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Preservice Secondary Mathematics Teachers' Reflective Noticing from 360-degree Video Recordings of Their Own Teaching

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The benefits of using video in teacher education as a tool for reflection and for developing professional expertise have long been recognized. Recent introduction of 360 video technology holds promise to extend these benefits as it allows prospective teachers to reflect on their own performance by considering the classroom from multiple perspectives. This study examined nine prospective secondary teachers' (PSTs) noticing and self-reflection on the 360 recordings of their own teaching. The PSTs, enrolled in a capstone course *Mathematical Reasoning and Proving for Secondary Teachers*, taught a proof-oriented lesson to small groups of students in local schools while capturing their teaching with 360 video cameras. We analyzed the PSTs' written comments on their

video and reflection reports to identify the categories of noticing afforded by the 360 technology as well as the instances of PSTs' learning. The results point to the powerful potential of 360 videos for supporting PSTs' self-reflection and professional growth.

Keywords: 360 video, Noticing, Reflection, Mathematics Teacher Education, Field experiences

INTRODUCTION

Video technologies have long been used to ground pre-service teacher education in the practice of teaching (Blomberg et al., 2013; Rich & Hannafin, 2009), due to their affordances in strengthening connections between university coursework and the realm of teaching practice (Ball & Forzani, 2010; Grossman, 2005). The underlying mechanism, which makes learning from video possible, is reflection. There are multiple definitions of reflection, which may involve a variety of cognitive processes such as perceiving, interpreting, analyzing, critiquing, questioning, considering alternatives, theorizing, planning, and connecting to prior experiences or general theoretical principles of teaching and learning (Anderson, 2019; Brookfield, 2017; Dewey, 1933; Farrell, 2018; Moore-Russo & Wilsey, 2014; Postholm, 2008; Revans, 1982; Schön, 1987).

While both video of one's own practice and the videos of other teachers have been successfully used in mathematics teacher education to engage teachers in reflective practices, reflecting on one's own teaching has been widely recognized as a powerful means for advancing professional expertise (Seidel et al., 2011). Within pre-service teacher education, reflections on one's own teaching can be difficult to utilize since prospective teachers usually do not have access to classrooms. Nevertheless, it has been suggested that whenever such videos are available, prospective teachers tend to view them as more relevant and beneficial to their own practice (Walshe & Driver, 2019). The high personal relevance may more effectively stimulate productive reflection and promote noticing of more significant aspects of teaching and learning (Seidel et al., 2011). Moreover, Abell, Bryan, and Anderson (1998) argued that watching a video of another person's teaching was less conducive to prospective teachers' reflections on their own beliefs and practices, as prospective teachers felt too distant from the events and individuals presented in these videos.

Despite the benefits of reflection to one's own practice, research suggests that there are several barriers to productive reflection. For example, prospective teachers are often reluctant to critically analyze their own teaching, only focusing on positive aspects (Abell et al., 1998). In addition, prospective teachers often experience difficulties in noticing important aspects of teaching and learning, even when they may be apparent in the video. This phenomenon is known as "inattentional blindness", meaning that what one sees, or does not see, is a product of the person's knowledge, expectations, and intentions (Simons & Chabris, 1999). Hence, novices' noticing and reflection tend to differ from those of experts (Schoenfeld, 2011; Sherin & Star, 2011).

Considering these challenges, researchers have emphasized the importance of structuring and scaffolding self-reflective learning experiences (Moore-Russo & Wilsey, 2014; Tripp & Rich, 2012; Walshe & Driver, 2019). This requires attending to at least two separate aspects. First, there is the pedagogical aspect, which refers to the structure of the experience in terms of specific prompts, collaborative or individual modes of reflection, and the amount of scaffolding. Second is the technical aspect which refers to the choice of video type, e.g., edited or raw, camera positioning in the classroom, the length of video, and the video annotation platform (Rich & Hannafin, 2009). The recent advance of 360 video technology bears new possibilities and holds a particular promise for supporting prospective teachers' reflective practices. Despite the fast-growing interest in using 360 video technology in teacher education, research on this topic is still limited, due to its novelty.

This study examines the affordances of 360 video mediated field-based experience to support prospective secondary teachers' (PSTs') reflection on their own teaching, in the context of a capstone course *Mathematical Reasoning and Proving for Secondary Teachers.* We examine two research questions:

(1) What do pre-service teachers notice when watching 360 video recordings of their own lesson enactment?
(2) What do prospective teachers learn from reflecting on 360 video recordings of their own teaching?

