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Journal
Cognition and Instruction, 35(3)

ISSN
0737-0008

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Publication Date
2017-07-03

DOI
10.1080/07370008.2017.1317125

Cognition and Instruction

ISSN: 0737-0008 (Print) 1532-690X (Online) Journal homepage: http://www.tandfonline.com/loi/hcgi20

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To cite this article: Elizabeth A. van Es, Mary Cashen, Tara Barnhart & Anamarie Auger (2017): Learning to Notice Mathematics Instruction: Using Video to Develop Preservice Teachers' Vision of Ambitious Pedagogy, Cognition and Instruction, DOI: 10.1080/07370008.2017.1317125

To link to this article: http://dx.doi.org/10.1080/07370008.2017.1317125

Published online: 03 May 2017.

COGNITION AND INSTRUCTION
http://dx.doi.org/10.1080/07370008.2017.1317125

Learning to Notice Mathematics Instruction: Using Video to Develop Preservice Teachers' Vision of Ambitious Pedagogy

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ABSTRACT
Video is used extensively in teacher preparation, raising questions about what and how preservice teachers learn through video observation and analysis. We investigate the development of candidates' noticing of ambitious mathematics pedagogy in the context of a video-based course designed to cultivate ways of seeing and interpreting classroom interactions. Qualitative analysis of candidates' observations of teaching at the beginning and end of the course generated a framework of practices and associated approaches for noticing instructional interactions. The 3 practices include *attending to features of instruction*, *elaborating on observations*, and *integrating observations to reason about instruction*. Findings reveal that variations in candidates' noticing was tied to their attention to the details of the features of ambitious pedagogy and to the extent to which they integrated observations to examine the relation between student thinking, teaching practice, and mathematical content.

Research in teacher education in the last decade has drawn attention to an important skill for teaching—the ability to attend to and reason about teaching and learning—that is referred to as *teacher noticing* (Sherin, Jacobs, & Philipp, 2011). One reason is that it captures teachers' in-the-moment decision making, which relies on teachers attending to what students are thinking and doing, and reasoning about student ideas to make informed choices about how to proceed with a lesson (Ball & Cohen, 1999; Mason, 2002; Rodgers, 2002; Schoenfeld, 2011). This ability to notice is central to the types of teaching advocated by mathematics education reform initiatives that promote a student-centered, responsive approach to instruction (National Council of Teachers of Mathematics [NCTM], 2000, 2014; National Governors Association Center [NGAC], 2010; National Research Council [NRC], 2001). Within this vision, teachers create discourse-rich environments where students share, discuss, and reason together about mathematical ideas. In this model, teachers attend closely to student thinking—what their work represents about their understanding, similarities and differences in their thinking, and the development of their mathematical understanding. This is similar to what Schoenfeld (2011) called "diagnostic teaching" (p. 463)—a model of teaching whereby teachers have well formulated, content-rich goals, an awareness of students' different ideas and understandings of the mathematics, and practices for using students' ideas to inform teaching decisions. Research finds that classroom environments that achieve the vision of reform become generative learning spaces for both teachers and students (Franke, Carpenter, Levi, & Fennema, 2001; Jacobs, Lamb, & Philipp, 2010).

In this study, we investigate the nature and development of preservice teachers' noticing of ambitious mathematics instruction. In particular, we examine whether teacher candidates who participated in a video-based teacher credential course, *Learning to Learn from Teaching*, developed ways of noticing features of ambitious mathematic pedagogy that align with those put forth by the mathematics education

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community (NCTM, 2000, 2014; NRC, 2001). In addition, we investigate the nature and development of their noticing practices over time. By characterizing how they approach the work of noticing, we can gain insight into the complexity of developing a vision of ambitious teaching that can inform the design of learning experiences for pre-service teachers.

We focus on secondary mathematics candidates' noticing for several reasons. First, students' mathematics achievement and motivation declines as they enter middle and high school (Fredricks & Eccles, 2002; Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002; Köller, Baumert, & Schnabel, 2001). Identifying ways to support secondary teachers in adopting a more relational, responsive approach to instruction may play an important role in helping secondary students have more positive learning experiences (Boaler & Greeno, 2000). Second, with greater numbers of students enrolling in Algebra, a gateway for advanced mathematics learning, but fewer of them experiencing success (Stein, Kaufman, Sherman, & Hillen, 2011), learning to see teaching as an interactional activity that is largely informed by student thinking may be a crucial piece for improving learning and persistence at this critical juncture. Third, a variety of standards documents emphasize students engaging in mathematical reasoning to promote conceptual understanding, while also developing productive dispositions in the discipline (NCTM, 2000; NGAC, 2010; NRC, 2001). To accomplish this vision, teachers need conceptual frameworks to focus instruction on student ideas, to identify ideas that are noteworthy with respect to the learning goal, and to navigate conversations that are mathematically substantive and productive for student learning. We view the construct of noticing as a critical component for addressing these issues. By equipping prospective teachers with frameworks to help them learn to attend to important elements of instructional interactions and providing experiences in which they dissect the work of teaching to understand what constitutes a pedagogy of ambitious instruction, we propose that they can develop a more robust vision of mathematics teaching and learning that can guide their instructional decision making.

Thus, the central questions for this study include: (a) Do secondary mathematics teacher candidates learn to notice ambitious pedagogy in the context of the *Learning to Learn from Teaching* course? (b) What are variations in the ways that candidates notice instructional interactions and develop their noticing over time? And (c) what might these differences reveal about designing learning experiences to cultivate teacher candidates' noticing of ambitious mathematics pedagogy? We locate this study within a broader line of inquiry that integrates video in teacher education to cultivate new forms of noticing (Blomberg, Renkl, Sherin, Borkl, & Seidel, 2013; Gaudin & Chaliès, 2015). Recognizing that developing expertise takes time and that there is more than one trajectory to competence (Lajoie, 2003; Schoenfeld, 2011), we identify different approaches teacher candidates use to notice ambitious mathematics pedagogy and examine variations in the ways they develop practices for noticing mathematics instruction to theorize the link between their practices and participation in a video-based course explicitly focused on cultivating candidates' noticing and analysis of mathematics teaching and learning. To be clear, this study does not examine candidates' instructional practice, a subject we take up elsewhere (Sun & van Es, 2015). The focus here is on how teacher candidates come to notice the work of teaching—to decompose the work of teaching by attending and reasoning about salient features of classroom interactions—to develop a vision of ambitious mathematics teaching that can guide instructional decision-making.

Theoretical framework

This study is framed by research on teacher noticing and research on the teaching and learning of professional practice. An extensive body of research in teacher education has focused on understanding teachers' noticing (Erickson, 2007; Kersting, 2008; Mason, 2002; Seidel & Stürmer, 2014; Sherin et al., 2011; Stürmer, Könings, & Seidel, 2013). Though not a particularly new idea (see Copeland, Birmingham, DeMeulle, D'Emidio-Cason, & Natal, 1994; Erickson et al., 1986; Frederiksen, 1992), teacher noticing has gained increased attention for several reasons. The teaching expertise literature shows that more expert teachers have greater sensitivities to certain aspects of practice that enable them to hone in on noteworthy features of classroom interactions. They also have strategies for analyzing, using, and inquiring into their practice that support them in orchestrating more meaningful instructional interactions (Berliner, 1994; Erickson, 2011; Mason, 2002; Russ, Sherin, & Sherin, 2011; Seidel & Stürmer, 2014). Furthermore, teachers who have more sophisticated ways of looking at, and making sense of, classroom interactions show greater gains in student achievement (Kersting, 2008), suggesting that this is an important skill to cultivate in prospective teachers. Finally, research advocates for teacher education to provide prospective teachers with conceptual tools that will equip them to learn in and from their practice (Feiman-Nemser, 2001; Hiebert, Morris, Berk, & Jansen, 2007; Kennedy, 2016; Lampert, 2001, 2010). We propose that to develop routine and systematic ways of learning from practice entails learning to observe and make sense of classroom interactions guided by a vision of ambitious mathematics pedagogy.

There is broad agreement that noticing consists of an ability to attend to noteworthy features of instruction, to reason about what is observed in meaningful ways, and to decide how to respond (Jacobs et al., 2010; Sherin, 2007; Sherin et al., 2011; Stürmer et al., 2013). This suggests that learning to highlight and interpret classroom interactions involves acquiring tools and frameworks to help guide what to look for and how to characterize the work of teaching (Erickson, 2011; Mason, 2011). Research also suggests that noticing involves coming to see the details of observed phenomena and taking on different perspectives to gain deeper insight into what is observed (Rodgers, 2002; Sherin & Russ, 2014). Finally, noticing entails drawing connections between observed phenomena to develop a more robust and elaborate vision of instruction (Santagata & Angelici, 2010).

