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ORIGINAL ARTICLE

Using video representations of teaching in practice-based professional development programs

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Abstract This article explores how video can be used in practice-based professional development (PD) programs to serve as a focal point for teachers' collaborative exploration of the central activities of teaching. We argue that by choosing video clips, posing substantive questions, and facilitating productive conversations, professional developers can guide teachers to examine central aspects of learning and instruction. We draw primarily from our experiences developing and studying two mathematics PD programs, the Problem-Solving Cycle (PSC) and Learning and Teaching Geometry (LTG). While both programs feature classroom video in a central role, they illustrate different approaches to practice-based PD. The PSC, an adaptive model of PD, provides a framework within which facilitators tailor activities to suit their local context. By contrast, LTG is a highly specified model of PD, which details in advance particular learning goals, design characteristics, and extensive support materials for facilitators. We propose a continuum of video use in PD from highly adaptive to highly specified and consider the affordances and constraints of different approaches exemplified by the PSC and LTG programs.

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1 Introduction

Teacher professional development (PD) has been in high demand during the last decade, as an essential factor in achieving the ambitious goals for student learning set by current educational reform movements. A general consensus that the teacher education programs currently available to novice and experienced teachers are inadequate to meet these demands has been the impetus for efforts to design models of PD that are grounded in a theoretical perspective on teacher learning. While there is no single empirically validated theory of teacher learning to inform such models, several features of effective PD have been identified across a number of theoretical frameworks and research projects and adopted within the teacher education community. Many teacher educators, e.g., share the view that professional education for teachers should (a) be a collaborative endeavor, (b) be about the work of teaching, and (c) situate learning opportunities for teachers in the context of that work (see, e.g., Ball and Cohen 1999; Borko et al. 2010; Kazemi and Hubbard 2008). Situating professional learning opportunities in practice does not imply that PD must take place in a teacher's own classroom. Rather, as Ball and Cohen (1999) explained, practice-based PD entails identifying the central activities of instructional practice, selecting or creating materials that usefully depict the work of teaching, and using these materials to create opportunities for teacher learning.

In this chapter, we explore how practice-based PD programs can encourage teachers to deeply consider ways to improve their instruction and enhance learning opportunities for their students. We focus, in particular, on the role that video can play in these PD efforts, as a medium to provide a shared experience and to serve as a focal point for teachers' collaborative exploration of the central activities of teaching. Using intentionally chosen video representations of teaching to situate PD activities in classroom practice and posing substantive questions to focus teachers' attention, practice-based PD programs invite analytic thinking and productive conversations. They support professional developers to guide teachers in the purposeful examination of selected aspects of learning and instruction.

2 The role of video in practice-based PD

Materials taken from actual classrooms play a key role in practice-based PD. Records of practice—such as classroom video, examples of student work, lesson plans, and instructional materials—bring the central activities of teaching into the PD setting, providing an opportunity for teachers to collaboratively study their practice without being physically present in the classroom. They enable teachers to examine one another's instructional strategies and student learning, as well as the content addressed in the lessons, and to discuss ideas for improvement (Ball and Cohen 1999; Borko et al. 2008; Kazemi and Franke 2004; Little et al. 2003).

Video has become increasingly popular in PD as a means for capturing the everyday experiences of teachers and students. As Sherin (2004) explained, "Video allows one to enter the world of the classroom without having to be in the position of teaching in-the-moment" (p. 13). Thus, it can be used to create a shared experience, serving as a focal point for teachers' collaborative exploration of the central activities of teaching. Video records can highlight aspects of classroom life that a teacher might not notice in the midst of carrying out a lesson.

Brophy (2004) cautioned that teachers do not necessarily gain new insights about their practice from watching classroom video. Rather, what teachers attend to when they watch classroom video and how they interpret what they notice are likely to be guided by their conceptions of effective instruction. Erickson (2007) suggested that this is particularly true for experienced teachers, when watching minimally edited footage. For these teachers, minimally edited classroom video functions more like a projective test than a window into practice, "an inherently ambiguous and incomplete stimulus that invites reaction and speculation" based on their pedagogical commitments and narrative understanding of teaching (p. 152).

Findings from Jacobs and Morita's (2002) study of Japanese and American teachers' evaluations of mathematics lessons illustrate this idea. Jacobs and Morita presented a straightforward, open-ended task to these two groups of teachers, asking them to point out "strengths" and "weaknesses" in videotaped mathematics lessons. Whereas the American teachers were generally supportive of the instructional scripts underlying the Japanese and American lessons, the Japanese teachers critiqued both lessons against a highly detailed "Japanese" script. The researchers concluded that what teachers commented on mapped onto their beliefs about how mathematics should be taught, and that these beliefs varied dramatically across countries.

Sherin and colleagues (Sherin 2007; Sherin and Han 2004; van Es and Sherin 2002, 2008) expanded on this line of inquiry to examine what American teachers noticed when watching video in a PD setting, and how their attention to particular classroom events changed over time. For example, they found that the teachers' discussions shifted from a primary focus on pedagogical issues to a stronger focus on students and their mathematical ideas. Moreover, the teachers engaged in increasingly detailed and complex analyses of student thinking, and they more closely connected their discussions of pedagogy with their analyses of student thinking. These studies suggest that classroom video can be used to provide an opportunity for teachers to interpret and reflect on instructional practices, and that the nature of teachers' reflections and discussions can change over time. An unanswered question, however, is how PD programs can capitalize on the power of video representations of teaching to guide teachers' attention and reflection in an intentional manner.

Our chapter seeks to provide some initial responses to this question by considering how teachers' reflections and conversations in practice-based PD can be scaffolded through the purposeful selection and use of video footage. In particular, we hypothesize that by carefully choosing video clips that invite analytical thinking, by providing substantive questions to focus teachers' attention, and by facilitating productive conversations, professional developers can guide teachers to examine critical aspects of learning and instruction. In highlighting the role of video, we do not suggest that it is the most central or important component of a practice-based PD program. Rather, our premise is simply that professional developers should be aware of the power of video as well as the challenges that accompany its use.

