards to improve science instruction (National Governors Association Center for Best Practices, Council of Chief State School Officers [NGACBP], 2010; NRC, 2012, 2015). A common emphasis in these documents 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 (Duschl, Schweingruber, & Shouse, 2007; NRC, 2012, 2015).

Calls to promote the development of science literacy through classroom discourse and blending of content and practice are not new (see Anelli, 2011), 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 knowledge and skills often isolated from their real-world contexts (AAAS, 2009; NRC, 2012, 2015).

To disrupt this pervasive and persistent teaching pattern in the US and achieve the vision of reform, research must link what is known about ambitious science teaching practices and how to support teachers to shift their practice to achieve this vision (Cochran-Smith & Lytle, 2009; Grossman & McDonald, 2008; Thompson, Windschitl, & Braaten, 2013).

Research documents the need for teachers to see images of possibilities in order to learn what is entailed in enacting the vision of ambitious instruction and to collect evidence that students' participation in ambitious forms of science teaching works in practice (Cobb, 2017; Guskey, 2002). Other research suggests that as teachers work through challenges of incremental implementation of new practices they benefit from the support of others to problematize and work through dilemmas of practice (Gallimore, Ermeling, Saunders, & Goldenberg, 2009; Horn & Little, 2010).

We, therefore, designed a video club (Sherin, 2004) informed by these approaches to teacher development to support secondary science teachers to teach in ways that cultivate students' scientific reasoning skills. Building on prior research (van Es & Sherin, 2008), we conjectured that bringing teachers together to view and analyze both video records of others enacting ambitious science practice and their own efforts implementing these practices would accomplish three goals: (a) help them develop a vision of instruction focused on evidence-based reasoning; (b) learn new ways of seeing and interpreting student thinking, and (c) support their enactment of practices focused on student thinking in their classrooms.

In this study, we focus on the third goal, participating teachers' instructional practice. In particular, we asked, "Do the teachers who participated in the video club experiment with enacting the ambitious instructional practices promoted in the video club meetings?" Our study aimed to contribute to existing research findings that teachers who meet regularly with colleagues to analyze video of teaching adopt student-centered instructional practices (Borko, Jacobs, Eiteljorg, & Pittman, 2008; Roth et al., 2011; Sherin & van Es, 2009; van Es & Sherin, 2010).

Given how challenging it can be for teachers to transform their teaching (Guskey, 2002), we sought to uncover the complexity involved for teachers as they learned about and developed a new vision of science instruction and enacted new practices in teaching. These findings have implications for the ways we conceptualize teacher learning and for designing and implementing professional development to support sustained shifts in practice.

Theoretical Framework

Our study was informed by social theories of learning and research on teacher learning in professional communities of practice (Greeno, Collins, & Resnick, 1996; Wenger, 2011). This perspective, when applied to teacher development, recognizes that teachers learn through collaborative problem solving around instructional dilemmas (Curry, 2008; Horn & Little, 2010; Putnam & Borko, 2000). In addition, they need to learn forms of talk that are productive for teacher learning; specifically, how to be analytic and critical about practice by using evidence from classroom interactions to make claims about teaching effectiveness to move teaching practice forward (Rodgers, 2002; Stigler & Hiebert, 2016; Yeh & Santagata, 2015).

This view of learning also emphasizes the central role that tools play in shaping learning and development. Teacher learning is shaped by the affordances of the tools and tasks with which they engage (Hatch, Shuttleworth, Jaffee, & Marri, 2016). To become a member of a community, teachers need access to frameworks and tools that represent the values of the community, to focus their attention to the dimensions of practice valued by the community, and to help develop a discourse for systematically analyzing teaching and learning (Borko, Koellner, Jacobs, & Seago, 2011; Horn & Little, 2010; van Es & Sherin, 2010).

We also recognize that teacher learning is a complex system of interactions between the participant, professional context, and the content of the professional development (Borko, 2004; Opfer & Pedder, 2011). It is a cyclical, multidirectional process, in which the knowledge teachers construct from classroom and professional development settings moves back and forth over time (Kazemi & Hubbard, 2008).

Teacher change is an incremental process in which transformations in teaching are a collection of adjustments and revisions that build over time (Stigler & Thompson, 2009; Janssen, Westbroek, Doyle & van Driel, 2013). Teachers, then, are active participants in their learning, who build their own understanding of the affordances of a student-centered approach through collective exploration with support (McLaughlin & Talbert, 2006). In so doing, they can apply learning to new situations and future problems that they, themselves, identify (Franke, Carpenter, Levi, & Fennema, 2001).

From this perspective then, the community of practice to which we want to apprentice teachers is one that recognizes students as agents in their learning, who have knowledge and resources that can be leveraged to move their science learning forward. Moreover, we conceptualize learning to improve science teaching as situated in teachers' work and that their classrooms are sites for learning in and from practice. At the same time, we understand that interactions teachers have with colleagues around shared problems of practice in a structured learning environment, along with the support of resources (both human and material), can advance their ways of seeing and enacting science instruction. We now apply this perspective to the particular demands of science education.

Defining Ambitious Science Instruction

National standards documents call for an increased focus on student learning to leverage evidence for scientific claims, developing scientific habits of mind, and composing evidence-based explanations (NGACBP, 2010; NGSS Lead States, 2013; NRC, 2012, 2015). The goal is for students to learn how ideas are generated by science — in essence, how science works (AAAS, 2009; Duschl, 2008; NRC, 2012, 2015). In this vision, teachers and students take on fundamentally new roles and engage in fundamentally different kinds of interaction, what has recently been termed as "ambitious science teaching" (Windschitl, Thompson, Braaten, & Stroupe, 2012). Our definition is consistent with Windschitl and colleagues who argued that teachers must design and enact opportunities for students to explore a disciplinary phenomenon involving core disciplinary ideas, elicit students' thinking about those ideas, help students begin to organize their ideas into a proposed mechanism to explain the phenomenon, and leverage evidence to refine their proposed mechanistic explanations.