By using the term *ambitious mathematics instruction*, we refer to a broad line of inquiry that focuses on creating and sustaining learning environments where student work is the center of activity, with the goal of students developing procedural fluency, deep and enduring mathematics understanding, and positive dispositions and identities as mathematics learners (Carpenter & Lehrer, 1999; NCTM, 2000, 2014; NRC, 2001). In this vision, the work of teaching entails providing students opportunities to grapple with complex tasks, generate solutions, and communicate their reasoning in small-group and whole-class contexts (Hiebert & Grouws, 2007; NCTM, 2014). This requires shifting roles for teachers and students, with students explaining and questioning one another and taking on increased responsibility for one another's learning (Hufferd-Ackles, Fuson, & Sherin, 2014; Stein, Engle, Smith, & Hughes, 2008). In addition, teachers create classroom norms that promote presentation, argumentation, and justification of mathematical ideas (Carpenter & Lehrer, 1999; NCTM, 2014), while also honoring the unique and valuable contributions that students bring to the learning setting (Boaler & Staples, 2008). It is this vision of teaching, promoted by national reform documents and the mathematics education research community (Franke et al., 2009; Lampert, Beasley, Ghousseini, Kazemi, & Franke, 2010; NCTM, 2014; NRC, 2001), as well as reflected in assessment systems for improving teaching (Darling-Hammond, 2006) that we ascribe and use as the foundation for a vision of ambitious pedagogy to which we seek to apprentice future teachers.

Preparing preservice teachers' to learn to notice ambitious pedagogy is not without its difficulties. It is well documented that prospective teachers use their own experiences as learners to determine what to focus on and how to reason about what they see during instruction (Kagan & Tippins, 1991; Lortie, 1975; Pajares, 1992). Because their prior experiences and pedagogical commitments inform their observations and reasoning about instruction, it can be difficult to shift their focus to elements of classroom interactions that are counter to those they have come to value through their experiences (Erickson, 2011; Schoenfeld, 2011). Thus, research is needed that explores not only the nature and substance of preservice teachers' noticing, but also how to design learning environments that create opportunities for preservice teachers to develop new ways of attending to and making sense of instruction.

Pedagogies for learning to teach

Research on the teaching and learning of professional practice offers insight into pedagogical approaches to develop new ways of noticing. Grossman and colleagues (2009) identified three key concepts that underscore pedagogies for preparing practitioners: using *representations of practice* to gain insight into and study the work of teaching, *decomposing practice* into its constituent parts, and engaging in *approximations of practice* that provide access to the core practices of a profession. Recent efforts to improve the preparation of mathematics teachers focus on developing prospective teachers' beginning repertoire—the techniques, skills, and approaches that, when routinely enacted, can achieve the vision of ambitious pedagogy (Ghousseini, 2009; Grossman et al., 2009; Lampert et al., 2010, 2013). Other research underscores the importance of developing conceptual frameworks to inform instructional decisions (Grossman, Smagorinsky, & Valencia, 1999; Kennedy, 2016; Shulman, 1992). We propose that developing teacher candidates' noticing, guided by a framework of ambitious pedagogy, can become a conceptual tool that can inform decompositions of teaching as captured in representations of practice and provide a shared, precise language for identifying the salient features of instruction that characterize this model of instruction in practice (McDonald, Kazemi, & Kavanagh, 2013). We also contend that helping preservice teachers learn how to look at and make sense of classroom interactions, guided by a shared vision of ambitious instruction, can better prepare them to attend to and respond to students in the moment of instruction and adopt a student-centered frame to their teaching (Levin, Hammer, & Coffey, 2009; Russ & Sherin, 2013). Moreover, we posit that the core work of teaching entails not only taking action in the classroom, but also engaging in ongoing observation and analysis of teaching (see Feiman-Nemser, 2001), and thus involves developing practices for seeing and reasoning about features of classroom interactions so that they can become both objects of inquiry in reflection, as well as objects of attention during instruction.

Using video to learn to decompose classroom interactions

Although video has been used historically in teacher education (Sherin, 2004), advances in video technology for capturing, editing, and sharing video make its use even more widespread (Gaudin & Chaliès, 2015). Two aspects of video are relevant for this study. First, representations of teaching captured in video can bring to life images of instructional practice that are not widely enacted in school contexts (Hatch & Grossman, 2009). These videos can help prospective teachers learn to decompose and develop a common language for describing ambitious mathematics instruction (McDonald et al., 2013; Sherin, 2007). By viewing video records of teaching, teacher candidates can develop shared ways of seeing "classroom discourse" (NCTM, 2014), "conceptual understanding and mathematical reasoning" (NRC, 2001), and "equitable instruction" (NCTM, 2014) as they arise in the details of classroom interactions.

Second, the permanence of video offers prospective teachers opportunities to adopt analytic practices for viewing and discussing teaching (Blomberg et al., 2013; Lampert & Ball, 1998; Santagata & Yeh, 2013). Prospective teachers can take time to study a classroom interaction together and contemplate a variety of explanations they may not have previously considered, in contrast to fieldwork experiences where candidates observe an experienced classroom teacher alone and have few, if any, opportunities to explore the details of their observation with others to make sense of the work of teaching (Gomez, Sherin, Griesdorn, & Finn, 2008).

Video has proven to be a powerful tool for helping preservice teachers learn to notice instructional practice and for promoting more systematic reflection of teaching (Blomberg et al., 2013; Calandra & Rich, 2015; Gaudin & Chaliès, 2015; McFadden, Ellis, Anwar, & Roehrig, 2014; Stockero, Rupnow, & Pascoe, 2015; Santagata & Yeh, 2013). It is well documented that when teacher candidates enter teacher education, their noticing of instruction is underdeveloped and that they can improve their observation of teaching in the context of a course (Jacobs et al., 2010; Roller, 2016; Schäfer & Siedel, 2015; Star & Strickland, 2008; Stockero et al., 2015). For example, some research finds that using video in teacher education can help attune teacher candidates to the complexities of children's thinking, children's competencies to learn mathematics, and children's multiple mathematical knowledge bases (Dyer & Sherin, 2015; Star & Strickland, 2008; Stockero et al., 2015; Turner et al., 2012). Attuning teacher candidates to student thinking and participation in discourse-rich classrooms with video can aid candidates not only in attending to student thinking during instruction (Santagata & Yeh, 2013; Sun & van Es, 2015), but also support them in planning instruction focused on eliciting and responding to student ideas (Calandra & Rich, 2015).

Research also finds that video analysis can help candidates become more precise in their reflections on teaching (Calandra & Rich, 2015). Studying video can help teachers carefully examine specific interactions that unfold in a lesson and analyze how those interactions influence students making progress toward to the learning goal (Osmanoglu, 2016; Santagata & Yeh, 2013; Stockero, 2008). Moreover, systematic analysis of teaching with video can also influence candidates' beliefs about students as learners and their content knowledge for teaching (Cho & Huang, 2014; Turner et al., 2012).

Although video analysis can support candidates in noticing and reflecting on the complexity of mathematics classroom interactions, what is largely missing is a clear articulation of the structure of a course designed explicitly to support noticing and systematic analysis of teaching and its contribution to recent efforts to develop a pedagogy for teacher education (see, for exception, Santagata & Yeh, 2013). Moreover, little research explores variations in preservice teachers' learning to notice over time, by examining the noticing practices they take up in the analysis of teaching and how those practices change through participation in a course focused on noticing instruction in purposeful ways. Thus, our study is guided by three goals: (a) to investigate if candidates develop ways of noticing ambitious mathematics instruction in the context of a video-based course; (b) to identify different approaches candidates use to notice instructional interactions, as well as variations in the development of their noticing over time; and (c) to consider what these differences may reveal about the complexity of learning to notice classroom interactions in new ways to theorize on the relation between candidates' noticing and the course design. Findings of this research have implications for designing learning experiences using video to cultivate preservice teachers' noticing that can set them on a trajectory for developing expertise in teaching.