In the remainder of the chapter, we consider several concerns and challenges related to the use of video. We draw primarily from our experiences developing and field-testing two mathematics PD programs, the Problem-Solving Cycle (PSC) and Learning and Teaching Geometry (LTG). While both programs feature classroom video in a central role, they illustrate different approaches to practice-based PD (Koellner & Seago, 2010). These approaches can be understood as falling along a continuum of video use in PD (see Fig. 1). On one end of the continuum are PD

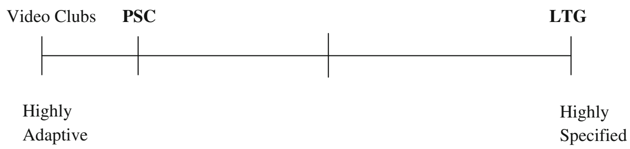

Fig. 1 Continuum of video use in PD

approaches that are *highly adaptive*. Highly adaptive approaches have goals and resources derived from the local context and facilitation based on general guidelines rather than specific activities and materials. On the other end of the continuum are *highly specified* approaches to PD where goals, resources and facilitation materials are specified for a particular predetermined PD experience.

Video study groups are an example of *highly adaptive* approaches to PD. A video study group is typically defined as teachers who share video of their own classrooms and discuss aspects of their instructional practice that are of interest to them (Sherin and Han 2004). The PSC can be described as an example of *adaptive* PD (Horn 2008), in which video is selected from participants' classrooms, most resources emerge organically from the group (although certain facilitation resources are available), and facilitators select video clips and make design decisions to take into account the local context in which they work. By contrast, LTG is an example of *highly specified* PD—i.e., a PD program that generally involves published materials that specify in advance particular learning goals, make explicit their design characteristics, and provide extensive supports and resources for facilitators.

In the following sections, we present overviews of the PSC and LTG programs. We next consider how these two programs use video representations of teaching to guide teachers' reflections and conversations about mathematics content, core instructional practices, and student ideas. We then present brief vignettes and discuss two critical aspects of using video in PD: (1) identifying features of video excerpts that work well for practice-based PD and (2) scaffolding teachers' viewing and discussions of video. The chapter concludes with a consideration of critical aspects of the different approaches to incorporating video into practice-based PD.

3 Overview of the PSC

The PSC is an iterative, long-term approach to supporting teachers' learning. Each iteration of the PSC consists of three interconnected workshops in which teachers share a common mathematical and pedagogical experience, organized around a rich mathematical task. Central activities for participants include solving the mathematical task, teaching it to their students, and using video from the lessons to situate explorations of students' mathematical reasoning and the teachers' instructional practices. Successive iterations build on one another and capitalize on teachers' expanding knowledge, interests, and sense of community. (For additional information, see Koellner et al. 2007; Jacobs et al. 2007.)

During Workshop 1 of the PSC, teachers collaboratively solve the selected mathematical task and then develop plans for teaching the task to their students. The main goal of this workshop is to help teachers develop the content knowledge necessary for planning and teaching a lesson with the task, and the majority of time is spent by teachers doing the problem, debriefing various solution strategies, considering how their students might solve the problem, and creating lesson plans that modify the problem or otherwise take into account the specific nature of their classrooms. After Workshop 1, participants teach the task to their own students, and the lessons are videotaped. The facilitator then selects video clips and related artifacts for use in Workshops 2 and 3.

Workshops 2 and 3 focus on the teachers' classroom experiences and rely heavily on the selected video clips. The goals of these two workshops are to help teachers learn more about the mathematical concepts and skills entailed in the task, explore a variety of instructional strategies for teaching the task, and improve their ability to analyze and build on student thinking. The major focus of Workshop 2 is the role played by the teacher in implementing the problem. Video clips serve as a springboard for exploring topics such as ways to introduce the task, questions to pose as students work on the task, and methods of managing the classroom discourse. The activities in Workshop 3 are focused on the close examination of students' mathematical reasoning. Video clips, as well as other artifacts such as students' written work on the PSC problem, focus teachers' attention on topics such as unexpected methods that students used to solve the problem, ways they explained and justified their ideas, and ways in which language has the potential to both promote and hinder student learning.

The mathematical concepts and solution strategies entailed in the PSC problem and specific topics addressed during Workshops 2 and 3 depend on the concerns and interests of the teachers, facilitators, schools, and districts. In all cases, classroom video plays a central role as a means for framing workshop activities and conversations. Minimally edited video excerpts from participating teachers' classrooms help to ground Workshops 2 and 3 in the common experience of teaching the PSC task. The video motivates productive discussions by providing concrete instances of teachers' pedagogical strategies and students' mathematical reasoning related to the mathematical concepts embedded in students' solution methods (Borko et al. 2008).

4 Overview of LTG

The LTG project is currently creating modular, sequenced PD materials for middle school mathematics teachers, building on the designers' experiences in developing and using the "Learning and Teaching Linear Functions" video case materials (Seago et al. 2004). LTG will produce highly specified, commercially available materials that outline in advance a particular set of goals and activities, and will provide video clips and questions to be used for facilitating those activities. The LTG materials, focusing on classroom geometry lessons, are intended to initiate inquiry into key content and pedagogical issues with respect to teaching and learning the concept of mathematical similarity.

To create the materials, the LTG project team engaged in a six-phase design process: (1) developing a learning trajectory and a corresponding sequence of tasks that would provide a mathematically robust experience for middle school teachers around learning and teaching similarity, vetted by a group of mathematicians, (2) using a strategic videotaping process to film a number of classroom lessons in which teachers used tasks provided by our project team or related problems from their curriculum (videotaping over a period of multiple years to yield clips connected to each of the learning goals), (3) selecting promising video clips from these lessons to map on to the learning trajectory and identifying needs for additional videotaping, (4) designing PD modules that incorporate these video clips, (5) developing video case resources for teachers and facilitators, and (6) revising materials based upon formative evaluation data (Seago, Driscoll & Jacobs, 2010).

A core component of the materials will be a set of video cases highlighting teachers' and students' experiences working with similarity problems in their classrooms. The video representations of teaching contained within the modules are intentionally unscripted, minimally edited, and organized in a sequenced and cohesive manner in order to scaffold teacher learning along the mathematical learning trajectory. The goal is to create PD materials that represent authentic classroom teaching that reflects the complexities of practice and the inherent dilemmas in teaching mathematical content across multiple and varied contexts.