Achieving this goal requires an instructional shift away from the transmission of facts toward designing tasks that create space for students to grapple with data and observations and develop a culture of talk that promotes their sense-making and evidence-based argument building (Kang, Windschitl, Stroupe, & Thompson, 2016; NRC, 2015; Pimentel & McNeill, 2013).

A central component of this instructional approach is noticing and responding to student thinking (Luna & Sherin, 2017; Stroupe, 2014; Thompson et al., 2016). Once instruction is designed and implemented that surfaces students' observations and hypotheses about why and how the natural world operates, teachers must then help students organize their ideas to test and refine their hypotheses based on evidence.

When students' observations and explanations are treated as objects of inquiry for teachers and the class, interactions around students' thinking extend beyond formative checks for understanding and become an integral part of the students' learning process itself (Coffey, Hammer, Levin, & Grant, 2011; Ruiz-Primo & Furtak, 2006). To do this, teachers must be able to recognize how students are thinking about a disciplinary core idea and make on-the-fly decisions about how best to respond (Chin, 2007; Hammer, Goldberg, & Fargason, 2012).

The vision of science instruction defined here has been shown to elevate the quality, depth, and rigor of science learning, broaden participation among diverse communities in science, and meet the demands of a more technology and scientifically based workforce (AAAS, 2009; Roth & Lee, 2002; Thompson et al., 2013). While this vision is worthwhile, fundamentally changing science instruction is no simple matter. One of the central challenges involved in this work is supporting teacher learning and change in practice.

Challenges for Teaching Ambitious Science

The obstacles to achieving a vision of ambitious science instruction are numerous. Because many U.S. teachers have not experienced learning themselves in classrooms organized around student ideas (Santagata, Gallimore, & Stigler, 2005; Windschitl & Thompson, 2006), they often lack an appropriate frame of reference or conceptual models through which to enact this type of teaching (Sandoval, Deneroff, & Franke, 2002). In addition, because students, not teachers, are building and testing explanations based on evidence, ambitious science instruction requires redefining roles for both teachers and their students (Anderson, 2002; McNeill & Pimentel, 2010; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001).

A classroom centered on students' ideas shifts some authority and control over classroom activity from teachers to students. This ceding of control may be perceived as too much of a risk for destabilizing classroom activity and, therefore, impractical (Janssen et al., 2013). Moreover, in an accountability climate, not having the degree of control over what and how content is addressed, as in more didactic teaching approaches, can cause teachers anxiety (Anderson, 2012).

Enacting tasks organized to elicit and work with students' ideas to develop understanding of the science content can also be challenging for teachers. Specifically, research has found that it can be challenging for teachers to learn how to launch rigorous explorations of phenomena that can sustain extended discourse about disciplinary core ideas, to shift attention to different aspects of students' ideas, and to manage a different type of classroom discourse (Kang et al., 2016; Pimentel & McNeill, 2013; Tekkumru Kisa & Stein, 2015). In ambitious science teaching, the tasks in which students participate are less about memorizing the content and more about problematizing the content, work that requires considerable support (Windschitl et al., 2012). Even if students are engaged in a high-quality task, when teachers were not responsive to students' ideas, the learning experience lacks rigor (Thompson et al., 2016).

The discourse associated with instructional choices and tasks may either open up or limit opportunities for students to participate (Olitsky, 2006). This situtation is problematic because instructional changes often occur only as teachers' perceptions of their students' capabilities evolve (Timperley, 2008). If teachers do not experience success launching tasks that elicit students' ideas, their perceptions of students' capabilities may not change, and teachers are unlikely to continue attempting implementation of rigorous tasks.

Once students' ideas are made central to instruction, responsiveness to those ideas is, itself, a demanding task. Teachers must first recognize students' ideas as worthy of attention, interpret what those ideas mean about students' sense-making of the science, and then connect them to next teaching moves (Levin, Hammer, & Coffey, 2009; Sherin, Jacobs, & Philipp, 2011). What teachers notice at any given moment depends on their shifting epistemological priorities at the time — perhaps verifying correctness of ideas one moment and encouraging the reasoning process the next (Russ & Luna, 2013; Scott, Mortimer, & Aguiar, 2006).

Teachers must make in the moment decisions about which student ideas to pursue and in which order (Cartier, Smith, Stein, & Ross, 2013). At the same time, they must balance a variety of elements for holding students accountable in a discourse rich classroom — accountability to the learning community, to scientific reasoning, and to the content — to achieve both science process and content goals (Michaels, O'Connor, & Resnick, 2008). To manage classroom science discourse, then, requires a robust repertoire of skills and substantial support and guidance while refining these skills (Richards & Elby, 2014; Windschitl, et al., 2012).

The Affordances of Video-based Professional Development for Responding to these Challenges

Video analysis of teaching shows promise in addressing some of these challenges (Blomberg, Renkl, Sherin, Borko, & Seidel, 2013; Calandra & Rich, 2015; Gaudin & Chaliès, 2015). First, the genre of video captures the complexity and specificity of classroom interactions and, therefore, affords careful study of the detailed ways in which teachers construct interactions focused on students and their ideas (Hatch & Grossman, 2009; Sherin, 2004). As a result, teachers can develop a keen eye for seeing features of instructional interactions that are consequential for student learning and develop a shared language for characterizing ambitious teaching (Grossman & McDonald, 2008; van Es, Cashen, Barnhart, & Auger, 2017).