Research context: *Learning to Learn from Teaching Project*

This study took place in the context of the *Learning to Learn from Teaching Project* as part of the teacher preparation program at a large western university (see Santagata & van Es, 2010). In the 2008–2009 academic year, the *Learning to Learn from Teaching* course (referred throughout as *Learning from Teaching*) was incorporated into the first quarter of a three-quarter teacher credential program in an effort to equip prospective teachers with skills and practices for learning from practice (Feiman-Nemser, 2001). The class met 12 times over a 3-month period, for 3 hr once a week. The first author was the instructor for the course. Candidates were concurrently assigned a field placement in which they observed a classroom mentor teacher for 1 to 2 hr each week. The subjects of this study include one cohort of secondary mathematics teaching candidates ($n = 33$, 7 men, 26 women) who enrolled in the same section of the *Learning from Teaching* course.

Research on mathematics teaching, noticing, lesson analysis, and reflection informed the design of the *Learning from Teaching* course (Hiebert et al., 2007; NCTM, 2014; NRC, 2001; Rodgers, 2002; Santagata & van Es, 2010). The course consisted of three main phases (see Table 1).

The first phase (weeks 1–4) introduced candidates to research-based frameworks in mathematics teaching and focused on five core dimensions of classroom interactions: student thinking, task quality, teacher questioning, classroom discourse, and formative assessment (Boaler & Humphreys, 2005; Black, Harrison, Lee, Marshall, & Wiliam, 2004; Carpenter & Lehrer, 1999; Hufferd-Ackles et al., 2014; Stein,

Table 1. Overview of course design.

Phase 1 – Introduce Frameworks for Noticing Mathematics Instruction	Phase 2 – Describing and Interpreting Observed Events	Phase 3 – Integrating and Elaborating on Observations
Student Thinking and Understanding	Provide accurate descriptions of observed events	Examine classrooms as dynamic, interactional spaces
Cognitively Demanding Tasks	Reference artifacts as evidence of observations (highlighting points in time)	Elaborate on the details of observed events
Teacher Questioning to Promote Understanding	Interrogate the meaning behind observations	Make connections between observed features of instructions
Promoting Classroom Discourse through Student-to- Student Talk		
Using Formative Assessment to Gain Insight into Student Thinking		

Smith, Henningsen, & Silver, 2009). We recognize that a vision of ambitious pedagogy includes additional dimensions, such as equity, curriculum, and disciplinary literacy (Ippolito, Lawrence, & Zaller, 2013; NCTM, 2000, 2014; NRC, 2001; Turner et al., 2012; Wager, 2014). However, the first author, who designed and taught the course, focused on these five dimensions because of the centrality of making thinking visible for analyzing teaching and learning (Hiebert et al., 2007). Though the course was designed and taught prior to the more recent adoption of the Common Core State Standards, the topics of focus are consistent with aims of these standards (NGAC, 2010).

The second phase (week 5–9) emphasized attending to the details of interactions, to what actually occurred in the classroom interaction and creating accurate depictions of those events (Rodgers, 2002; van Es, 2011). Candidates also contemplated a variety of interpretations of observed phenomena (e.g. what might a student explanation reveal about her understanding; how might different teachers' questions promote different types of mathematical thinking). In this way, candidates used the frameworks to which they were introduced previously to guide what they highlighted and to inform their interpretations of what they observed.

The last phase of the course (weeks 10–12) drew on research on lesson analysis (Hiebert et al., 2007) to promote candidates' noticing of classrooms as interactional spaces that link students, teaching, and content by examining the relationships between student thinking, the nature of the task, specific teaching moves, and classroom discourse. Throughout each phase, the instructor pressed candidates to use evidence from the videos to make claims about observations and encouraged them to use the details of the interactions to make sense of what was observed. Tasks and discussions emphasized the importance of considering a range of interpretations and adopting alternative points of view to make sense of classroom interactions.

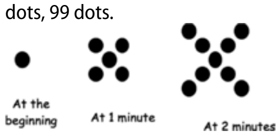
Together, these three phases intend to provide teacher candidates with conceptual tools for noticing and analyzing teaching (Grossman et al., 1999; Kennedy, 2016) that guide the substance of what teachers attend to and how they reason about these observations, while also providing a structure for engaging in evidence-based analysis of instruction. We might think of these as design principles, with the first phase of the course focused on developing what candidates attend to in classroom interactions, the second phase emphasizing attention to the details and reasoning about observed events, and the third phase directed to bringing together discrete observations and interpretations into more integrated analyses.

Data collection

The main source of data for this study consists of a pre- and postvideo analysis task that the first author administered at the beginning and the end of the *Learning from Teaching* course. The task was specifically designed to gain insight into the nature and development of candidate noticing through participation in the course. Candidates viewed two video clips, each between 3 and 6 min long, during the second and final class meetings. The clips came from published materials and were selected because they represented students working on cognitively demanding tasks, the teacher and students interacting in different settings (e.g., a whole class and a small-group setting), students sharing a range of ideas and understandings, and both students and teachers positioned as the source of mathematical ideas. Table 2 provides a summary of each video clip and features of instruction that reflect the learning goals for the course. Of course, there were additional features that could be observed in the clips, such as the materials on the walls and the seating arrangement, as well as others that could not be seen but that may be of interest to an observer, such as how many total students were in the class. We chose these clips because, together, they embody different dimensions of ambitious pedagogy that we sought to support candidates to notice.

To complete the video analysis task, the candidates viewed the first video clip and then responded to four prompts: (a) What do you notice? (b) Describe what's going on in the clip. (c) How did the teaching support student thinking and learning? And (d) was anything else noteworthy? They were then shown the clip a second time and were able to modify or add to their responses. The same format was followed for viewing the second clip. The candidates had 1 hr to complete this task. We analyzed data from 31 of the 33 candidates because data from one candidate was missing for the pre- task and one

Table 2. Objects of noticing in video analysis task.

	Summary of Clip	Example Features of Ambitious Instruction
Working Backwards [1]	Students were provided the following image and posed the following question: For the first sequence determine how many minutes will have elapsed when you have 25 dots, 73 dots, 99 dots.  The clip begins with the teacher inviting groups to share how they determined the number of minutes for 25 dots, then 73 dots and then 99 dots. The class also discusses the difference between an equation and expression, as a way to develop precision in using mathematical language.	Student thinking: • Irma knew to get greater number of dots need to add 1 and times by 4 • Brandy set up an algorithm that would work to calculate the minutes given any number of dots Mathematical focus and task: High cognitive demand • Multiple representations of thinking (graphic approach) • The task suggests a discrete function so 99, which is not possible, but allows students to reason about an answer by following a procedure. Pedagogies for Making Thinking Visible: • Having manipulatives available to represent mathematics • Linking student strategies to previous concepts • Orchestrating whole class discussion by eliciting different strategies Classroom Discourse: • Giving ownership to student ideas (naming the ideas) • Asking students to explain their thinking and justify their reasoning
Equation for Dial-n-Go2	As part of a lesson in Linear Functions, students in this algebra class analyze competing cell phone plans. One of the plans is a linear function and the other is a piece-wise function. Students are provided scenarios for four different people, with different cell phone needs. They are asked to analyze the graphs and consider which plan would be better suited for each individual. In this clip, four students work together to determine the slope of the piece-wise function. The teacher sits with the group and listens to how students approach the problem and asks them a variety of questions to probe their thinking, help them progress through the task, and encourage them reason through the problem.	Student thinking: • Dante wants to find the point of intersection and other students focus on finding the slope of the portion of graph that has a rate of change • When students test the slope and interpret in the context of the graph, they recognize the y-intercept is incorrect Mathematical focus and task: High cognitive demand (doing math) • Non-algorithmic thinking and reasoning; promotes struggle • Analysis of the task and cognitive effort because of its unpredictable. Pedagogies for Making Thinking Visible: • Teacher uses a range of questions to elicit thinking; to generate discussion; and to link and apply what students do mathematically to interpret the graphs within the broader context of the problem. Classroom Discourse: • Students are the source of ideas and act as questioners • Teacher asks questions to place responsibility for learning in students' hands

[1](Seago, Mumme, & Branca, 2004); [2](The Concord Consortium, 2005).

student did not complete the post- task, because he withdrew from the program midway through the course.

Data analysis

Data analysis was largely qualitative in nature and consisted of two main phases. The first phase focused on examining whether candidates shifted in their noticing from the beginning to the end of the course and the second phase on qualitative differences in candidates' noticing at each point in time and variations in their noticing over time. We describe each phase below.