In developing the LTG model, several dozen mathematics teachers across the country were chosen to be videotaped as they implemented either the mathematical similarity problems designed by the LTG research team or other related similarity problems from their own curriculum. A key objective was to obtain images of instruction where transformations (e.g., rotations, reflections, dilations) played a central role in students' geometric thinking. From these recorded lessons, video clips were selected that provided insight into (1) what an emerging understanding of similarity among middle school students looks like and (2) instructional strategies that can foster students' understanding of similarity.

The LTG materials will include resources to support facilitation of the video cases, such as detailed session agendas with explicitly stated goals, PowerPoint slides, lesson graphs,[1] time-coded transcripts, and a field guide (illustrated dictionary) of key mathematical terms. These resources are intended to support facilitators as they adapt the materials to their own context while maintaining the mathematical and pedagogical storyline of each module.

Thus, LTG's highly specified use of video provides an important contrast to the PSC's adaptive use of video. The LTG program includes a predetermined substantive focus, a pre-specified mathematical trajectory and materials designed to support that trajectory, and the use of video clips from classrooms of teachers other than the PD participants. At the same time, both the PSC and LTG programs use video representations of teaching to situate the PD in classroom activity settings, establish a collegial learning community, and enhance teachers' knowledge of mathematics for teaching.

5 Using video to enhance teachers' knowledge of mathematics for teaching

Ball and colleagues have identified and elucidated the construct "knowledge of mathematics for teaching"—the mathematical knowledge that teachers must have in order to do the mathematical work of teaching effectively (e.g., Ball and Bass 2000; Ball, Thames and Phelps, 2008). This knowledge can be broken down into multiple components, which have been labeled and described in different ways. In this chapter, we refer to the components as (1) knowledge about mathematical content, (2) knowledge about core instructional practices, and (3) knowledge about core practices for eliciting and building on student thinking. It is important to note that these three components are tightly interconnected in classroom teaching and learning. Our goal in attempting to disentangle them is to explore the specific ways that video can be used to situate the

[1] Designed by Nanette Seago, a one-page lesson graph maps a concise development of the mathematics as it unfolds through the dynamics of teacher and student interactions across time during the lesson. The lesson graph provides context for the video clips, as well as representations of the mathematics in motion.

exploration of each component in classroom practice, drawing on examples from the PSC and LTG programs.

5.1 Using video to guide exploration of mathematics content

Ball and Bass (2000) described the mathematical content knowledge needed for teaching as including both “common content knowledge” and “specialized content knowledge.” Common content knowledge can be defined as a basic understanding of mathematics acquired by any well-educated adult and used in a wide variety of settings. Specialized content knowledge is the mathematical knowledge unique to teaching. It involves a deeper, more nuanced understanding that enables teachers to evaluate the multiple, sometimes novel and unexpected mathematical representations and solution strategies that students bring to the classroom, to analyze (rather than just recognize) errors, to give mathematical explanations, to use developmentally appropriate mathematical representations, and to be explicit about their mathematical language and practices (Ball and Bass, 2000; Ball, Thames and Phelps, 2008). Both common and specialized content knowledge are addressed in the PSC and LTG programs, with particular emphasis placed on specialized content knowledge.

In both the PSC and LTG programs, prior to watching a given video clip, teachers grapple with the same mathematical task the videotaped students tackled. Significant time is devoted to forecasting alternative solutions, comparing solutions, and anticipating student misconceptions. Typical conversations include consideration of (1) the mathematical skills, procedures, and concepts entailed in the task; (2) the mathematical reasoning and possible solution strategies (correct and incorrect) that students are likely to apply to the task; (3) the affordances and constraints of different mathematical representations (e.g., pictures, tables, graphs, equations); and (4) students’ background knowledge and scaffolds that might be helpful to support learning.

An important contrast between the PSC and LTG programs is that whereas the mathematical focus is predetermined in LTG and built into the published materials (including the video clips), it is not prescribed in the PSC. PSC facilitators can determine whether to cover algebra, geometry, linear functions, ratio and proportion, or any other topic area according to the goals and interests of the teachers, school, or district. There is also not a pre-specified learning trajectory for teachers participating in the PSC. Different PSC facilitators may have more or less developed notions of the mathematical terrain that they want to cover over a certain period of time. Another important contrast is that exploring mathematical content is foregrounded in Workshop 1 of the PSC, but not necessarily in Workshops 2 and 3, whereas in LTG materials the central focus on attending to and analyzing specific mathematical content (similarity) is consistent throughout.

5.2 Using video to guide exploration of core instructional practices

In addition to promoting teachers’ *content knowledge* (common and specialized), a major focus of the PSC and LTG programs is promoting teachers’ *pedagogical content knowledge* (Shulman, 1987). Both programs use video footage to foster the exploration of core practices of teaching. Grossman et al. (2009) defined these practices as high-leverage, high-frequency sets of strategies and techniques that can be enacted across different curricula and instructional approaches, that preserve the integrity and complexity of teaching, that are research-based, and that have the potential to improve student achievement. Some core practices of teaching—such as providing clear instructional explanations, asking generative questions, and leading a class discussion—cut across grade levels and subject areas. Others are specific to particular grades or subjects.

In the PSC, during Workshop 2, teachers consider selected core instructional practices by watching and discussing video clips from their lessons. Having all taught the same task, the teachers now explore pedagogical topics such as how they introduced the task, orchestrated classroom discourse, facilitated group work, mediated student thinking, or concluded the lesson. As they analyze purposefully chosen video clips and participate in guided discussions, teachers in this workshop are given the opportunity to critically reflect on their own practices along with those of their colleagues, using the common mathematical task as the context.

The LTG materials also guide teachers to consider core instructional practices that are intertwined with the mathematical content, in the interest of equipping teachers with a larger repertoire of strategies to foster their students’ understanding. For example, some video clips are selected to highlight such practices as using representations, making connections between important mathematical ideas, encouraging convincing mathematical explanations, and summarizing key points. For these clips, the LTG materials note specific topics that facilitators should encourage teachers to discuss. Thus, as the teachers consider important mathematical ideas, they do so within the context of core instructional practices.