THEORETICAL PERSPECTIVES

The use of video to support practice-based teacher education

Video has been used in mathematics teacher education to ground the preparation of future teachers in practice and to bridge between university coursework and classroom practice (Ball & Forzani, 2010; Brophy, 2004; Grossman, 2005). In a review of 225 studies (not limited to mathematics) which examined the use of video in teacher education, Gaudin and Chaliès (2015) identified two common goals for the use of video: (1) building practical knowledge of how to act in a classroom, and (2) building knowledge of interpreting and reflecting on recordings of teaching and learning.

Several features of video make it particularly valuable and suitable for these purposes. While capturing the complexity of instruction, the video can make practice accessible and manageable, for example, when specific sections of video are carefully chosen by instructors to highlight particular aspects of practice. The video allows the viewer to slow down and repeatedly observe a classroom situation to understand, interpret and reflect on various elements. This process helps to activate teacher knowledge and make connections between the observed events with personal experiences and with theoretical concepts that prospective teachers learn in their university classrooms (Blomberg et al., 2013; Rich & Hannafin, 2009; Santagata et al., 2005).

Blomberg et al. (2013) describes a variety of ways and pedagogical approaches in which video has been used in mathematics teacher education. They note that despite providing a window into teaching practice, watching a video of someone else teaching can generate a feeling of being unrealistic and unrelated to the PSTs' experiences; thus, the videos might not spur prospective teachers to reflect on their own beliefs and practices, defying the purpose of the activity (Abell et al., 1998). Blomberg and colleagues conclude that, whenever videos of prospective teachers' own practice are available, they stimulate meaningful reflection more effectively and provide more substantial opportunities for teachers' professional growth.

Reflection

Becoming an expert mathematics teacher is a career-long process, which involves conscious reflection on one's experience and intentionally seeking improvement. Moore-Russo and Wilsey (2014) maintain that helping prospective teachers develop reflective practices is one of the goals of

teacher preparation programs. Schön (1987) distinguished between two types of reflection. *Reflection-in-action* refers to a spontaneous, rapid response to a situation at hand that occurs during the moment of instruction. *Reflection-on-action* occurs after the action and involves a careful and critical deliberation on practice (Anderson, 2019; Postholm, 2008). But learning from reflection requires looking forward as much as looking backward, not to get stuck on past experiences, but to develop "new understandings, greater insights and/or greater responsibility for future actions" (Anderson, 2019, p. 2). Some scholars consider this a third type of reflection: *Reflection-for-action* (Jay & Johnson, 2002; Moore-Russo & Wilsey, 2014; Wilson, 2008). This process occurs when teachers connect their past and present experiences with theoretical ideas and develop personal theories for acting in particular types of classroom situations (Killion & Todnem, 1991).

According to Dreyfus and Dreyfus (1986), novices tend to act somewhat mechanistically, by following scripts. As they become more aware of their environments, teachers reflect on their practices and grow in proficiency, they think more analytically about their actions. For experts, this analytical knowledge is an internalized part of their intuition, such that "experts know what to do based on mature practised understanding" (Postholm, 2008, p. 1720). While much of teacher knowledge is tacit and unconscious (Polanyi, 1967), it is critical to put it into words so it can become an object of conscious reflection that can be shared and used as a reference for action (Dewey, 1933; Postholm, 2008). Thus, for a video-based reflection to be conducive to learning, prospective teachers need to reflect on it in either written form or by discussing video with others. Working with in-service teachers, Sherin and van Es (2005) as well as Borko et al., 2008 found that watching and discussing video excerpts with peers helped teachers develop shared language for describing and analyzing student mathematical thinking and teaching practices. This, in turn, fostered productive conversations among teachers and improvements in instruction. Shepherd and Hannafin (2009) describe how written reflections on various artifacts of teaching in the electronic portfolio format supported prospective teachers' developing reflective practices, helped them to re-examine classroom practices and plan for future improvements.