Phase 1: Development of candidate noticing in the learning from teaching course

The first phase investigated the development of teacher candidates' noticing from the beginning to the end of the course. Informed by research on noticing, systematic reflection of teaching, and lesson analysis and the goals of the course (Davis, 2006; Jansen & Spitzer, 2009; Morris, 2006; Santagata & Angelici,

Table 3. Coding framework for noticing ambitious pedagogy.

Category and Definition	Levels within Category
Mathematical Content & Learning Goal The extent to which the candidate attends to the mathematical focus and task of the lesson.	0 – Little or no attention to the mathematics of the lesson 1 – Identifies the mathematical task or problem and/ or judges the quality of the task 2 – Attends to and infers from the task or problem to a broader learning goal and/ or draws inference(s) about the appropriateness of the task to accomplish the learning goal
Student Thinking The extent to which candidate attends to student mathematical thinking	0 –Attention primarily on student behavior, general participation and/ or engagement of the whole class 1 – Identifies student correct/ incorrect answers; Attention on the class or group as a whole 2 – Attends to and infers student thinking – what their ideas, confusions, and errors, reveal about their thinking; Differentiates between individual students' mathematical thinking
Pedagogies for Making Thinking Visible The extent to which the candidate attends to the teacher, the choices the teacher makes throughout the lesson, and the teachers' role for making student thinking visible and an object of inquiry in the class.	0 – Little or no attention to how the teacher gains insight into student thinking; Attends to management and arrangement of students and class 1 – Identifies teaching strategies and choices the teacher makes in the lesson to make thinking visible; and/ or judges the effectiveness of strategies 2 – Attends to and infers the ways teacher makes thinking visible and how teaching strategies influence student thinking and learning
Classroom Discourse Norms The extent to which the candidate attends to the norms of communicating mathematical ideas and the roles teachers and students take on to support student learning.	0 – Attends to the overall feeling of a classroom interaction/ environment 1 – Attends primarily to the teachers' role in classroom discourse; Identifies general norms for sharing ideas 2 – Attend to norms for teachers and students to communicate ideas and infers how participating in discourse influences student thinking and learning
Specificity The level of detail in the candidate's comments and the extent to which the candidate accurately depicts the events in the clip.	0 – Vague commentary; not specific to the clip 1 – Uses both vague language and some details to describe events in the clip 2 – Detailed and elaborate description of events particular to the clip; References quotes, excerpts, and points in time.
Making Connections The extent to which the candidate integrates observations of focus – noticing the features of ambitious pedagogy as integrated and connected.	0 – Little or no linking of noticed events 1 – Some connections made between observed features but mostly discrete observations; Little elaboration of the connections that are made. 2 – Integrated analyses that links observations and inferences of teaching, content, and student thinking; More elaborate reasoning and sense-making of what is observed.

2010; Star & Strickland, 2008; van Es & Sherin, 2008), we identified common dimensions to characterize what teachers observe and how they analyze teaching and learning. We were particularly interested in whether the candidates attended to features in the video segments that were the subject of the course, if they became more descriptive and interpretive in their responses, and if they elaborated on details of the interactions and made connections between what they observed. We randomly selected a subset of four cases from the pre and post data sets, for a total of eight pre analysis task responses and eight post analysis responses, and reviewed their responses to each question. Through an iterative process, we constructed a three-level coding scheme related to six different dimensions (Miles, Huberman, & Saldaña, 2014). Four of the six dimensions capture the substantive focus of candidate noticing: *mathematical task*, *student thinking*, *pedagogies for making thinking visible*,[1] and *classroom discourse*. The two other dimensions, *specificity* and *making connections*, capture the level of detail and integration of the observations.

Once we defined the categories, we returned to the subset of cases and examined similarities and differences in the candidates' responses with respect to the six categories. Using the constant comparative method (Glaser & Strauss, 1967), we developed a three-level coding framework (see Table 3) to capture variations we observed in the data, similar to other research that examines the nature and development of teacher noticing and lesson analysis (Davis, 2006; Santagata & Angelici, 2010; van Es, 2011).

The first four dimensions capture what the candidates highlighted in their observations, and we noted differences in the level of detail and inferential nature of their responses. A Level 0 for each dimension

[1]This category includes formative assessment practices that were introduced in the course as well.

reflects little or no attention to the elements of focus in the course (e.g., no mention of the mathematical task or student thinking) and an ambiguity with respect to that topic; Level 1 referred to responses that demonstrated attention to the element with an identification or evaluation of a feature of the classroom interaction related to the category of focus, and Level 2 captured an interpretive, sense-making stance toward what was observed.

The two additional dimensions, *specificity* and *making connections*, also consisted of three levels. Level 0 reflected oversimplified language that was not specific to the clip and no linking of events; Level 1 responses suggested some attention to details and inconsistently made connections between observed event; and Level 2 consisted of specific, detailed, and elaborate responses, including quotes and points in time in the clip to reference events that were related to the clips, with clear links being made between observed events and interactions.

We began by open coding (Saldaña, 2012) candidates' response to capture the details of their noticing and then wrote analytic memos (Miles et al., 2014) to capture the overall nature and substantive focus of their noticing for each clip at the two points in time. Using the open coding and analytic memos, we assigned one overall score for each dimension for the pre and post tasks (See Table 3). We assigned one score for each dimension for each clip for a couple of reasons. We noticed that some candidates might answer the first and second questions ("What do you notice?" and "Describe what's going on in the clip") by listing certain features of clips and then use those lists to inform the answer to the third question ("How did the teacher support student learning?"). In that case, responses to the first two questions capture what is noticed, and the third question captures the inferential and elaborative nature of the response. Although the responses did not always follow this pattern, we determined that if we had scored by response to each question, we might have missed the relation between responses. This method is consistent with other research that examines teacher noticing and analysis using more open-ended prompts (Davis, 2006; Santagata & Angelici, 2010; van Es & Sherin, 2002, 2008;). In addition, we were not interested in whether candidates focused on one feature of instruction over another, but, rather, whether they attended to the range of features of ambitious pedagogy and how they noticed these events. Thus, we wanted to capture the nature of their noticing on each dimension for each clip at both points in time.

To ensure that the research team developed shared lenses for analyzing candidate responses, we selected four additional sets of responses and coded them independently and then met to review our coding. This is consistent with research that recognizes that working with participants' responses requires research teams to engage in cycles of analysis (Weston et al., 2001). Two categories were difficult for the research team to distinguish from each other, *pedagogies for making thinking visible* and *classroom discourse*, so we returned to the literature and the coded cases until we gained confidence that we had a shared understanding of these categories in terms of the goals of ambitious mathematics pedagogy and how particular events and interactions in classroom interactions represent each category.

We then divided the remaining 23 cases among the first three authors who individually coded the responses to both clips for the pre and post tasks. To ensure interrater reliability, the second and third authors randomly selected a subset of cases and coded them individually and then discussed their coding and analytic memos. Interrater reliability across the six categories was 93%. Any disagreements were resolved through discussion until consensus was reached.

Phase 2: Investigating variations in candidate noticing practices

After we coded the pre and post tasks with this framework, we observed that, as a group, the candidates shifted in their noticing of classroom interactions from the beginning to the end of the course. However, having reviewed their written responses and our own memos, it was clear that the candidates did not all notice in the same ways at each point in time, and they did not shift in the same ways from the beginning to the end of the course, which raised questions for us about differences in candidates' noticing. Thus, we returned to the data and further elaborated our analytic memos to capture more details about the development of their approaches to noticing over time. Our analysis was informed by research that conceptualizes the work of learning to teach as a sociocultural activity and recognizes that teacher candidates develop knowledge, dispositions, identities and practices through participation in various settings and over time (Putnam & Borko, 2000; Turner et al., 2012). Moreover, research suggests that noticing is an active and intentional act; that it is consequential to the learning opportunities afforded to students; and that it is a high leverage practice for teaching (Erickson, 2011; Kersting, 2008; Mason, 2011; McDonald et al., 2013). Thus, we wanted to better understand the relation between learning to see classrooms in particular ways in the context of a learning setting and the various practices teacher candidates took up for looking at and making sense of teaching.