Second, video is easy to capture, store, and edit for analysis. Teachers can quickly and seamlessly collect and view segments from each other's classrooms, allowing them to deprivatize their practice and analyze instruction with colleagues without the in-the-moment demands of teaching (Hatch & Grossman, 2009; Sherin, 2004). Finally, video can selectively capture events and interactions, focusing teachers on particular features of teaching and learning, what Sherin and van Es (2007) referred to as the "keyhole effect." While looking through a keyhole limits the scope of what can be seen, it also zooms in on a particular aspect of instruction, reducing the cognitive load and enabling up-close analysis of instructional interactions (Borko et al., 2008; Luna & Sherin, 2017).

Given these affordances, video is being used increasingly in professional development to help teachers form new visions and support the enactment of new instructional practice, with growing evidence showing its value for impacting both teacher and student learning (Calandra & Rich, 2015; Gaudin & Chaliès, 2015; Roth et al., 2011; Seago, Jacobs, Heck, Nelson, & Malzahn, 2014; Tripp & Rich, 2012). Research provides evidence that teachers who studied video records of practice developed a vision of ambitious instruction, learning to see what constitutes participation in the practice of science and how students participate in that work (McDonald & Rook, 2014).

Additionally, teachers who analyzed videos focused on worthwhile student ideas developed attention to students' disciplinary thinking and learning, a central aim of ambitious science instruction. Understanding and making sense of students' ideas can be challenging for a variety of reasons. Because they are still learning the content, students do not yet have well-developed disciplinary language to articulate their thinking. In addition, teachers often interpret what students say from their own perspectives. Video has been shown to help teachers suspend their own thinking to learn to focus on what students are saying, to make sense of their thinking, and to broaden their interpretations and consider student thinking from different points of view (Luna & Sherin, 2017; Tekkumru Kisa & Stein, 2015; van Es & Sherin, 2008; Walkoe, 2015).

Research also has found that systematic observation and analysis of teaching with video can influence teachers' instructional decisions and practice (Borko et al., 2008; Sherin & van Es, 2009; Tripp & Rich, 2012). Some research has found that when teachers observe video of teaching, they attempt to enact what they observe in their classroom (Grant & Kline, 2010; Yeh & Santagata, 2015).

Van Es and Sherin (2010) found, for example, that when teachers participated in a video club focused on students' thinking they not only shifted to attend to the details of student thinking in the video club meetings, but they also came to enact practices to elicit and probe student thinking during classroom interactions. This result suggests that studying video records of practice can help teachers develop discourse practices for attending to and working with student ideas that equip them for facilitating student-centered, responsive interactions during instruction.

Finally, studying video records of teaching can lead to improvements in teacher knowledge and impact student learning. Roth et al. (2011) investigated the relationship between teachers' participation in the video-based professional development program, Science Teachers Learning from Lesson Analysis (STeLLA). STeLLA leveraged the affordances of videos of others' and teachers' own practice to develop teachers' content knowledge of science and understanding of students' thinking of science. The study found that teachers developed deeper content understandings, became more analytic about science teaching in terms of student thinking and science content goals, and made improvements to teaching in terms of their attention to student thinking and the disciplinary goals of the lesson. Additionally, students of these teachers demonstrated improvements in their science content learning in four different content areas. This finding provides evidence, then, that analyzing practice as it is linked to science content and student thinking can be a lever for improving science teaching practice.

While research provides strong and compelling evidence that studying video records of teaching can support teacher learning, less is known about how teachers who participate in these learning environments attempt to shift instruction based on what they learn in these settings to achieve the vision promoted in professional development. Kazemi and Hubbard (2008) argued that because of the diversity of teachers' contexts, experiences, beliefs and dispositions, and practices, they will not experience professional development in the same way and they will take up what they learn in these settings differently in their own work. We, therefore, extend prior research on the use of video in teacher professional development by providing case studies of secondary science teachers who participated in a video club to illuminate the complexity of teachers' experimenting with and transforming their teaching.

Research Design

Study Context

The study took place in a suburban school district in southern California in the United States. The first author (Barnhart) approached the science departments of two high schools in the district and invited teachers to participate in a video club focused on developing students' evidence-based reasoning. The two schools serve predominantly socioeconomically disadvantaged students whose first language was not English. The first author was a former teacher at one of the study high schools and had ongoing relationships with several faculty members through her position as a teacher educator and science methods instructor at a local state university.

Five teachers volunteered to participate — two from one campus and three from the other campus. Each were paid a small stipend for their participation. On average, they had 15 years of teaching experience. All but one had an advanced degree in their disciplines or in education and had taken on leadership roles in teaching, either as a mentor teacher for student teachers, department chair, or course lead. This fact suggested to us that they were all highly engaged in their profession and in learning to become better teachers.

These two schools were selected because teachers at both sites had experience working in collaborative groups with colleagues to analyze school and classroom based data. For the previous 6 years both schools had dedicated segments of the school day to subject-alike faculty meetings with the purpose of examining practice, typically focused on designing common science labs and analyzing the results of common assessments. 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.

Given the high level of professional and leadership experience of the participants and their familiarity with professional learning community work, we anticipated they would quickly engage in collaborative and critical analysis of teaching artifacts, such as videos of teaching and student work samples. We also suspected that the level of critique during collaborative time likely had room for enhancement, as 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; Horn & Little, 2010). The following section briefly describes the structure and design of the video club meetings.