However, not every type of reflection is beneficial; purely descriptive, anecdotal, or non-critical accounts of classroom practice, or claims that are not supported by evidence, have limited value for advancing teacher learning. For a reflection to be productive, teachers need to (a) attend to the multiple aspects of classroom environment, such as student thinking and learning, the act of teaching, the subject matter, and the interactions between them; (b) interpret, analyze, and integrate these various aspects; and (c) con-

nect these aspects to past experiences, theoretical principles, and future actions (Davis, 2006; Jay & Johnson, 2002; Moore-Russo & Wilsey, 2014). This description implies a close connection between reflection and the construct of teacher noticing (e.g., Sherin & van Es, 2005).

Noticing

Educational researchers have increasingly recognized teacher noticing as an important aspect of the teaching profession (e.g., Dindyal et al., 2021; Mason, 2002; van Es & Sherin, 2002). The construct of *teacher noticing* encompasses navigating and sense making of the "blooming, buzzing confusion of sensory data" that teachers are faced with every day during instruction (Sherin & Star, 2011). In order to manage this abundance of sensory data, teachers need to focus on elements of the classroom environment that are most likely to support student learning, while leaving or possibly ignoring others that are not as relevant to the lesson (Mason, 2002; Miller, 2011; Sherin et al., 2011).

Although several conceptualizations of teacher noticing have been proposed (see Dindyal et al., 2021 for a recent overview), they share some similarities, and most models include two or three dimensions. Van Es and Sherin (2008) define teacher noticing as having three dimensions: (1) identifying what is important or noteworthy in a classroom situation, (2) reasoning about the noticed events, and (3) making connections between events and broader principles of teaching and learning that they represent. Other three-dimensional models of noticing have components of attending / perceiving, interpreting, and deciding how to respond (Jacobs et al., 2010; König et al., 2014). Still, other researchers conceptualize noticing as having only two components: attending and interpreting (e.g., Goldsmith & Seago, 2011; Stockero, 2021).

In this study, we adopt a two-dimensional model of noticing with the components of attending and interpreting. The *attending* dimension signifies what teachers deem as important or noteworthy in a classroom that deserves further examination. Not all teachers perceive the same things in a particular classroom situation. Since perception and cognition are interdependent, what one sees or does not see in a particular situation depends on the persons' knowledge, expectations, and beliefs; therefore, novices often perceive less than or different things than experts do (Scheiner, 2021; Schoenfeld, 2011; Sherin & Star, 2011). The second dimension of noticing is *interpretation*, or reasoning about the perceived event. Teachers rely on their knowl-

edge and expertise to reason about classroom situations; hence, prospective teachers often find it difficult to make sense of classroom events.

The two dimensions of teacher noticing - attending and interpreting - are closely aligned with the first two components of productive reflection, defined above. In line with that definition, we consider connecting to broader theoretical principles of teaching and learning as an aspect of productive reflection, or reflection-for-action. Scheiner (2021) cautions against thinking about perceiving and interpreting as sequential processes, suggesting instead that they occur simultaneously and immediately through an embodied experience in an environment, even if verbalizing what one perceives and interprets may require a more deliberate effort. On the contrary, connecting the noticed events to broader theoretical principles is a conscious, analytic process belonging to the realm of reflection.

The processes of reflecting on one's own teaching and noticing are closely related to and develop in tandem through experience. To support the co-development of these processes, prospective teachers need structured opportunities to notice and reflect on the aspects of their own teaching. Video technology, in particular 360 videos, seem to offer unique affordances in this regard.

360 videos for supporting noticing and reflection

The use of 360 technology is an emerging avenue of inquiry within mathematics teacher education. Ibrahim-Didi (2015) argues that standard video tools "do not provide the spatial and temporal situatedness required to help preservice teachers to draw on their body-based reflective capabilities" (p. 7). On the contrary, a 360 video camera captures classroom events from a single position but in a full 360-degree span, evoking the bodily experience of presence. In addition, the user can interact with the recorded video through controls that allow the viewer to pan and look around in all directions, viewing what happens at a particular moment from multiple perspectives.

The purported advantages of 360 video technology should not be taken at face value. Thus, several empirical studies attempted to establish the affordances of 360 video-supported reflection in comparison with other tools such as more standard, single-view video or just memory recall (Ferdig & Kosko, 2020; Kosko et al., 2021; Walshe & Driver, 2019). Walshe and Driver found that, when compared to simple memory recall, the 360 video assisted prospective teachers to reflect in more nuanced ways upon students' thinking, emotions, and engagement in the mathematics classroom; it also

supported prospective teachers' self-efficacy. While this advantage over memory recall alone is expected, Kosko et al. (2021) found that prospective elementary teachers oriented their written reflections toward student actions more often when reflecting upon 360 videos than standard video. Further, Ferdig and Kosko (2020) established that 360 technology significantly improved prospective teachers' feelings of immersion and presence when compared to standard video alone.