During this phase of analysis, we used the analytic memos to investigate how individual candidates approached the noticing task and shifted their noticing over time. This analysis enabled us to characterize the work of noticing in this context, differences among the group in terms of their noticing practices and variations in learning to notice over time. We also reviewed the analytic memos with the course goals in mind to understand if there were features from the course that were salient in their responses (e.g., attending to the mathematical task or student thinking) or if they adopted ways of noticing that might be tied to the course design (e.g., more descriptive early on to more elaborate and integrated later in time). After we developed profiles of each candidate's shifts in noticing, we then compared their profiles through an iterative process of reviewing the data and memos to look for similarities and differences in the development of their noticing of ambitious mathematics pedagogy. We viewed this process as a way for the research team to gain a shared understanding of variations in candidate noticing, as well as how development on some dimensions may influence development on others and how shifts in noticing may be tied to their experiences in the course (Barnhart & van Es, 2015; Seidel & Stürmer, 2014; Weston et al., 2001). We report our findings below.

Results

Data analysis revealed several noteworthy results. First, the candidates developed new ways of noticing informed by the framework of ambitious mathematics instruction promoted in the *Learning from Teaching* course. Second, we identified practices that candidates used to notice classroom interactions. Importantly, we found that they entered the program with different approaches for noticing and they developed their noticing practices in different ways over time. We elaborate on these findings in the following and then discuss the implications of these results in relation to designing video-based learning environments to cultivate new forms of noticing.

Development of candidates' noticing in the learning from teaching course

We first sought to understand if teacher candidates learned to notice ambitious pedagogy in the context of the course. In other words, did the candidates come to attend to elements of ambitious mathematics pedagogy promoted in the course, become more interpretive in the analysis, and more precisely characterize what they noticed and examine the relationships between observed events? Our analysis revealed that the candidates shifted on these dimensions from the beginning to the end of the course (see Table 4 for a distribution of the coding from the pre to the post video analysis task).

Table 4. Distribution of scoring in the pre and post video analysis task.

		Pre Video Analysis Task			Post Video Analysis Task		
		L0	L1	L2	L0	L1	L2
What notice	Mathematical Content & Learning Goal	19	11	1	3	15	13
	Student Thinking	21	10	0	3	17	11
	Pedagogies for Making Thinking Visible	3	26	2	1	12	18
	Classroom Discourse Norms	11	20	0	1	19	11
How notice	Specificity	21	10	0	2	11	17
	Making Connections	21	8	2	8	15	8

Note. N = 31 participants. L0 = Level 0; L1 = Level 1; L2 = Level 2.

Table 5. Teacher candidates' approaches to noticing instruction.

Attending to Features of Instruction	
Using Generic Frames to Observe Instruction	Providing simplified observations and evaluations guided by generic frames of effective teaching
Using Framework Terminology	Using the framework of ambitious mathematics instruction promoted in the course to identify events and interactions that stood out to them.
Elaborating on Observations	
Providing Detailed Descriptions	Describing in detail observed events without a clear vision of instruction guiding observations
Exploring Details of Ambitious Instruction	Using the framework of ambitious teaching to highlight features of instruction, with greater focus on the details of observed phenomena.
Integrating Observations to Reason about Instruction	
Blending Visions of Teaching to Analyze Instruction	Drawing on different frameworks of instruction to inform observations of instruction; providing detailed and interpretive analysis of observed events.
Using a Vision of Ambitious Teaching to Systematically Analyze Instruction	Using frameworks from the course to identify and interpret specific features of classroom interactions and making connections between the features they observed in systematic ways.

Early on, the candidates paid little attention to the mathematical content and student thinking and attended generally to teaching practices for making thinking visible and classroom discourse. They typically identified and evaluated what they observed, and made few connections between elements they highlighted. By the end of the course, however, the candidates showed an increased attention to and interpretation of features of ambitious pedagogy and their accounts of what they observed became increasingly precise, detailed, and integrated.

These findings are consistent with prior research that shows that teacher candidates can improve their noticing in the context of an experience focused on this goal (Stockero et al., 2015). However, the literature also suggests that there is likely variation in candidates' noticing and that they do not learn to notice in the same ways (Turner et al., 2012; van Es & Sherin, 2008; Wager, 2014). The distribution of scores on the three levels at both points in time suggest this was the case—that the candidates did not all enter the course noticing classroom interactions in the same ways and that there were differences in the ways they shifted in their noticing. Thus, we investigated variations in candidates' noticing and what these differences might reveal about the practices they develop for noticing ambitious instruction.

Characterizing candidates' noticing practices

Our analysis resulted in a framework that characterizes teacher candidates' noticing practices and identifies approaches associated with each practice (see Table 5). The framework is intended to articulate the work of noticing: attending to features, elaborating on what is observed, and integrating observations to make sense of complex phenomena (Erickson, 2011; Lampert, 2001; Mason, 2011). We use this framework to elucidate the various ways candidates noticed instruction and to identify practices they came to take up over time and how they did so in different ways.

The first practice, attending to features of instruction, captures the act of deciding what to focus on in the complex field of examining classroom interactions. One approach, using generic frameworks to observe instruction, involves using a generic vocabulary of instruction to guide observations of teaching. It refers to identifying features of instruction that seem to reflect teachers' perceptions of effective teaching and learning, but provide little insight into the teaching-learning process, such as noting how the desks are arranged (e.g., "the desks have messy arrangements"), the grouping of students (e.g., "the students are sitting oddly, some in groups and some by themselves"), as well generally on the teacher and the class and how the teacher and students as a whole participate in the class (e.g., "The teacher asked students to explain how they got their answer"). The other approach, using framework terminology, concerns using the language of ambitious instruction to highlight noteworthy events, such as referring to the type of discourse taking place (e.g., "student-to-student discourse" or "student-generated discussion"); student thinking (e.g., "one student said he used a graphic way" and "student thinking—one student realizes they are provided with points to help them calculate the slope"); or teacher questioning (e.g., "The teacher asks clarifying and elaborating questions to probe student ideas"). In both cases, the candidates note features of the interaction but appear to draw on different frameworks to guide their attending.

The second practice, elaborating on observations, captures candidates providing rich descriptions of what they observe (see Rodgers, 2002). We identified two approaches candidates used to elaborate. The first, providing detailed descriptions, includes responses that consist of lists of observations or play-by-play narrative accounts of what occurred in the video. For example, for one candidate, Candice, the majority of posttest response was a step-by-step account of what unfolded in the clip: The teacher asked students to apply a rule to get to "how many minutes if you have 25 dots;" the student presented the answer; the teacher then asked if everyone agrees; the teacher asks how many minutes for 73 dots and 99 dots; students answered and explained how they solved each; the teacher explains the difference between an expression and an equation.

Another approach, exploring details of ambitious instruction, involves elaborating on what is observed as it is linked to features of ambitious mathematics teaching. In this case, the candidates note details related to various features of instruction emphasized in the course. One candidate, for example, organized her response in terms of the framework of ambitious instruction and provided details for each. For student thinking, for example, she observed: "Trying to find the intercept; trying to find the slope;" "Every hundred minutes it goes up $30;" "Where do they get those numbers from?"; "Different ways of finding slope—point slope, y-intercept, use two points to find slope." Similarly, for task, she noted, "Find out which is the best wireless plan;" "How can you find the slope of the line?" and "Students have to think critically to interpret what the graphs mean. … They need to compare two linear graphs to figure out which will save the most money. … It provides a real life situation to grapple with." Although both approaches provide details, the distinction is that in the second approach the candidate called out particular features of ambitious instruction—in this case, student thinking and mathematical task—and provided details to elaborate on what was observed.

The third practice, integrating observations to reason about instruction, concerns drawing connections between observed phenomena to reason about instruction. The difference between the approaches tied to this practice is that some candidates' observations draw on a range of frameworks to analyze instruction, what we call *blending visions*, whereas other candidates' responses are guided primarily by a vision of mathematics teaching focused on student ideas, what we refer to as *using a vision of ambitious teaching to systematically analyzing instruction*. We use the case of Yandel to illustrate blending visions. In response to the second clip, he attended to student thinking, listing a variety of events and interactions to support this observation: Students discuss how to find the slope of the line; they identify the points on the line; they used the formula for slope; one student explained to another how to determine the coordinate and then use the coordinate to find the slope. He also explained that the "teacher provides some guidance by asking them how they got their answer or 'Do you agree with that?'" Thus, his attention was on student thinking, how they work together to help each other, and the role of the teacher in this process.

However, he also noted, "There are only four students in the class. The teacher gives students undivided attention. All of the students have a TI-83 calculator." At the end of the response, he returned to the size of the class, "There are background noises which might indicate there are more students in the class but it is a very small class. It might be a tutorial." Although much of his response was focused on student mathematical thinking and student-to-student and teacher-student interactions, he also attended to issues that were less consequential to the mathematical thinking in this segment—the size of the class, the type of calculator, and the background noise. We define this as blending visions because he appears to draw on different frameworks to guide his noticing.