Video Club Design

The video club consisted of five after-school meetings over the course of one semester. Each meeting lasted about 90 minutes. The design of the club was informed by prior research showing that viewing and discussing video records of teaching can help teachers adopt more student-centered instructional practices (Roth et al., 2011; van Es & Sherin, 2010). This video club drew on research suggesting that viewing others' videos has affordances for developing a vision of possibilities, while also recognizing the benefits of viewing video from one's own teaching for supporting application to one's own practice (Seidel, Sturmer, Blomberg, Kobarg, & Schwindt, 2011). Therefore, the first few meetings focused on watching video from published sources (as also in Santagata, 2009; Windschitl & Thompson, 2006) to see and examine instances of students engaged in evidence-based reasoning. We shifted focus to videos and artifacts from participants' own classrooms for the last few meetings to provide an opportunity to collaboratively examine efforts to implement ambitious science teaching with a student-centered focus (Sherin & Han, 2004). Artifacts were purposefully curated to stimulate rich discussion about students' disciplinary reasoning (Sherin & van Es, 2009).

To be clear, the explicit purpose of this design was not to collaboratively design and revise lessons (Stigler & Hiebert, 2016). Our goal was to encourage disruption of normal patterns of examining practice by promoting focus on students' disciplinary 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).

To frame the video discussions, participants were invited to complete the task that was the focus of the video and develop an ideal response to each prompt featured in the video. In addition, participants constructed a rubric to specify what it looks and sounds like for students to participate in evidence-based reasoning. Putting themselves in the position of the students, they attempted the tasks and discussed different ways students may make sense of the disciplinary content. They used their explanations of students' reasoning to define the desired components of students' explanations in the evidence-based reasoning rubric.

Taken together, these tasks focused participants' analysis on student thinking (as recommended in Borko et al., 2011; Levin et al., 2009). The rubric was not intended to be given to students or to be used for formally assessing student work but rather as a tool 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. This approach is consistent with research that advocates for teachers to develop shared frameworks and tools for conceptualizing the work of teaching (Grossman & McDonald, 2008). We conjectured that this set of experiences would support teachers experimenting with discourse practices that elicit and focus on students' reasoning and sense-making of science (see Table 1).

Data

Data for the study consisted of recordings and transcripts from the five video club meetings, participant interviews, and classroom observation data from four of the five participating teachers' classrooms, along with samples of student work from the recorded lessons. The participants were unable to attend each meeting due to family obligations, school field trips, and personal medical issues. Mitch and Ron attended four of the five meetings, William and Vincent attended three meetings, and Laurel attended two. Each video club meeting was video and audio recorded and transcribed.

Table 1
Features of Video Club Design

Features	Meetings 1 and 2	Meeting 3	Meeting 4 and 5
Goal	Developing a vision of evidence-based reasoning; Constructing a rubric to assess evidence-based reasoning in practice.	Developing a vision of evidence-based reasoning; Using a rubric to assess evidence-based reasoning in practice.	Applying a vision of evidence-based reasoning; Using a rubric to assess evidence-based reasoning in practice.
Artifacts	Published videos that provide models of students' evidence-based reasoning and classroom interactions and practices that promote evidence-based reasoning. Meeting 1: tanker crush - ambitiousscienceteaching.org Meeting 2: yeast metabolism - ambitiousscienceteaching.org & pulleys - timssvideo.com	Published videos and student work that provide models of students' evidence-based reasoning and classroom interactions and practices that promote evidence-based reasoning. Meeting 3: sound - ambitiousscienceteaching.org	Participants' videos and student work that demonstrate attempts to enact classroom interactions and practices that promote evidence-based reasoning. Meeting 4: can crush -William's classroom Meeting 5: pendulums -Mitch's classroom
Discussion norms	Eliciting observations from videos to interpret students' evidence-based reasoning; Modeling practices for participating in collaborative, critical discourse with video.	Pressing for evidence to support sustained analytic conversations about students' evidence-based reasoning.	Pressing for evidence and inviting alternate interpretations to distributed participation; Creating supportive and analytic conversations about students' evidence-based reasoning.
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

In addition, the first author conducted between two and six classroom observations of each teacher. Each observed lesson was between 55 minutes and 120 minutes long, depending on whether the lesson fell on a regular or block schedule day. When observing a lesson, we also collected student work samples that exemplified participants' attempts to implement the inquiry practices featured in the first three video club meetings. When the participants' schedules allowed, the first author also conducted and audio recorded a debrief session with a participant after observing the lesson. Though only lasting a few minutes, these debrief sessions provided insight into teachers' reasoning and instructional decision-making, as well as their perceptions about the success of the lesson and the student thinking the lesson elicited. One teacher, Laurel, had a variety of issues emerge in her personal life that limited opportunities to observe her teaching. We chose to exclude her from the analysis.

The first author also conducted pre- and postinterviews with each participant to learn what they each hoped to gain or perceived they gained by participating in the video club, what they considered as their role as science teachers, and how they judged that learning occurred in their classrooms. We were also interested in perceived shifts related to 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.

Data Analysis

We were interested in understanding whether participants in the video club experimented with enacting the vision of ambitious instruction in their teaching that was promoted in the video club meetings. Because we theorized that improving teaching happens through seeing images of the vision of instruction and cycles of teachers experimenting and analyzing teaching (Koellner et al., 2007), we wanted to gain deeper insight into what it means for teachers to engage in this complex work of transforming teaching. Therefore, we drew on qualitative methods (Miles, Huberman, & Saldaña, 2014) and constructed case studies of each participating teacher to gain insight into their process of taking up new practices in their teaching and how their participation in the video club may have influenced their practice (as instructed in Yin, 2013).

Examining both the development of teachers' vision in the context of the video club and their instruction was beyond the scope of this study. Therefore, we focused primarily on the impact of participation on teaching and use the video club and interview data to provide explanations for their efforts to experiment with practices focused on students' evidence-based reasoning.