The PSC and LTG models are both designed to provide teachers with multiple and varied opportunities to study and analyze teaching, with the goal of encouraging more informed decisions about their own instructional practices.

In both programs, the focal instructional practices for a given workshop are determined in advance by the facilitators or designers. Although the conversations generated by the video clips naturally have some degree of open-endedness, they are framed with a particular direction in mind. In other words, clips are selected and guidelines for viewing and discussing video are developed with the intention of helping teachers to explore particular instructional practices. Important contrasts between the PSC and LTG along this dimension include the instructional practices that are highlighted, and the degree to which the video is "familiar" to the teachers.

In the case of the PSC, as with the selection of the mathematical topic, the choice of practices to consider and video clips to view is determined by the facilitator. The use of video from the teachers' own lessons helps ensure that the instructional practices to be explored match the interests and needs of the participants. At the same time, because the video clips originate from lessons taught by the participating teachers, the choice of clips is restricted to the (generally small) set of lessons that were videotaped. Thus, what the teachers did in their lessons and the ways the lessons unfolded set the parameters for the topics that are available for exploration.

In the case of LTG, the video is filmed in classrooms unfamiliar to the participating teachers. A relatively large number of teachers are videotaped to ensure the availability of high-quality clips representing a wide range of core practices. Capitalizing on the strategy of filming multiple teachers implementing the same problem (or portions of the same problem)—each with unique student populations and using different instructional techniques—the developers select video clips that seem most likely to initiate inquiry into relevant mathematical and pedagogical issues.

5.3 Using video to guide exploration of student ideas

Another set of core practices of teaching highlights learning about students' mathematical thinking and using their ideas to influence instructional decisions and actions. This set is composed of more fine-grained practices such as eliciting student thinking during interactive teaching, making sense of students' ambiguous or incomplete solutions, analyzing students' correct and incorrect solution strategies, and eliciting further thinking (Grossman et al. 2009; Kazemi and Hubbard 2008). Video intended to promote the discussion of these core practices is featured prominently in both the PSC and LTG programs.

In the PSC program, Workshop 3 provides opportunities for teachers to consider the various forms of mathematical reasoning their students applied to the task. Teachers typically watch video clips of students grappling with mathematics concepts in diverse ways that reflect different levels of mathematical ability and different solution strategies. For example, teachers might view students explaining their strategies to fellow students or to the teacher, during small-group work or as they share their solutions with the whole class. Teachers often are encouraged to consider ways in which they might elicit, support, and build on these various ideas.

In LTG, teachers view clips that make students' thinking visible and therefore serve as a starting point for teachers to investigate complex (and often emerging) mathematical ideas. Clips typically represent a conceptual hurdle or portray some degree of mathematical confusion, based on the expectation that they are likely to provoke inquiry and discussion. Of particular relevance are clips that highlight students engaging with similarity tasks using a dynamic or transformational approach. The goal of such clips is to help teachers recognize the distinction between a static view that focuses on the numerical examination of discrete similar figures and a dynamic view that focuses on enlarging or reducing figures geometrically to create similar figures.

Both the PSC and LTG programs seek to encourage teachers to attend to and interpret students' thinking using video clips that portray interesting, unusual, emerging, or incorrect ideas about an important mathematical topic. Contrasts between the two PD programs are similar to those discussed with respect to the exploration of core instructional practices. PSC facilitators review videotaped lessons taught by the group and select the clips and discussion issues they deem relevant to that group. LTG facilitators use clips prepared and sequenced by the designers to support conversations focused on selected mathematical ideas.

6 Critical aspects of using video in PD

To be an effective tool for teacher learning in PD, video representations of teaching must be selected to address specific learning goals (e.g., enhancing teachers' specialized content knowledge, improving teachers' ability to analyze students' incorrect solution strategies) and incorporated into activities designed to scaffold teachers' progress toward those goals (Brophy 2004; Seidel et al. 2005). A key consideration in planning PD activities is how to promote teachers' examination of features within the video clips that are central to those goals. In the sections that follow, we first present brief vignettes that illustrate the use of video in the PSC and LTG programs. Next, we consider two critical aspects of using video in practice-based PD—selecting effective video clips and scaffolding teachers' viewing and discussions of video footage.

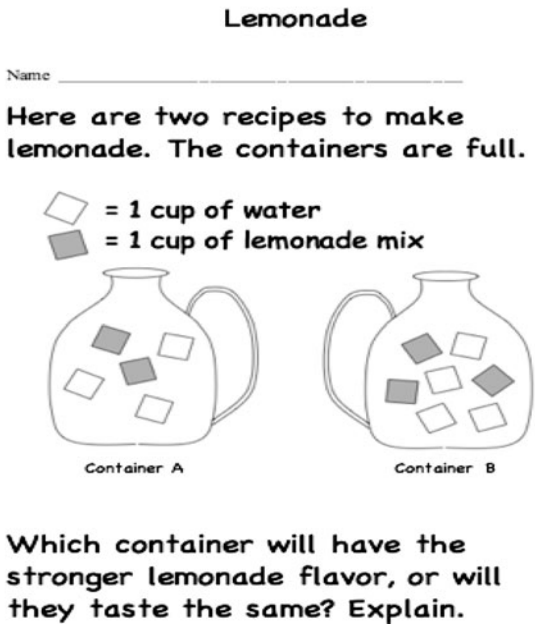

Fig. 2 The Lemonade Problem

6.1 A sample video clip and discussion in the PSC

As part of the "Implementing the Problem Solving Cycle (iPSC)" project, we studied the process of scaling up the PSC by preparing facilitators to implement and sustain the program in their schools (Jacobs, Borko & Koellner, 2009). We recruited middle school mathematics teachers from a large urban school district to serve as PSC facilitators, and provided them with 2½ years of extensive training and support. One of these mathematics teachers, Mandy Perkins,[2] facilitated the PSC with a group of her colleagues at Field Middle School. The first iteration of the PSC that she facilitated (in Fall 2008) used the Lemonade Problem (adapted from Van de Walle, 2008; see Fig. 2). The Lemonade Problem involves a comparison of two containers of lemonade, in order to determine which has a stronger flavor. In Container A, there are two cups of lemonade and three cups of water. In Container B, there are three cups of lemonade and four cups of water.