The other approach, using a vision of ambitious teaching to systematically analyze instruction, refers to those responses that focus primarily on the details of mathematical content and task, student thinking, teachers' roles in making student thinking visible and working with student ideas, and classroom discourse, and that link these events to draw inferences about them. In response to the second clip the candidates viewed, Mary, began her response by noting:

> I notice that the four students do not have a clear understanding of the conceptual or procedural knowledge to solve linear graphs. The teacher does not tell them how to solve the problem, instead she guides them. She allows students to express their thoughts even though sometimes their thinking may be incorrect, like when one of the male students says the slope is 300 minutes for every 30 dollars. Additionally, the students are unclear about how to find the slope of the line.

Her response focused on understanding students' mathematical thinking, and she linked it to the task and to the role of the teacher and the students in the interaction. She followed this initial response with more precise and detailed observations: "The teacher guides the student to notice that for the first 200 minutes on the x-axis, the line is flat at $30;" "One student interprets that as the 'graph is flat,' and acknowledges that the charge for the first 200 minutes is always $30;" and "Dante doesn't seem to understand how to solve for slope using the points. Another student explains to Dante how to solve using the points. They conclude that the slope after 200 minutes is $30 for every additional 100 minutes."

Mary then concluded the response by integrating what she observed. She claimed that the teaching supported student thinking by "allowing students to think and work out the problem for themselves." Yet, she was also tentative in the claims she made, noting that "the teacher's guidance may have been unsuccessful because still the students do not seem to understand how to solve for the slope of the linear graph," suggesting that she was willing to consider alternative explanations. Thus, looking at the response as a whole, Mary attended to specific features of instruction emphasized in the course, in this case the mathematics, students' thinking and their role as reasoners and collaborators in their learning, and teachers' moves to promote mathematical reasoning. She also appeared to be trying to figure out what was going on during the interaction and contemplated what might have happened and why.

Variations in candidates' noticing

Once we identified the practices and associated approaches, we returned to the data to examine variations in candidates' noticing at both the start and end of the course (see Table 6). We pursued this analysis for two reasons. First, we wanted to understand if there were some noticing practices that candidates brought to the observation of teaching at the start of the preparation program and how their noticing practices developed over time. Second, we wanted to understand if developing on some dimensions may lead to developing on others, such that being provided frameworks to guide one's noticing can be generative for continuing to hone and improve ones' noticing and analysis (Barnhart & van Es, 2015; Erickson, 2011).

At the start of the course, the candidates drew on three approaches: using generic frames to observe instruction, providing detailed descriptions, and blending visions of teaching to analyze instruction. All three approaches reveal that most candidates' objects of attention were more general in nature. That said, five candidates entered the program providing more detailed narrative accounts of what they observed. In addition, three candidates entered the course integrating observations—framing portions of their responses in terms of features of ambitious instruction, while also drawing on other frameworks to inform their observations, and linking the features of instruction they observed.

At the end of the course, however, the candidates' noticing developed primarily on two practices—attending and elaborating. Across the group, 15 of the candidates shifted to attending primarily to the features of instruction promoted in the course (*U*sing framework terminology, exploring details of ambitious instruction, and using vision of ambitious teaching to systematically analyze teaching). Additionally, 26 of the candidates developed the practice of elaborating, providing more detailed and expansive observations (providing detailed descriptions, exploring details of ambitious instruction, blending visions of teaching to analyzing instruction, and using vision of ambitious teaching to systematically analyze teaching). Finally, 11 of the candidates' integrating practice shifted to using the

Table 6. Trajectory of noticing instruction by candidate.

	Pre Video Task	Post Video Task
Benjamin	Generic Frames	Generic Frames
Caleb	Generic Frames	Generic Frames
Genevieve	Generic Frames	Generic Frames
Maggie	Generic Frames	Using Terminology
Shannon	Generic Frames	Using Terminology
Candice	Generic Frames	Detailed Description
Carrie	Generic Frames	Detailed Description
Eddie	Generic Frames	Detailed Description
Evey	Generic Frames	Detailed Description
Veronica	Generic Frames	Detailed Description
Caitlyn	Generic Frames	Exploring Details AP
Cheryl	Generic Frames	Exploring Details AP
Chloe	Generic Frames	Exploring Details AP
Hailey	Generic Frames	Exploring Details AP
Kasie	Generic Frames	Exploring Details AP
Melanie	Generic Frames	Exploring Details AP
Nida	Generic Frames	Exploring Details AP
Camille	Generic Frames	Blending Vision
Carol	Generic Frames	Blending Vision
Denise	Generic Frames	Blending Vision
Frances	Generic Frames	Blending Vision
Hal	Generic Frames	Blending Vision
Oliver	Generic Frames	Blending Vision
Abigail	Detailed Description	Exploring Details AP
Jacey	Detailed Description	Exploring Details AP
Jamie	Detailed Description	Exploring Details AP
Angela	Detailed Description	Blending Vision
Yandel	Detailed Description	Blending Vision
Janice	Blending Vision	Using Vision
Malcolm	Blending Vision	Using Vision
Mary	Blending Vision	Using Vision

vision of instruction promoted in the course to frame their observations (blending visions of teaching to analyzing instruction, and using vision of ambitious teaching to systematically analyze teaching). However, of this group, eight of them drew on alternative frameworks of teaching to guide their noticing.

This finding is noteworthy for a few reasons. First, given the course design and that the frameworks were introduced early in the course and continued to frame the second and third phases of the course, we anticipated that the candidates would leverage the language of ambitious pedagogy to guide their attending. Yet, this was not the case across the cohort. Second, some research suggests that developing an ability to notice certain features in detail will support candidates in integrating observations to make sense of instructional interactions (Barnhart & van Es, 2015; Seidel & Stürmer, 2014; Schaefer & Seidel, 2015). Our findings support this research and suggest that honing one's practices for elaborating may be integral to shifting to more sophisticated forms of noticing.

Variations in candidates' noticing trajectories

After identifying the three practices and associated approaches, we then returned to the data to investigate the variations in candidates' trajectories for learning to notice from the beginning to the end of the course. We provide a summary of the findings, along with example cases, to illustrate how candidates shifted in relation to the forms of noticing ambitious instruction promoted in the course and how their practices for noticing developed over time.

Most of the candidates ($n = 23$) entered the course drawing on generic terminology with little to no elaboration and integration of observed events. When we look at the shifts in their noticing over time, we find that they developed in a variety of different ways in relation to the three practices. Aside from three candidates whose noticing practices did not change from the pre to the post task (Benjamin, Genevieve, and Caleb), the other 20 candidates' noticing shifted differently in relation to the three practices. Two of the candidates (Maggie and Shannon) developed their ways of attending, using the terminology ambitious instruction to highlight what they observed. For example, both Maggie and Shannon shifted from attending to students' answers, a phrase they used consistently to refer to student work in the video, to labeling what they observed in terms of "student thinking," and "norms for classroom talk." Although the language they used to identify what they observed shifted, they did not provide more detailed, integrated observations.

Twelve candidates developed practices for elaborating. Of this group, five candidates (Candice, Carrie, Eddie, Evey, and Veronica) provided rich descriptions of more generic classroom features. Evey's responses in the pre and post video task represent this shift. In the prevideo analysis task, she highlighted few events or interactions. She noted the mathematics that was the focus of the clip but aside from that, her observations were limited. For instance, responding to the second clip, she wrote,

> Students are arranged in groups. All students participate orally. A group of students is having a mathematical discussion. They are trying to determine an equation that models the price of a particular cell phone company based on data and a graph. The teacher's role is that of a facilitator; she allows the students to come up with and verify their own ideas.

Aside from the fourth sentence that identifies the mathematics, the rest of the response is quite general: Students are in groups, they participate orally, and the teacher acts as a facilitator.

In the post task, she provided a more detailed observation of what she observed: "The teacher asks questions to the group ('do you agree with that?') to answer student questions ('how can you find the slope of the line? … look at your paper'); Teacher asked questions that related the problem to the real-world situation ('so what could you tell your customer?'); 'What do you notice about the line?'" Here, Evey provided more detailed, elaborate observations of the teacher's questions but it is not clear that it is guided by a vision of ambitious instruction.