In the first phase of our analysis we looked at the participants' instructional practice over the course of the video club semester. This analysis was informed by prior research that identified several dimensions on which teachers' practice shifted as they participated in a video club, including making student thinking visible during instruction, pressing students to elaborate on their thinking, and learning about student thinking while teaching (van Es & Sherin, 2010), as well as the Electronic Quality of Inquiry Protocol (EQUIP) that identifies features of instruction for advancing inquiry in science classrooms (Marshall, Horton, & White, 2009).

The EQUIP provides descriptions for four levels of inquiry for several factors known to influence the quality of inquiry in a lesson: Instruction, Discourse, Assessment, and Curriculum. Because we were primarily interested in how participants experimented with instructional moves and promoted classroom discourse to explore students' evidence-based reasoning, we used the Instruction and Discourse indicators of the EQUIP framework to score the lessons on the following dimensions: (a) types of tasks students engaged with and the instructional goals of these tasks; (b) the sequence of instructional events; (c) the roles of the students and the teacher in knowledge construction; and (d) the types and function of questions in classroom interactions. Together, these two frameworks helped us identify the extent to which student talk and thinking became a focus of classroom interactions and how teachers treated student ideas.

Because lessons have different phases, instructional techniques and resulting discourse change throughout the lesson. A single code would not capture the frequency of questioning or changing roles during a lesson; therefore, we segmented the lessons in 2-minute time segments and coded on the dimensions in these segments (see Borko et al., 2008, who also used this approach). We then used the coding on these dimensions to construct an analytic memo to characterize the nature of instruction and discourse for each lesson. An example of a typical analytic memo from one participant's' chemistry lesson follows:

This was a verification of concept lab that followed direct instruction on specific heat. Group members worked together to complete calculations. Some teacher questioning about concepts, asking students to make predictions, explain what would happen if..., what does this number mean..., etc., but seems like about half of the questions were about completing calculations. Students are in lab groups collecting data about change in temperature in different metals to identify an unknown. Students are asked as part of lab sheet to sketch using arrows to show direction of energy flow. It is not clear based on teachers' questioning of groups that students understand the purpose of the apparatus they used or the calculations the completed. Although there was some questioning about reasoning, students' inquiries were highly structured and had little agency in the design or display of results (other than the drawing).

An additional note was added to summarize the postlesson debrief if one occurred for the lesson. Finally, we looked across the analytic memos for each observation for each teacher and constructed a summative memo to examine patterns or changes over time.

In the second phase of analysis, we looked at participation in the video club meetings to investigate how each participant was thinking about student reasoning, their roles as science teachers, and how their instructional choices influence student reasoning. Informed by the literature on teacher noticing and artifact analysis (Levin et al., 2009; Sherin & van Es, 2009; Star & Strickland, 2008) to analyze participants' contributions in video club meetings, the meeting transcripts were coded for topic and stance. We were primarily interested if participants attended to instruction, classroom management, student behavior, student thinking, classroom climate, assessment, or disciplinary core ideas (see van Es & Sherin, 2008).

We were also interested if the participants took a descriptive, interpretive, or evaluative stance to the analysis of artifacts (van Es & Sherin, 2008). Research suggests that attending to the details represented in artifacts affords teachers seeing more noteworthy events, while taking an interpretive stance broadens teachers' sense-making as the consider what unfolded in the lesson from diverse points of view (Rodgers, 2002; van Es & Sherin, 2008). An analytic memo characterizing each teacher's participation was written for each meeting. A summary memo was also written to characterize the general character of group discourse for each meeting.

We next analyzed the interviews to gain insight into the participants' reasoning behind the instructional choices observed in the lessons (as recommended by Hatch, 2002). Pre- and postinterviews with each participant were transcribed and open coded with a focus on how they defined their roles as science teachers, their motivation and goals for participating in the video club, what they found challenging in terms of enacting instructional practices, what they found to be most impactful about participation in the video club, and their next steps. We then wrote an analytic memo for each interview.

In the third phase of analysis, we created a time-ordered matrix for each participant to build our cases. This matrix allowed us to examine teachers' perceptions about the shifts in their practice as they participated in the video club using various sources of data as they were collected over time, including Pre-interview, Video Club Meeting 1, Observation 1, Video Club Meeting 2, Observation 2, and so on, concluding with the postinterview (as recommended by Miles et al., 2014).

In the cells for each data source, we noted evidence from the data that highlighted participants' interests, struggles, perceived obstacles and opportunities, changing roles, and goals for their teaching relative to the goal of the video club. Using this time-ordered matrix, we wrote an analytic memo for each case (as in Miles et al., 2014). An example of one section (obstacles and concerns) from two different participants' time ordered matrix can be found in Appendices A and B.

We then looked across the four participants' cases to identify patterns of similarities and differences related to their efforts to experiment with ambitious science teaching practices, what practices they experimented with, and why. Also, just as importantly, we wanted to understand what parts of practice were not open for experimentation and why. We returned to the transcripts of video club meetings and analytic memos of these meetings for confirming and disconfirming evidence of these patterns. We grouped elements from the cases into five categories: goals, learnings, concerns, and constraints/freedoms and created a summary representation of the results.

Results

Synthesizing participants' practice along with their contributions during video club meetings and interviews, some similarities and differences emerged (see Table 2). First, in terms of instructional practice, with the exception of Mitch, all participants relied largely on direct instruction followed by lab exploration. This lesson structure was not the type featured in the video models of ambitious science teaching in the early video club meetings. While lesson structure may not have shifted, 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 postinterviews, 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.