These studies lay an important foundation foregrounding the advantages of 360 video empirically. Our study takes a more open, exploratory approach to examining the affordances of 360 video to support prospective secondary teachers' reflections on their own teaching. In particular, we explored what PSTs notice when watching the 360 videos of their own teaching and what learning opportunities emerged from reflecting on these recordings.

METHODS

The setting

The capstone course *Mathematical Reasoning and Proving for Secondary Teachers* was developed as part of a 3-year NSF-funded research project aimed to enhance PSTs' knowledge, dispositions, and practical skills for integrating reasoning and proving in teaching mathematics (Buchbinder & McCrone, 2020). The study described herein took place in the third year of the project. The course activities were designed to help PSTs crystalize their knowledge of the logical aspects of proof, connect it with knowledge of students' conceptions and with topics from secondary school curricula (beyond high-school geometry). One key component of the course is a field-experience in which the PSTs develop a lesson plan that integrates aspects of proof with a topic from the secondary mathematics curriculum and teach this lesson to a small group of students in local middle or high schools. The lessons are 50-minutes long and take place during school hours.

The PSTs video-recorded these lessons by placing *Gear 360* video cameras on a small tripod on one of the students' desks to capture the full 360 view of the board, the students and themselves. After the lesson, the PSTs returned the cameras to the course instructor, the first author of this paper, who uploaded their video to an online Learning Management System (LMS) and assigned each PST their own video to view and reflect upon. The PSTs' teaching of the lesson and the video uploads happened on the same day.

The reflection assignment consisted of two parts. In the first part, completed on the LMS, the PSTs were asked to watch their video, and about every five minutes pause it and write a reflective comment, with the relevant timestamp. The exact wording of the task was: "Briefly describe what happened in the lesson during this 5-min episode and reflect on either an instance of student thinking that you found interesting in it or on your teaching move that happened in this episode. You should have about 8-9 comments per lesson."

The LMS allows for watching the 360 video recording in one of the two modes: static and dynamic (Figures 1 and 2, respectively) and write comments below the video noting a timestamp. Once the comment is posted, the time stamp becomes a live link to a particular episode of the video. In the static mode (Figure 1) the PST viewed two circles, each showing a 180° view of the classroom. The image in Figure 1 shows the PST who approached a table with five students sitting around it. Note, the student in the middle of the image is captured by both lenses; the student on the far right and far left sides of the image is the same person.

Comment 4 4:40 In triangles 2 and 3, the transformation looks like a reflection at first, which one student said, but then other students said it couldn't be. The reasoning they gave for it not being a reflection is because the colors of the sides didn't match up. I think this is very important that the student realized this. The reason I know it is not a reflection is because the perpendicular bisector of the angles didn't match up, but they wouldn't know that, since I never gave them the formal definition of rotation yet. The fact that they realized the congruent sides (colors) wouldn't be lined up made me happy knowing that they were thinking about the congruency aspect of rigid motions. Also, they understood they needed to use a rotation and translation here.

Figure 1. Static view of two 180° lenses, with the accompanying reflective comment made by the PST about the video episode with 4:40 time stamp.

The dynamic viewing mode showed a single view, but which could be moved around with the computer mouse to access the 360° view, as indicated by the icon in the bottom right corner of the screen (Figure 2). The PSTs could switch between the two modes of viewing at any moment, as they wished.

Figure 2. Dynamic view of 360° video.

After commenting on the video, the PSTs completed the second part of the reflection assignment – a written report with the following prompts:

1. Reflect on the aspects of your lesson specific to reasoning and proving: How did you integrate reasoning and proving in your lesson? Do you feel that at the end of the lesson students understood some of these ideas? How do you know?
2. In what ways did you engage students in making sense of mathematics?
3. What aspects of students' thinking did you find particularly interesting / surprising?
4. On the scale 1 (low) – 5 (high) evaluate your own performance in the lesson. Explain.
5. Identify two episodes in your lesson, 2-4 minutes each; provide time stamps. Episode 1: a part of the lesson, which went very well (in your opinion). Explain why you chose this episode. Episode 2: a part of the lesson that you think did not go as well as you hoped it would. Explain why you chose this episode.