The other seven candidates (Caitlyn, Cheryl, Chloe, Hailey, Kasie, Melanie, and Nida) developed practices for both attending and elaborating—providing more detailed and elaborate accounts of what they observed and framing their observations in relation to features of ambitious instruction, such as students' mathematical thinking and the nature and quality of the mathematical task. Similar to Evey, they shifted to elaborating what they observed, but the framework of ambitions instruction guided their noticing. Caitlyn, for example, organized what she noticed in categories labeled *tasks*, *student thinking*, *tools*, and *formative assessment*, and she identified specific events in relation to these topics. For task, she wrote "Working Backwards … How long will it take to get 25 dots, 73 dots, and 99 dots" and for student thinking, she noted that students came to the board to explain and one student had a graphic way. Unlike those who simply labeled observations with framework terminology, this group also provided elaborate details to further explain what they observed. She wrote, for instance, "This is a meaningful task. … It makes them think critically about the graphs and how to interpret it. It also provides a real life situation for the students to grapple with." Responses such as this suggest that these candidates developed practices for both attending and elaborating toward a vision of ambitious instruction.

Six additional candidates (Camille, Carol, Denise, Frances, Hal, and Oliver) shifted in all three practices: attending, elaborating, and integrating. In the post task, their noticing was characterized as blending visions of instruction. They all attended to features of ambitious instruction, they elaborated their observations, and they began to synthesize and inquire about observed phenomena. However, they also continued to attend to features of instruction outside of a framework of ambitious pedagogy. Camille, for instance, labeled her observations in terms of the frameworks from the course, highlighting events in terms of the nature of classroom talk—using phrases like "math talk" and "students explaining" and "task promoted conceptual thinking"—and she inferred how the teacher's and students' roles in the math talk community promoted mathematical thinking. At the same time, she also focused on student interest and effort, asking questions in response to the last prompt, "What does the teacher do when students throw down the pencil and lost interest? What happens when students don't like to put effort into solving problems?" Her noticing, like the others in this group, appears to be guided by other frameworks for teaching and learning—in this case, some ideas about students and their motivation—which are fundamentally different from the framework used in the course to tie student learning to features of classroom interactions that advance mathematical thinking.

Overall, the video-based course appears to have provided the candidates who entered with underdeveloped frameworks for observing teaching opportunities to develop practices for noticing in new ways. All but three of the candidates shifted on the three practices, however, not all took up the framework of ambitious pedagogy to inform what they attended to in their observations. This suggests then that elaborating is a practice that can be more readily honed in a course focused on observing and analyzing teaching, but that the tasks and activities that were a part of the course did not provide sufficient opportunity for the candidates to appropriate new frameworks to guide their attending - a subject we will return to in the discussion.

Five additional candidates provided detailed descriptions of the instructional interactions at the beginning of the course. Of this group, three of them (Abigail, Jacey, and Jamie) developed their practice of attending, drawing on the frameworks of the course to highlight features of the lessons, while continuing to offer more detailed accounts of what occurred. Two of these candidates (Angela and Yandel) shifted in all three practices and were blending visions to notice instruction in the post task. Thus, what distinguishes this group from the ones who entered the course with generic frames is that they continued to see the details, but they adopted alternative frameworks to guide what they were seeing. In addition, in terms of their descriptions, they became more precise in their descriptions. Early on, they highlighted a range of phenomena but their responses consisted of more vague characterizations to describe what they saw; in the post task, they identified specific statements and used them to elaborate on the classroom interactions.

Finally, three candidates entered the course blending visions (Janice, Malcolm, and Mary). They had some awareness of key features to attend to as they entered the course, but they also drew on more generic frameworks to identify noteworthy events, while still providing more detailed accounts of instruction. Their responses were also more inferential and sought to draw connections between what they observed. The important shift for this group is in relation to their attending. What they highlighted was tied more closely to features of ambitious instruction that were the subject of the course, noting, describing, and interpreting students' thinking with respect to the mathematics and then tying what they inferred about student thinking to the teachers' questioning to elicit student thinking and their efforts to develop discourse-rich classrooms.

Malcolm's responses to the first clip illustrate this shift. Early on, in response to the first prompt, he noted, "The teacher asks for input from students to create a hypothesis to describe some kind of behavior, in this case a description of a pattern. First, he asks for input from a group, then asks for agreement from other students. Then he asks students to explain or provide alternate means." He provided more detail in response to the next two prompts: "Asks from group how they obtained the answer"; "Asks students to explain—'does everybody understand that?"; "Asks for student input; then moves on with lecture;" "Liked the way he remembered what particular students said." He continued his response, taking on a more interpretive stance, "I had a little trouble figuring out exactly what they were doing. … I think it had to do with forming an equation based upon on output pattern and relating the concept of expression with equation." He also evaluated what he observed, using phrases like "I liked how he asked for alternative means, but it seems a questionable way to figure out if a class is following you" and he noted some discipline issues, when teachers had to "rein students in" a couple times during the lesson. Although Malcolm noted the details of how the teacher elicited student ideas and inferred the purpose of the mathematical task, his response also consisted of less precise language, making it unclear what informed how he looked at and interpreted what he observed.

In the post task, his observation was much more precise to what unfolded in the clip. He noted the questions the teacher asked and identified student explanations and approaches for solving the task. Moreover, for each observation, he inferred the importance relative to the framework of the course. For instance, he noted the teacher ascribed a name to students' method "What Irma said" and then explained that "naming a procedure/theory after a student" is part of classroom discourse. Similarly, when the teacher asked, "Who else?" he inferred that the teacher was interested in hearing student thinking and a variety of student thinking, not just the right or wrong answer. Thus, features of ambitious instruction framed his observations and he interpreted the function they served in the interaction. Like the other two candidates who shifted to using a vision of ambitious pedagogy to systematically analyze instruction, he then drew on the long list of observations and inferences to make sense of the interaction as a whole.

> Rather than solving problems and having the answer be the end of the discussion, the clip shows that students are asked to explain their answers and how they came up with them. They are invited to comment on what other students have said and how they have done what they did. The majority of the time is spent on the process: how, why, what did you do. There is not just one way to do anything in this class, meaning there are a variety of ways for students and teachers to interact both in terms of content and discourse.

Taken together, this response represents the shift we observed with these candidates on the practices of attending, elaborating, and integrating. What they came to observe was guided by a vision of ambitious instruction, but they also became even more elaborate, interpretive, and precise in their observations. We now turn to discuss these results.

Discussion

Our study was motivated by research that shows that video can be a powerful tool for supporting candidates in developing skills at noticing and analyzing teaching in the context of a course (Blomberg et al., 2013; Gaudin & Chaliès, 2015; Santagata & Yeh, 2013), but with less research that investigates variations in candidates' noticing and how the learning experiences of which they are a part are tied to the ways that they come to notice instruction over time.

Consistent with other research, we found that participation in the video-based course supported candidates in learning to notice classroom instruction in more substantive ways, attending to the details of the mathematics, student thinking, and the ways that classroom discourse and pedagogies for making thinking visible supported student learning (van Es & Sherin, 2002; Santagata & Yeh, 2013; Schäfer & Seidel, 2015; Star & Strickland, 2008; Stockero et al., 2015; Stürmer et al., 2013). We find it promising that, as a group, the candidates developed a common language to characterize instruction informed by a vision of ambitious instruction, particularly because a major shortcoming of teacher education is the lack of a shared language to define the work of teaching (Grossman & McDonald, 2008; McDonald et al., 2013). Our findings suggest that providing candidates with frameworks that define the core work of mathematics instruction and engaging them in cycles of observation and analysis of teaching with video can provide them with a way in to noticing the complexity of this vision of instruction.

An important contribution of this study is the framework that identifies three broad noticing practices—attending to features of instruction, elaborating on observations, and integrating observations to reason about teaching—and associated approaches, distinguished by the extent to which candidates' observations were informed by a vision of ambitious instruction or whether they drew on a more generic vocabulary of teaching to inform what they identified as noteworthy. Importantly, we did not seek to define the noticing practices or associated approaches in terms of the levels defined in our earlier coding scheme, nor in relation to the design principles that informed the course. Nevertheless, it seems that some approaches, and some coordination of practices, may in fact reflect higher levels of noticing than others. For example, using generic frameworks to observe teaching aligned with responses that were coded Level 0 on most dimensions, and exploring details of ambitious instruction was mainly used when there was evidence of noticing at Level 1 across several dimensions. Analysis into the relationship between the approaches and the coding on the various dimensions is an important area for future inquiry.