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

Experimenters

Analysis of recordings from William's and Mitch's classrooms along with student work samples indicated that they implemented classroom practices resembling 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 postinterviews. William and Mitch both experimented with ways to make their students' thinking more visible in different ways.

Table 2
Analysis of Classroom Observations, Interviews, and Video Club Participation

Data Sources	Experimenters		Postponers	
	William	**Mitch**	**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.	Mostly concerned with correctness. Short IRE sequences dominant.	Mostly focused on correctness of data collection and calculations. IRE sequences 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.”	“I want to be better.”	“I’m curious about me. What can I change?”
Perceived 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.	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?”	“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.”

William. 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 behavior 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 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 the January observation of William's classroom prior to the 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 only 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 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:

> 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 postinterview 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. 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 he considered to be "misconceptions" the drawings revealed. 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. This was an interesting choice given his goal was to stimulate 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.” Therefore, at this early stage, Mitch may have wanted to introduce both his students and himself to this new type of instruction incrementally.

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, "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."

Postponers

Two teachers, Ron and Vince, were reluctant to experiment with new practices. Analysis of these teachers' lessons revealed little experimentation with the ambitious practices modeled in the video club. They continued to employ teacher-directed activity with little responsiveness to students' disciplinary ideas. However, both expressed the desire to enact changes to make their teaching more responsive and student centered in the future. Each case was examined to gain insight into the different reasons for their reluctance to experiment during the course of the study.

Ron. Ron, a biology teacher with 10 years of experience, stated his goal for participating in the video club as "wanting to be better." He confided that he was reluctant to watch himself on video having negative feelings about that experience from his credential program. He said, however, if this approach could make him a better teacher, that he would "give it a shot."

We observed two of Ron's lessons, one on speciation using whale fossils and scenario cards and one on evolution using fossils of an imaginary organism, Caminalcules. In both cases, he relied on direct instruction followed by a verification activity. Students were active participants in both lessons, and Ron circulated to check in and question them about their progress during group work.

During the speciation lesson, while checking in with groups he would point out a feature the group may have overlooked or provide additional "evidence to consider." When a student asked Ron if their arrangement was correct, Ron replied that whatever arrangement they had was "OK as long as they were able to explain it."

The student pairs discussed their observations of the fossils and at times compared and debated their choices with the other pair sharing their lab table. Near the end of the lesson, he recorded each group's fossil arrangement on the board and revealed what was considered the correct answer. During whole-class discussion of the scenarios, he would call on one student with the correct answer and ask him or her to explain their reasoning. He did not ask students with the incorrect answer to explain their reasoning, and did he not encourage students to press each other about their ideas.

In a debrief with Ron after this lesson, he expressed that he was pleased with the way students were communicating and noted that he had changed the directions to make the language “easier” for his students. Attention to vocabulary and students’ language issues was a common theme for Ron across the video club. He mentioned students’ use of vocabulary and the difficulty students had in expressing themselves in writing in Meetings 1, 2 and 5 (he was unable to attend Meeting 4). In Meeting 5 he indicated that his students often knew more than what they could communicate to him, explaining that “putting their ideas in writing is hard for them.”

During the evolution lesson, Ron circulated while students worked, pointing out overlooked features of the fossils and answering students’ questions. Members of the groups would debate the best placement of the fossils with each other and check with Ron for correctness prior to gluing them down on their poster. Unlike his comment to students to just be able to explain their answers, Ron would correct incorrect fossil patterns, usually by asking students to explain, “Why do you think this one goes here?” He did not ask this question when students had correct fossil patterns.

Ron seemed mostly concerned with the correctness of students’ answers and appeared to view the right answer as something students could only arrive at with help from the teacher. In the first video club while watching students trying to puzzle out what caused the collapse of the tanker truck he questioned, “How would they know that if they hadn't been taught that? They would have to be told.” This approach to instruction could explain why Ron approached his revealing and explaining of “correct” answers to students in both the whale fossil and Caminalcule lessons. Leaving students too long to sort out their understanding of the concepts did not appear to be acceptable to Ron at that time.

Ron may have shifted his opinion on student autonomy by the end of the video club. When asked to reflect on his experiences, Ron mentioned that, though he saw the value of having students develop and discuss their understanding of data and observations, he still had concerns: “This approach will take more time. They are going to be all over the place, but they will figure it out. I still have to figure out how to make this work. I want to be better.”

He was also concerned about the pacing of instruction and maintaining momentum across several days of instruction. He did say that the adoption of new standards was “good timing” because it necessitated a rewriting of the curriculum. Ron mentioned that he was “afraid he didn’t change much” over the course of the video club because “he already had the lessons planned.” Ron spent much of the previous summer planning out his year, so it is understandable that he was reluctant to abandon what represented a significant amount of time, thought, and effort for him.

Vincent. Vincent, a 15-year veteran and a former department chair with a master’s degree in teaching science, teaches AP Physics and Earth Science. Vincent, when asked why he chose to participate in the video club, mentioned that he conducted research for his master’s thesis and wanted to “pay it forward.” He also commented that he was “curious” about himself and wondered what he could change about his teaching. The class he chose to focus on in this study was his AP Physics class. Preparing students for the AP exam and for college-level physics was his stated goal as an instructor, and that responsibility heavily influenced his instruction. This goal was evident in the instruction we witnessed; every lesson we observed was either students engaging in one of the required AP Physics labs or a simulation of the AP exam.

Vincent relied on a pattern of direct instruction followed by a verification lab. In January, students collected data using pulleys and masses to calculate g, acceleration due to gravity. In February, students collected data on the kinematics of a ball rolling down a ramp to calculate its velocity and acceleration. Vince defined what data his students were to collect and how to set up the apparatus in these labs. His students spent most of their time in lab groups collecting data while Vince circulated to check for understanding. The exception was the April lesson in which students engaged in a lab experience designed to mimic the AP Physics exam.