To ensure that the events of the lesson were fresh in the PSTs' minds, they were given only three days to complete all parts of the reflection report. During the capstone course, each PST completed four such planning-teaching-reflecting cycles, approximately once every four weeks. The mathematical content of the lessons was requested by the cooperating teachers in whose classrooms the PSTs taught. A particular aspect of proof, which the PSTs integrated in their lessons, was tied to one of four course modules: (a) direct proof / argument evaluation, (b) conditional statements, (c) quantification and the role of examples in proving, and (d) indirect reasoning. It is important to note that this capstone course was the only one in the teacher preparation program, which had a field-based component. Prior to this course, the PSTs had no classroom teaching experience. The classroom teaching was intended to be a learning experience for the PSTs; thus, their classroom performance was not assessed. However, the reflection reports were graded and comprised 30% of the course grade.

Participants and Data Collection

The PSTs participating in the study were nine seniors in the Mathematics Education program at a Northeastern US public university. All but one PST were female. Prior to this course, the PSTs completed the majority of their mathematics coursework, including a course on mathematical proof, and two courses in mathematics education.

The main sources of data for this paper were the PSTs' reflective comments on the 360 videos. Secondary data sources were the written reflection reports, as described above, and the summative essay in which the PSTs reflected on the course as a whole. The prompt in the summative essay that provided a source of data for this study asked the PSTs to write about how watching the 360 video recording of their own teaching and reflecting on it contributed to their learning in the course.

The data for this paper came from the course module: *Quantification and the role of examples in proving*. This module was chosen as the focus of analysis for a few reasons. One, this was the third module in the course, so at this point in the semester, the PSTs were proficient with setting up the 360 cameras and using the LMS to reflect on their lessons. They also overcame the initial surprise of how their voice sounded on camera and were not distracted by this. The second reason was that this was the module with the highest number of lesson plans that were ranked by the research team as having high potential for engaging students with reasoning and prov-

ing (Buchbinder & McCrone, 2020). Of the eight lesson plans developed by the PSTs for that proof theme, five had high potential for engaging students with reasoning and proving, one lesson plan had some occasional opportunities for student engagement with proof, and two lesson plans had only minimal connection to the proof theme. The high number of potentially strong lesson plans made the module *Quantification and the role of examples in proving* an interesting one to analyze in terms of PSTs' reflections on the enacted lessons and their takeaways from them.

Data analysis

The analysis progressed in several steps. The *Gear 360* cameras automatically generate video files of about 11 minutes long (2 GB of data), resulting in about 4-5 clips per each PST's 50-minute lesson. The total number of video segments analyzed was 41.

First, the research team watched all PSTs' video clips and made detailed notes, about one comment per minute, of the observed features of the lesson, noting the relevant time stamps. These comments concerned aspects of video, such as: the mathematical content of the lesson, teacher moves and interactions with students, and studens' interactions with the content and each other. The goal of this coding was not to create an exhaustive list of observable features, but to record the salient features in the video that could have been commented by a PST. Then, we overlayed our notes with the comments made by the PSTs in the LMS, using their timestamps, so that the two sets of comments could be viewed side by side. To the resulting tables we added data from the PSTs' reflection reports and summative essays. Such tables were created for each of the nine PSTs.

Next, we conducted two separate rounds of coding, one for each research question. To answer the first research question we analyzed the data for recuring themes to determine what the PSTs' noticed while watching the 360 videos of their teaching. With the literature on teacher noticing in the background of the analysis, we chose to let the data speak for itself and relied on open coding and constant comparison method associated with the grounded theory approach (Miles et al., 2018; Strauss & Corbin, 1998; Yin, 2015). Due to the novelty of the 360 video technology, it was important for us to keep an open mind about the types of categories of noticing that can arise from the analysis.

Once the categories of noticing were clearly defined, we re-reviewed all the PSTs' comments to verify that they were properly categorized. The

unit of analysis was a single comment, hence it could have multiple codes associated with it; but if a certain code appeared more than once in a single comment it was counted only once. This coding procedure generated a total of 146 coded instances. The average number of codes per PST was 16.2 (SD=4.6) ranging from 10 to 23 codes for PSTs.