One value of the framework is that it identifies core practices inside of noticing, particularly when viewing artifacts of practice. It also provides deeper insight into the variations in candidates' noticing, as well as in how they came to notice ambitious instruction over time. Though about two-thirds of the candidates used the language of ambitious instruction to guide their observations over time, they did not all come to attend to these features in systematic ways. Identifying the approaches candidates used also revealed that even as candidates' observations became more elaborate and integrated, some of them continued to draw on more generic lenses to identify noteworthy features of classroom interactions. We also found that as the candidates shifted to integrating observations, it was challenging to sustain attention to features of ambitious instruction, as several of them blended frameworks to focus their noticing. Thus, adopting what Miller (2011) referred to as "situation awareness" (p. 53)—perceiving meaningful events and comprehending their meaning—can be difficult.

These findings have implications for designing learning experiences to support noticing of ambitious pedagogy. Consistent with research that advocates for cycles of design, enactment, and reflection to develop high leverage practices (Lampert et al., 2013; McDonald et al., 2013), we propose that candidates who are learning to notice instruction in new ways may need to engage in multiple cycles of observation and analysis of teaching with a focus on explicit features of instruction. In so doing, they can make visible the conceptions of teaching they use to see mathematics teaching and learning and continue to hone their ways of observing and defining features of ambitious instruction as they play out in classroom interactions. Of course, candidates enter teacher education with frameworks about teaching and learning, and they develop others through their participation in courses and fieldwork experiences (Erickson, 2011; Grossman et al., 1999; Lortie, 1975). An important area for future inquiry concerns how candidates draw on alternative frameworks to notice, as well as how they come to distinguish between more and less meaningful frameworks to guide their noticing (see, for example, Goldsmith & Seago, 2013).

Our analysis also reveals that it is not so difficult for teacher candidates to become more descriptive and to hone in on the details of what they observe. Candidates who entered the course focusing on the details continued to do so, and for the most part, those who did not, shifted to more detailed observations by the end of the course. Research finds that learning to see the details in classroom interactions can promote teachers engaging in more substantive analyses of practice (Barnhart & van Es, 2015; Davis, 2006; Mason, 2011; Seidel & Stürmer, 2014). This supports one core feature of the course design: taking time to slow down instruction and examine the particulars of practice (Rodgers, 2002). It is the case that two candidates' responses were informed by the framework but did not include specific details to elaborate what they observed (using framework terminology). The fact that candidates used the framework to highlight what they observed suggests they were noticing these events more generally, what has been identified as more novice forms of noticing (see van Es, 2011).

Taken together, these findings have important implications for the study of preservice teacher learning and the design of learning environments for teacher preparation. We build on prior research by identifying practices for noticing and examining how candidates use these practices to notice teaching in more complex ways over time. Given the consequential nature of noticing for teaching (Erickson, 2011; Kersting, 2008), we see this work as contributing to efforts to cultivate teachers' noticing for their practice. Researchers and teacher educators can use these findings to assess the nature and development of candidates' noticing as they move through their pre-service experience. In addition, with greater emphasis on a practice-based approach to teacher education, our findings offer particular practices that can be the target for pre-service teacher learning.

We now consider the role video may have played in supporting the candidates in developing their noticing practices. Schoenfeld (2011) discussed the challenges inherent in teachers developing a student-centered orientation to teaching and strategies for helping teachers attend to students and their thinking. Several features of the *Learning from Teaching* course provided opportunities for candidates to develop ways of attending, elaborating, and integrating to adopt a more student-centered frame to observe instruction. They viewed and studied students being interviewed about mathematical concepts, as well as multiple classroom segments featuring student thinking and ambitious instructional practice. Careful selection of the videos, along with structured guidance in viewing the clips, appeared to help orient the candidates' attention to the mathematics and student thinking, and to the relation between teaching moves and student thinking and learning. The candidates also participated in two video-based field tasks—one in which they designed, conducted, and analyzed a student interview around a mathematical task and another in which they codesigned, taught, and analyzed a lesson focused on student thinking. Trying out tasks with students in real classrooms, recording them, and analyzing them allowed the vision of instruction to be brought to life in their own teaching. Throughout each task, attention was focused on the details of the interactions: who said what, what the interactions reveal about student thinking and learning, and how features of the lesson promoted certain forms of thinking. Thus, we propose three design features as central to supporting candidates in learning new ways of noticing mathematics instruction: foregrounding student learning of mathematics in the analysis, describing and naming pedagogical practices as they arise in representations of teaching, and engaging in joint design, enactment and shared noticing. Future inquiry is needed to examine how designing learning environments based on these features helps candidates develop and refine practices for noticing instruction that is generative for their learning.

Though we are encouraged by our findings, we recognize several limitations to this study. First, we recognize that the vision of mathematics teaching to which we sought to apprentice candidates to notice does not capture all features of ambitious instruction, such as issues of access and participation and how inequities are perpetuated in classroom contexts (NCTM, 2014; Turner et al., 2012; Wager, 2014). An important area for future research concerns the relation between frameworks for noticing and the development of candidates' noticing practices. We also did not conduct a microanalysis of the candidates' experiences in the course to understand how the instructional activities induced changes in their noticing. Additional research is needed that examines how the design principles we propose relate to conjectures on learning to notice mathematics teaching and how these come to be embodied in the instructional experience and lead to new forms of learning for teacher candidates (Sandoval, 2014). Finally, we recognize that the candidates' noticing of teaching is contingent on the instructional tasks and interactions represented in the videos of teaching that were the subjects of their observation. We propose that future research capture candidates' noticing practices in a wide range of classroom interactions and contexts to further elaborate and refine the noticing practices and associated approaches proposed here. It may also be the case that noticing in the act of teaching relies on alternative practices, ones that draw out student ideas so that they can be positioned to elaborate and further interpret the relation between teaching and learning during reflection. Further inquiry is needed to identify noticing practices in the variety of contexts in the work of teaching in which teacher noticing is central to the activity.

Conclusion

A central goal of teacher preparation includes providing candidates with tools to learn in and from their practice, which involves learning to see and makes sense of the detailed events and interactions in teaching and how they relate to promote student learning (Ball & Cohen, 1999; Feiman-Nemser, 2001; Hiebert et al., 2007; Lampert, 2001). Recent calls for the improvement of teacher education advocate for a practice-based approach that focuses the curriculum of teacher education on the core work of teaching practice (Grossman et al., 2009; McDonald et al., 2013). This study contributes to this effort by documenting the different practices of learning to notice ambitious pedagogy, while also offering a design that achieves this goal. Grossman and colleagues (2009) reported that teacher education programs often offer candidates opportunities to learn to reflect on teaching. However, we propose that the cycles of observation and analysis in which the candidates engaged in the *Learning from Teaching* course promoted a more systematic, deliberate way of noticing teaching, one that is guided by frameworks in the discipline and one that directly focuses teacher candidates' attention on student thinking and teaching in the discipline. Moreover, if part of the core work of teaching is attending and reasoning about student thinking during instruction and monitoring ones practice relative to student learning, then the *Learning from Teaching* course provided a context to engage in approximations of this practice (see Grossman et al., 2009) by providing opportunities for candidates to notice the work of ambitious mathematics instruction through structured video analysis, without the need to act in the moment of teaching.

The *Learning from Teaching* course was designed as part of a particular program that prioritized noticing and learning from practice as core goals of teacher preparation and embedded this course in the limited period of a teacher preparation program. This raises several questions about how the principles of using video might be embedded in teacher education programs more broadly, as well as how the broader system of teacher preparation supports candidates in developing a shared vision of instruction that can guide their noticing of teaching. Some questions concern how different participants in the teacher education system help candidates learn to look at and make sense of their practice, what tools and frameworks they use to guide their noticing, how different language systems are used to talk about teaching, and the consistency and inconsistency within and across contexts in the use of these tools and language to notice classroom interactions. We conjecture that such a systemic approach to studying teacher noticing and the development of a vision of ambitious pedagogy will raise new questions that will inform the design of learning opportunities for teachers, while also pressing the field to adopt alternative conceptual and theoretical frameworks for studying this central construct of teaching.

This research was supported by the Knowles Science Teaching Foundation. The opinions are those of the authors and do not necessarily reflect the opinions of the supporting agency. We wish to thank Tesha Sengupta-Irving, Miriam Gamoran Sherin, and members of the Center for Teacher Preparation and Professional Practice for their thoughtful feedback on this article.

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