Because the activity was a test simulation, Vincent did not attempt to engage students in extended discussion during their work at the lab benches. Students were engaged in collecting data and would ask each other for assistance in completing calculations and verify that each computed the same answer. Across all observations, Vincent's questioning consistently focused on verifying understanding of the lab setup, manipulation of the apparatus being used, and the correctness of students' calculations. He would occasionally ask open-ended questions, but frequently completed students' answers after they started to respond. Vince did not press students to explain why they were performing certain calculations and rarely asked students to reflect on what their data told them about the physics concept under investigation — both during the small group and large group discussion time.

In the video club meetings, Vincent often used the phrase "on the right track" with regard to students' answers. He also often mentioned the need to ferret out what he considered to be students' "misconceptions" in his pre- and postinterviews as well as in the video club meetings. Though these comments indicate that Vincent may have seen student learning and understanding taking place over time, it also indicates that he had a predefined correct answer he wanted students to arrive at.

In post lesson debriefs with Vincent, he mentioned his use of a new iPad cart with a data collection application. According to Vincent the most exciting feature was the access the software gave student to collecting more data points for each kinetic trial during labs. This feature, in turn, made students' results more accurate, which would then more closely match the formal physical law of motion the labs were designed to demonstrate. Verifying known constants or laws was one of the goals of each of the AP labs observed during the study. Vincent's excitement about the iPad software and the questioning he employed during instruction to ensure that students were collecting accurate data and completing calculations correctly reinforce the interpretation that verification of a predetermined correct answer was one of his instructional goals.

Vincent mentioned feeling constrained by the AP curriculum and expressed that he wished he had included his earth science class in the study, partly because there was more freedom in the curriculum and partly because those students "had more misconceptions." Although he did not experiment with his practice in the observed lessons over the course of the video club, he did report learning from the experience:

> I want to be less teacher centered. Less sage on the stage. I need to let them squirm a bit more so I can see where the misconceptions are, where they are stuck and why, not just say, "Oh, they are stuck," and help. I want more feedback from them.

When pressed about what that might look like in the future, Vincent expressed some concerns about changing:

> I'm not quite there yet where I ask them questions where it will make them think. Part of it may be the way I designed the labs or how I approach them. I immediately give them the purpose and tell them here's the relationship, now go find it. I was

> telling them what to measure, like giving them a treasure map, now go find the treasure. I'm having difficulty steering away from that.

He speculated that seeing more video examples of his colleagues would help with this shift.

Discussion

We described cases of four teachers to illustrate their efforts to experiment with practices to promote students' evidence-based reasoning as they participated in a semester-long video club. Observations suggest that participation in the video club stimulated changes in thinking for all participants. All four teachers reported seeing value in making student thinking visible and shifting more autonomy to students. However, they also expressed the view that knowing how to respond to students' ideas once they were raised and shifting to the next level of inquiry was challenging. Consistent with other research, the teachers also demonstrated a shift in attention to student thinking in the context of the video club (Luna & Sherin, 2017; van Es & Sherin, 2008; Walkoe, 2015).

However, not every participant incorporated visible changes into their instruction as a result of their video club participation. Mitch and William, the experimenters, applied their changing ideas about ambitious science teaching in different ways. Mitch attempted to create more openings for students to talk about data they collected. William incorporated the use of student-drawn conceptual models to supplement their written answers to postlab questions. Both Vincent and Ron, the postponers, acknowledged in their postinterviews that they perceived their practice changing very little and that they were dissatisfied with their current instructional practice. Interestingly, both described their current practice similarly as being rather formulaic, describing them as "cookbook" and "cookie-cutter."

That said, they both also shared a desire to change to more student-centered instruction. This raises the question, if both were dissatisfied with their practice and wanted to change, why did they not experiment? Issues of goal specificity, classroom context, perceived practicality of the instructional changes, and the video club design may have influenced what participants were and were not able to do (Hammer & Schifter, 2001; Janssen et al., 2013; Kazemi & Hubbard, 2008).

Ron's and Vincent's goals differed from the other participants' in two ways. First, William and Mitch'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, while Mitch's goal was to increase conversations. 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.

In contrast, Vincent and Ron did not articulate specific goals for participation in the video club. 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). Taking the time to help participants refine their personal goals could increase the perceived relevance of the professional development for participants and, in turn, increase the likelihood of experimentation with the instructional moves promoted in the professional development (Hammer & Schifter, 2001).

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. 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 former state mandated tests, but acknowledged that he was constrained because he had written his lesson plans for the semester prior to the start of the study, during the summer break. He also mentioned, both in postinterviews and during video club meetings, that he saw merits in using drawings but did not know how to use them. 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.

They also perceived the classroom contexts they chose to focus on as limiting their ability to experiment with new practices. Vincent perceived he had more freedom with the earth science curriculum, as compared to the AP course, while Ron indicated that he perceived the topics in the first semester better lent themselves to trying out new practices. Designers of professional development should, therefore, be mindful of the enacted curriculum and the affordances and complications that may arise when teachers’ curricular goals interact with those of the professional developer (as suggested in Remillard & Geist, 2002).

This is not to say that Vincent and Ron did not perceive benefit from 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. William and Mitch, on the other hand, were able to incorporate small but manageable changes into their existing instruction to act on their ideas from the video club. These changes did not fundamentally change the nature or purpose of the tasks students engaged in, which was usually a verification of concept activity.