Following the standard PSC protocol, Mandy held three workshops around the Lemonade Problem with her group of teachers. In Workshop 1, they solved the problem, analyzed multiple solution strategies, and created individual lesson plans. They then taught the problem in their respective classes. In Workshop 2, they watched video clips that Mandy selected and considered issues related to instructional practices for supporting students' proportional reasoning; in Workshop 3, the focus was primarily on students' reasoning. Here, we briefly recount some of the events that took place during Mandy's Workshop 3, including a description of two video clips she showed and how she scaffolded conversations around those clips in ways that promoted a professional learning environment.

[2] All teacher and school names used in discussions of the iPSC project are pseudonyms.

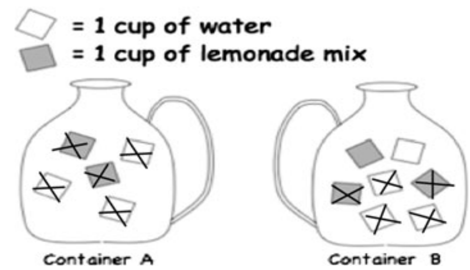

Fig. 3 Nicole's student's solution

Mandy tells the three participating teachers in her group—Nicole, Ellie, and James—that they will watch a pair of video clips from Nicole's lemonade lesson, and focus on analyzing what the students in those clips were thinking. In the first clip, a student shows her solution strategy on the Smart Board. She crosses off a cup of water in Container A and a cup of water in Container B. Then, she crosses off a cup of lemonade in Container A and a cup of lemonade in Container B. This crossing off continues until everything in Container A has been crossed off and Container B is left with one cup of water and one cup of lemonade (see Fig. 3).

The teachers watch the video clip twice. Before the second viewing, Mandy asks that they focus on the question: "What do you think the student's thinking is that's expressed at this point?" This question guides the teachers to consider what the student might have been thinking, and to try to predict which container she will say has the strongest flavor. The group notes that although they had anticipated solution strategies where students "pair" cups of water and lemonade within containers, they had not anticipated this sort of "elimination" strategy across containers, which they liken to "canceling" in mathematical equations. Nicole explains that other students in her class used this strategy as well. The group predicts that the videotaped student will say that Container B has a stronger lemonade flavor, or possibly that the lemonade flavor in the containers is the same.

Mandy restates their predictions, and shows the second video clip. In this clip, the student says that she thinks Container A will have the stronger flavor but she does not clearly explain why. As they watch the clip, the teachers laugh with surprise and exclaim, "How did she pick A?" Mandy encourages the teachers to take up this question, but they are highly uncertain about what the student might be thinking. Mandy decides to steers the conversation toward a consideration of instructional strategies; she asks the group, "Based on what we know, what are Nicole's options to support student learning, to move them in a direction to develop an understanding (of ratio)?" The teachers are hesitant about how to answer this question, but note that students who have little background with ratios, such as the student in the video, require support in looking at two variables at once. They agree that it may be beneficial for students to try out various incorrect approaches, such as eliminating, canceling, and subtracting, in order to understand why proportional reasoning is appropriate in these situations. Mandy draws this part of the workshop to a close by telling the group that later in the lesson, the videotaped student says that A has a stronger flavor because it contains less water. The teachers mull this reasoning over. They agree that the student is most likely only considering the amount of water in each container, and has concluded that less water yields a stronger lemonade flavor (regardless of the amount of lemonade).

The two short video clips Mandy selected, which showed a student grappling with the problem using an erroneous "elimination" strategy, afforded a lively discussion among the teachers in her group. Mandy selected the clips because they highlighted a student's misconceptions and erroneous solution, she intended that they would press her group both to ponder the student's reasoning and to discuss how a teacher, in this case Nicole, might help students consider the two variables, water and lemonade, relative to one another.

Mandy's guiding questions steered the group's conversation in the direction of instructional practice, in addition to unpacking student thinking. Pushing the teachers to go farther than simply noting what the student does and does not appear to understand, she asked them to generate ideas about teacher moves that might help this student. Building on student thinking is a vital but often extremely challenging component of effective instruction, especially when students are following a relatively complex logic that they struggle to articulate. Mandy thought hard about her guiding questions and was pleased with the result. As she explained, "I was prepared with different types of questions and things to ask them to keep the focus moving in the right direction. … connecting it strongly to the video and working off that lesson, and then trying to connect it to our daily teaching practice."

As is typical in adaptive models of PD, in the PSC program, video clips come from the participating teachers' own lessons. In the early stages of the PD experience, such as Mandy's workshop described above, facilitators typically chose clips from teachers who are willing and comfortable with the process, and can distance themselves from a critical analysis of their teaching. The most effective clips generally feature mathematically significant content that connects to the group's learning goals and allows teachers to explore alternative perspectives and different points of view. Thought-provoking guiding questions encourage teachers to identify the different mathematical ideas generated by the students, to examine the affordances and limitations of various instructional strategies, to think deeply about what each student does and does not understand, and to consider how they might build on the students' current thinking.

6.2 A sample video case and activities in LTG

As part of the LTG project materials, one video clip comes from an 8th grade lesson on dilation. In this 2-min clip, a student, Payne, is using dilation to determine whether two given rectangles are similar. Dilation, sometimes referred to as a tool for "stretching or shrinking" a figure proportionately, is a geometric transformation that can be applied to objects while maintaining their mathematical similarity. At the point in the LTG materials where this clip is included, teachers would already have had multiple experiences with the concept of dilation, including working on dilation problems and viewing other video clips related to dilation.

In the vignette that follows, we briefly discuss the lesson events as they unfolded in the video clip. Next, we describe how this clip is organized within the LTG materials. Lastly, we consider the features of the clip that make it well-suited for practice-based PD, and the rationale behind the discussion questions and other supporting materials that are provided to facilitators for use with this clip.

The teacher has distributed a handout containing drawings of eight rectangles, labeled A through H (see Fig. 4). The students must determine which rectangles are similar to Rectangle A.

After working on this problem at their seats for about 13 min, the teacher has students present their ideas using the Document Camera at the front of the room. Payne says that Rectangle C is a 60% dilation of Rectangle A; therefore, the two rectangles are similar. Payne shows how he lined up the upper left corners of the two rectangles, and found the 50% dilation point by folding Rectangle A in half (see Fig. 5).

Payne explains that he marked the 50% point and continued folding Rectangle A in increments of 10% (indicated by tally marks between 50 and 100%).

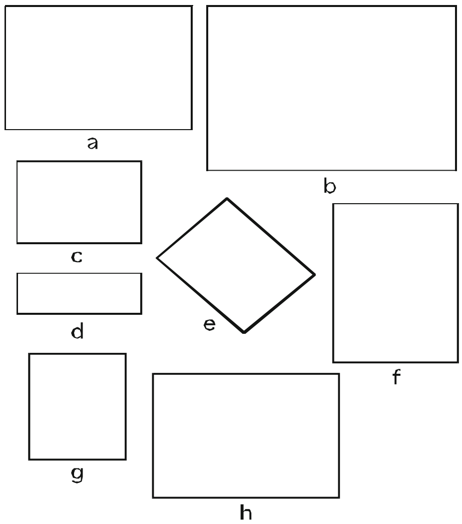

Fig. 4 Similar Rectangles task

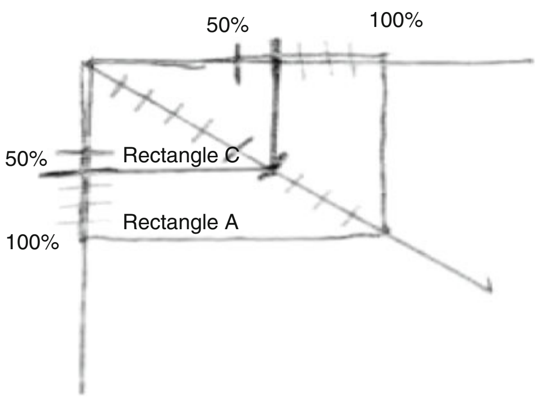

Fig. 5 Payne's method of demonstrating that rectangles are similar

> Eventually, he determined that Rectangle C lined up on the 60% marks. Payne shows that he drew a ray from the point of dilation through the bottom right vertices of both rectangles, which reinforced the notion that these were similar rectangles.

The video of Payne's rather unique approach to dilation is currently included in the Justifying Claims extension module. After completing the Foundation Module (roughly 30 h of PD), users of the LTG materials can elect to move into one of several extension modules, including the two-session (6 h) Justifying Claims module. The sessions in this module explore the connection between skills in justifying claims and a robust understanding of similarity, and instructional actions that are helpful in building students' skills to justify claims.

Prior to watching the clip of Payne demonstrating his solution, teachers are asked to solve the same problem while considering the following questions: (1) Is Rectangle C similar to Rectangle A? (2) How can you use various methods, including dilation, to test whether this is case? and (3) What kinds of explanations would you expect middle schoolers to provide? Facilitators are encouraged to have teachers explore solution methods that make use of several tools, including rulers and tracing paper. When they watch the subtitled video, teachers have a written transcript and a lesson graph to serve as references during their discussion of the clip.

As typical in highly specified PD, LTG facilitators are provided with supporting materials (including detailed session agendas and accompanying PowerPoint slides) that are designed to help them foster in-depth discussions about issues raised by viewing the video clip. The supporting materials for Payne's clip encourage facilitators to make sure that teachers fully understand Payne's method and explanation and, if appropriate, to help teachers replicate his method themselves. Guiding questions are designed to make the connection between the video clip and the session topic clear to the teachers, to focus their attention while watching the footage, and to enable them to stay "on track" and address the intended topic during the discussion.

The guiding questions provided for Payne's video clip are:

- What is Payne's explanation?
- What are the key mathematical concepts in the explanation?
- What evidence do we have that Payne understands these key concepts?
- What would Payne need to add to his explanation if he was asked to justify his method for other rectangles?
- What instructional moves could the teacher make to encourage this generalization to other rectangles?

These particular guiding questions are intended to help the group move into a discussion of Payne's understanding of the key mathematical concepts which his solution entails (such as dilation lines and center of dilation), and how a teacher might encourage Payne to justify and generalize his method. Used in this way, the video clip and guiding questions can prompt teachers to consider the kinds of mathematical tasks and pedagogical actions that help students move beyond mathematical conjectures and provide an important bridge to learning proof.

In the LTG program, we have found the video clips that work best are engaging, relevant, and accessible to the teachers, yet provide some degree of challenge and require the teachers to invest time and effort in carefully working through the mathematics or thinking through subtle pedagogical details. In addition, clips (such as Payne's) that include a unique solution strategy, representation, or explanation tend to be particularly appealing to teachers. Across the corpus of the LTG materials, the selected video clips show a range of student reasoning and a possible mathematical progression of thinking about specific mathematical concepts identified as part of the predetermined learning trajectory (e.g., using dilation to prove similarity). This degree of intentional sequencing across video clips is characteristic of a highly specified PD program; however, facilitators of adaptive programs might also sequence clips in a very purposeful manner within and/or across their PD workshops.

6.3 Selecting effective video clips

The process of selecting relatively short, manageable segments of actual mathematics lessons that capture teachers' attention, focus them in a particular direction, and foster productive conversations is something of a fine (and highly imperfect) art, requiring careful consideration of multiple issues. A key consideration for practice-based PD programs in general, and selecting video clips in particular, is the attention given to establishing a collegial learning community (Little, 2002). As Wilson and Berne (1999) noted in their review of effective PD programs, "The projects use different mechanisms for the development of that collegiality, but each project struggles with how to build trust and community while aiming for a professional discourse that includes and does not avoid critique (p. 195)." A strong community is particularly important when teachers are asked to discuss video representations of teaching with their colleagues. To encourage open and reflective conversations, the PD environment should be seen by the participants as a safe, supportive, and professional setting, in which the video is used to promote collective exploration of ways to improve teaching and learning.