Comments in video club meetings and postinterviews indicate that although they recognized that students’ ideas should drive future instruction both viewed the students’ drawing explanations to accompany a lab and reporting on their data as assessments *of* learning, not learning activities *themselves* (as found in Ruiz-Primo & Furtak, 2006). Prior research shows that changing practice is an incremental process in which teachers often make small, manageable changes then observe the results before undertaking more (Janssen et al., 2013; Star, 2015; Timperley, 2008). However, even these small adjustments challenged William and Mitch. Both expressed frustration with knowing how to follow up on students’ ideas once they were raised and how to support students in communicating their ideas. Both explained working with students’ ideas as an area for continued professional improvement. These small adjustments may have stayed within the amount of instructional disruption each could tolerate.

One issue that arises in this study is how often teachers needed to meet and analyze video to develop a vision and begin to experiment in practice. One main goal was to help teachers learn about student thinking and learn practices to help them get insight into student thinking and to work with students’ ideas in teaching. The relatively short duration of the video club may be one reason that two teachers did not experiment with new approaches to teaching. Participants in this video club demonstrated that they were able to engage in extended discussions about students' thinking by the third meeting, which is earlier than other video clubs (Sherin & van Es, 2009).

One value in using the published materials is that they were developed to capture worthwhile student disciplinary ideas. However, with only two additional meetings, there was insufficient opportunity to investigate students' thinking from their own classrooms, explore new approaches in practice, and return to the video club again to explore the new attempt. For teachers to experiment and fundamentally shift instruction, multiple cycles of observation and analysis of each other's teaching may be required, so they can get continuous feedback on practice. This approach would mark a different phase in the video club, one in which participants continue to collaboratively puzzle about practice through the examination of artifacts from their own classrooms. 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).

This analysis 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 four participants over the course of one semester. Not every participant was able to attend each meeting, and we were not able to observe each participant in his classroom on a regular basis. We also asked to observe a particular type of lesson, so it is unclear how reflective the classrooms observations were of the participants' practice. This requirement limited the data and, therefore, the opportunity to understand how participation in the video club influenced their practice. Moreover, this group was composed of individuals who had leadership experience, advanced degrees in education, or participated on district efforts to align curriculum with the goals of ambitious instruction. Each of these elements likely influenced the activity and participation in this video club (as also in Borko, 2004), an important subject for future inquiry.

Conclusion

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, 2004) to engage participants with particular tools, tasks, and forms of talk to promote the development of teachers' noticing of students' disciplinary thinking and exploring the instructional triangle using critical discourse. Participants demonstrated sustained noticing of student's disciplinary thinking in the meetings, and some applied this learning to make some adjustments to their classroom practice. This result is encouraging because small changes are implemented relatively easily and are, therefore, more likely to be sustained.

More importantly, they may also set up more ambitious changes in the future because t small changes in practice to incorporate more student-centered instruction may 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 et al., 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). With additional cycles of bringing artifacts of participants' own practice to the video club, that teachers in this setting may 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 teacher community. This result could be an important crucible for working through the instructional shifts demanded as teachers attempt to implement the *Next Generation Science Standards* (NGSS Lead States, 2013).

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Appendix A

Participant Time Ordered Matrix for Mitch – Concerns & Obstacles

Pre-Interview	Meeting 1	Meeting 2	Lesson 2/25	Meeting 4	Lesson 4/22	Lesson 5/20	Meeting 5	Postinterview
Facilitating discussion is hard – need to see models	"Our students they're not armed with appropriate vocabulary yet. They don't have any confidence. They don't have those words in their mouths or in their heads yet." Writing their reasoning is a challenge (drawing might be an alternative).	Students can make a coherent claim, but not support it. Students can describe evidence, but not in support of a claim. Need to do both. Very easy to "corner" students into an explanation. Introduction of gear complicates things.	"This is hard going, and I knew it would be after watching the video" "I did this to practice"	"Some kids 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?" Can describe evidence, but not connect back to claim.	Students seemed at a loss as to where to start. Students had a hard time connecting data to model. They could make a prediction, but could not explain the mechanism. Did not know how to participate? Not interested?	Trying out modeling, but still have concerns about using the data to support a conclusion. Didn't really get to press students on that though (b/c of time)	"You almost need a different kind of prompt. Is there a difference between medium and high quality in this prompt?" Crafting the "right" question is hard.	You never see enough of the right kind of model; how do you know a kid is logically connecting the evidence to the argument? I may not know the correct probing question yet to get them to talk; "what's the question to get this person to reconsider"

Appendix B
Participant Time Ordered Matrix for Vincent – Concerns & Obstacles

Pre-Interview	Lesson 1/13	Meeting 1	Lesson 2/12	Meeting 3	Meeting 4	Lesson 4/30	Postinterview
Students can complete calculations but sometimes need help seeing the big picture. They need guidance and help using the correct terms. They have a lot of misconceptions.	Excited about using iPads to collect more accurate data, but working out the kinks.	"Change their way of thinking without giving them the answer." "I'm trying to get away from you show them the equation and then you show them the model that describes the equation. But it was done the other way around here."	Wanted to use the iPads to get "good" data but couldn't get them.	Students have a lot of misconceptions about how sound travels.	"Do we need to ask more targeted questions" instead of "describe what happened"? Do the students really understand why they add water to the can and what would happen if you didn't? How do we get at that?	At this point in the semester, I have to let them figure out how to set up the equipment on their own or they won't do well on the AP test. They need to know how to set up the problem and draw the diagram without help.	Should have used a class with more misconceptions. "I want to be, less "cookie-cutter. I need to let them "squirm" a bit more so I can see where the misconceptions are, where they are stuck and why, I'm not quite there yet where I ask them question where it will make them think. I'm having difficulty with that."