In different types of practice-based PD, including both the PSC and LTG projects, the video clips that are shown to teachers are "examples," not "exemplars". That is, the clips are intended to serve as springboards for analysis and discussion about mathematics teaching and learning, not evaluations of the videotaped teacher. PD participants (and facilitators) may benefit from frequent reminders of this distinction. In our experience, as teachers work together to study and improve their practice, the community grows stronger and the participants become more comfortable with and adept at analyzing, and not evaluating, video (Borko et al. 2008). Facilitators of practice-based PD can capitalize on the advances in the teachers' analytical skills and the increasing strength of their professional learning community to help them explore more complex content and instances of teaching and learning that content. In adaptive PD, such as the PSC, facilitators may initially decide to select video clips that highlight instructional choices in a fundamentally positive light. As a stronger community becomes established, facilitators may decide to shift to clips that capture more problematic moments in the classroom or include segments of the lessons that pose a higher degree of challenge (mathematically and/or pedagogically) for the teachers. For example, in Mandy's workshop, she selected clips that engaged teachers in a conversation focused on helping students to think in a relative way about the amount of water compared to the amount of lemonade. This move from additive to multiplicative thinking is difficult for students and complex pedagogically for teachers; however, Mandy anticipated that her group was ready for such a challenge. In highly specified programs, such as LTG, sequencing the video clips so that they depict increasingly complex mathematics and follow a predetermined mathematical (and pedagogical) trajectory provides facilitators with sufficient time to establish a collegial community.

6.4 Scaffolding teachers' viewing and discussion of video footage

To ensure that video clip discussions connect to targeted learning goals for the PD session and that the talk remains focused, relevant, and productive, it is important that facilitators carefully scaffold both the viewing and discussion of video footage. By drawing on carefully crafted guiding questions and intentionally monitoring conversations, skillful facilitators can ensure that teachers critically analyze video while using evidence-based reasoning and respectful language.

Erickson (2007) warned that

> [N]ovice viewers of minimally edited video find themselves at sea, as it were, in a stream of continuous detail they don't know how to parse during the course of their real-time viewing in order to make sense of it. They see many trees but little forest, and gradually, in the absence of a sense of dimensions of analytic contrast, all the trees begin to look alike. (p. 146)

At the same time, Erickson recognized the potential power of using classroom video to support teacher learning and suggested that to take full advantage of the exciting possibilities that video offers, we should "invent new means of scaffolding for viewer attention and interpretation" (p. 154). Anticipating what teachers are likely to notice in video clips, guiding their explorations, and promoting open, thoughtful conversations are key elements to successful facilitation of practice-based PD. Guiding questions for both viewing and discussing video, prepared in advance of the PD session, can provide such scaffolding.

Our initial experiences using video representations of teaching in the PSC and LTG programs offer support for Erickson's suggestion. In the PSC program, having a set of prepared discussion questions has proven useful to facilitators not only as they frame and orchestrate conversations during the workshops but also in the planning stages as well. Going through the process of generating questions helps facilitators to specify and refine the selected learning goals, decide where the starting and ending points of the clip should be, and anticipate (to some degree) the nature of the conversation around the clip. The LTG materials provide facilitators with guiding questions, some indications about how teachers are likely to respond to the selected episode (based on pilot data), and specifications as to where the clips fit into the overall learning trajectory of the materials (Seago 2007).

As the examples from the PSC and LTG projects illustrate, guiding questions can be generated by individuals closer or farther removed from the actual PD workshops, depending on where the PD falls on the continuum from highly adaptive to highly specified. For instance, in adaptive models like the PSC, facilitators create the questions and in highly specified models like LTG, developers create the questions. Additionally, these guiding questions can be generated at different times depending on the type of PD. In highly adaptive models, the questions are likely to be created during the enactment of the PD, whereas in highly specified models, the questions are created during the material development process. The importance of guiding questions across different types of PD models is evidence for the robustness of using guiding questions when facilitating video-based PD activities.

7 Concluding thoughts and future directions

One important component of teaching expertise is the ability to observe and interpret classroom events as a lesson unfolds, and to make instructional decisions based on those interpretations. To promote mathematical inquiry and foster deep understanding of important mathematical ideas, teachers must be able to attend to the mathematics in what students say and do, interpret students' mathematical thinking, and respond in ways that build on their mathematical knowledge and reasoning. More than simply having mathematical knowledge for teaching, they must be able to activate and apply that knowledge in actual teaching situations. As Ball (2000) noted, "It is not just what mathematics teachers know but how they know it and what they are able to mobilize mathematically in the course of teaching" (p. 243).

In practice-based PD using video, such as the PSC and LTG programs described in this chapter, an important premise is that by improving their skills for observing and analyzing practice, teachers will develop the kinds of knowledge that they can activate and apply during instruction (Kersting et al. 2010). The argument has been made that the process of identifying and interpreting specific information from classroom video parallels what is demanded in teaching (Seago and Mumme 2002). In support of this argument, there is initial evidence that teachers who analyze student thinking via video become more effective at responding to student ideas during instruction (Cohen 2004), and that teachers' ability to analyze classroom video is related to student learning (Kersting et al. 2010).

As Erickson (2007) and others have reminded us, however, for the potential power of video as a learning tool for teachers to be realized, its use must be guided and scaffolded. When used within a PD program, clips should be purposefully selected to address specific program goals and embedded within activities that are carefully planned to scaffold teachers' progress toward those goals. One key component of planning, in addition to selecting the video clip, is deciding how to engage teachers with the video—how to guide their explorations of the mathematics, instructional practices, and student thinking; and how to establish community and orchestrate productive conversations.

Our experiences developing the PSC and LTG models of PD support these claims. Moreover, they provide initial insights about features of minimally edited classroom video and guiding questions that promote teacher learning. These experiences also suggest that differences in the nature of PD programs and the ways in which they incorporate video create different affordances and constraints for practice-based PD.

Highly specified practice-based PD programs, such as LTG, can be built around video clips selected and sequenced by developers to address key elements of a mathematical storyline. This approach to PD utilizes commercial quality video clips that highlight key mathematical and pedagogical ideas, affording the opportunity to carefully craft a cohesive learning sequence. One limitation, however, is that the learning goals and topics addressed in the materials may not fully meet the specific needs of a particular group of teachers.

In contrast, in adaptive PD programs, such as the PSC, facilitators can determine specific workshop goals, and select and sequence clips from lessons taught by the participating teachers. Adaptive approaches to PD tailor the focus of the workshops to the needs, interests, and concerns of participants. Moreover, there is some evidence that video from teachers' own classrooms is more motivating and has greater potential for supporting learning and promoting change in instructional practices than video from unknown teachers' classrooms (Seidel et al. 2005). One constraint of this approach is that the selection of video clips is limited by the quality of both the lessons taught by participants and the video recordings.

In our current research, we are building on what we have learned from the PSC and LTG projects as we continue to explore ways of using video in PD that capitalize on its potential power to facilitate the development of organized and accessible professional knowledge and content-specific pedagogical expertise. We are particularly interested in understanding how video can be used to support learning in a variety of practice-based PD programs, including adaptive and highly specified approaches and others along the continuum of video use in PD, and the affordances and constraints associated with the use of video in the different programs. The work of others in this field, including many noted in this special edition of *ZDM*, will help to shape and expand our collective knowledge base.

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References

Ball, D. L. (2000). Bridging practices: Intertwining content and pedagogy in teaching and learning to teach. *Journal of Teacher Education, 51*, 241–247.

Ball, D. L., & Bass, H. (2000). Interweaving content and pedagogy in teaching and learning to teach: Knowing and using mathematics. In J. Boaler (Ed.), *Multiple perspectives on the teaching and learning of mathematics* (pp. 83–104). Westport, CT: Ablex.

Ball, D. L., & Cohen, D. K. (1999). Developing practice, developing practitioners: Toward a practice-based theory of professional education. In L. Darling-Hammond & G. Sykes (Eds.), *Teaching as the learning profession: Handbook of policy and practice* (pp. 3–32). San Francisco: Jossey-Bass.

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

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

Borko, H., Jacobs, J., & Koellner, K. (2010). Contemporary approaches to teacher professional development: Processes and content. In P. Peterson, E. Baker, & B. McGaw (Eds.), *International encyclopedia of education* (Vol. 7, pp. 548–556). Oxford: Elsevier.

Brophy, J. (Ed.). (2004). *Advances in research on teaching, Vol. 10: Using video in teacher education*. Oxford, UK: Elsevier.

Cohen, S. (2004). *Teachers' professional development and the elementary mathematics classroom: Bringing understanding to light*. Mahwah, NJ: Erlbaum.

Erickson, F. (2007). Ways of seeing video: Toward a phenomenology of viewing minimally edited footage. In R. Goldman, R. Pea, B. Barron, & S. Derry (Eds.), *Video research in the learning sciences* (pp. 145–155). Mahwah, NJ: Erlbaum.

Grossman, P., Hammerness, K., & McDonald, M. (2009). Redefining teaching, re-imagining teacher education. *Teachers and Teaching: Theory and Practice, 15*(2), 273–289.

Horn, I. S. (2008). *Adaptive professional development: A pedagogy for inservice teacher education.* Manuscript in preparation.

Jacobs, J., Borko, H., & Koellner, K. (2009). The power of video as a tool for professional development and research: Examples from the Problem-Solving Cycle. In T. Janik & T. Seidel (Eds.), *The power of video studies in investigating teaching and learning in the classroom* (pp. 259–273). Munster: Waxmann Publishing.

Jacobs, J., Borko, H., Koellner, K., Schneider, C., Eiteljorg, E., & Roberts, S. A. (2007). The Problem-Solving Cycle: A model of mathematics professional development. *Journal of Mathematics Education Leadership, 10*(1), 42–57.

Jacobs, J., & Morita, E. (2002). Japanese and American teachers' evaluations of videotaped mathematics lessons. *Journal for Research in Mathematics Education, 33*(3), 154–175.

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: Attending to the coevolution of teachers' participation across contexts. *Journal of Teacher Education, 59*, 428–441.

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

Koellner, K., Jacobs, J., Borko, H., Schneider, C., Pittman, M., Eiteljorg, E., et al. (2007). The Problem-Solving Cycle: A model to support the development of teachers' professional knowledge. *Mathematical Thinking and Learning, 9*(3), 271–303.

Koellner, K., & Seago, N. (2010, July). Using video to study teacher learning. In *Discussion group facilitated at the 34th conference of the international group for the psychology of mathematics education*, Belo Horizonte, Brazil.

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*, 917–946.

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*, 185–192.

Seago, N. (2007). Fidelity and adaptation of PD materials: Can they co-exist? *Journal of Mathematics Education Leadership, 9*(2), 16–25.

Seago, N., Driscoll, M., & Jacobs, J. (2010). Transforming middle school geometry: Professional development materials that support the learning and teaching of similarity. *Middle Grades Research Journal* (in press).

Seago, N., & Mumme, J. (2002, April). *The issues and challenges in facilitating video cases for mathematics professional development*. Paper presented at the annual meeting of the American Educational Research Association, New Orleans, LA.

Seago, N., Mumme, J., & Branca, N. (2004). *Learning and teaching linear functions*. Portsmouth, NH: Heinemann.

Seidel, T., Prenzel, M., Rimmele, R., Schwindt, K., Kobarg, M., Meyer, L., et al. (2005, August). *Do videos really matter? The experimental study LUV on the use of videos in teachers' professional development.* Paper presented at the eleventh conference of the European Association for Research on Learning and Instruction (EARLI), Nicosia, Cyprus.

Sherin, M. G. (2004). New perspectives on the role of video in teacher education. In J. Brophy (Ed.), *Advances in research on teaching, Vol. 10: Using video in teacher education* (pp. 1–27). Oxford, UK: Elsevier.

Sherin, M. G. (2007). The development of teachers' professional vision in video clubs. In R. Goldman, R. Pea, B. Barron, & S. Derry (Eds.), *Video research in the learning sciences* (pp. 383–396). Mahwah, NJ: Erlbaum.

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

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*, 1–22.

Van de Walle, J. A. (2008). *Elementary and middle school mathematics: Teaching developmentally*. Boston, MA: Pearson Education.

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. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Education, 24*, 244–276.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of the research on contemporary professional development. In A. Iran-Nejad & P. D. Pearson (Eds.), *Review of Research in Education, 24*, 173–209.