Table 1 summarizes the seven categories of PSTs' noticing with examples of coding. The key words associated with the coding category in each example are bolded; the words in square brackets are added for clarification; all PSTs' names are pseudonyms.

Table 1

Categories of Noticing in 360 video

Category & Description	Example	Explanation of Example
Mathematical Content PST reflects on specific mathematics of their lesson and provides a rationale for including a particular content in the lesson.	**I am explaining that** the ways you prove and disprove existential vs universal statements is flipped… **I wanted the students to see that** when you are trying to show that something is either true for all elements (universal) or it does not exist for any element (existential), you have to use general terms since you are showing it applies or does not apply to all elements. **I think that showing this connection was important for the students to understand conceptually,** why this is the way you prove or disprove these types of statements. (Gemma: Video 1, Comment 11:25)	The PST, Gemma, explains why it is necessary to include an explanation in the lesson on how to prove/ disprove existential and universal statements.
Teaching of Content The PST reflects on how they taught the lesson. This could be a critique or a praise.	We had just finished the notes and moving into the activity with the transformations of congruent triangles. I made a comment to the students asking if they remembered what congruent means. One student said that it means everything is equal. I said "yes, so all the parts are congruent". So, although his definition is a good description of congruent images being "equal" **I did not go on to elaborate or give a formal definition for a refresher. Me saying all the parts are congruent doesn't help them because** I used the word congruent in the definition. **I should have taken a moment with them to explain better and not just quickly brush it off and not give them a valid definition.** (Bella: Video 1, Comment 9:17)	The PST, Bella, critiques the mathematical language she used to describe the meaning of congruent triangles. Bella explains why her teaching move was not helpful to a student and how this specific teaching moment could have been improved.

Category & Description	Example	Explanation of Example
Interaction Between Teacher and Students PST reflects on a specific interaction with a student or a group of students.	**I asked Ethan** how he is doing on the problem, and he responds with "I don't really know", so I try to prompt him by asking him what theorems he could use to prove the two [triangles] are congruent… **I liked the way I led his thinking here. I think I did a good job of prompting him but not overstepping and letting him think.** I couldn't really walk away, but **there was a point where I stopped prompting him and let him work by himself for a bit.** (Sylvia: Video 1, Comment 3:05)	Sylvia describes a specific interaction with a student and her approach to helping the student to get started on the problem, while providing him a space for autonomous thinking.
Interaction between Students PST reflects on student conversation they overheard, focusing on a specific detail of students' answer or their understanding.	As I was standing there, **I heard one of the students say** that there were no triangles with altitudes that lie outside of the triangle, **but another student showed** her a picture of an obtuse triangle and explained. The student immediately remembered learning that and understood. **I think group work is great because there may be things students need a reminder about and students can learn and teach each other.** (Gemma: Video 2, Comment 8:10)	Gemma summarizes an interaction between two students she overheard but was not a part of. Gemma reflects on the importance of student-to-student engagement.
Class Discussion The PST reflect on how a class discussion helped or did not help the students to understand the lesson.	I ask the difference of the "all dogs statement" and "there exists" statement and multiple students knew the difference but they did not know how to put it in words. **I thought we had a good discussion because multiple students participated and tried to add on to each other's comments and they were able to tell me the difference together.** I thought it was nice seeing them help each other out and try to communicate their thoughts to me. (Wendy: Video 2, Comment 2:50)	Wendy reflects on a class discussion of the difference between universal and existential statements using a real-life example. She notices students' difficulty putting their thinking into words, multiple students' contributions, and the eventual success through a whole class discussion.

Category & Description	Example	Explanation of Example
Student Participation The PST reflects on student participation either individual or group, commenting on how it impacted the lesson.	Since I only had three students, **I wanted them all to participate** with answering the questions. **One student seemed a little more shy and did not volunteer to answer some questions.** While she was working, I saw her work was correct so I called on her when I knew her work was correct so that she would not be too nervous to answer if she didn't know her answer was correct or not. I think it is important for students to feel comfortable answering questions and be okay with getting answers incorrect, because it allows for them and others to learn from their mistakes. (Sylvia: Video 3, Comment 6:03)	Sylvia reflects on an individual student's participation. She notices a student is timid and, knowing that the student is correct, decides to call on this student. Sylvia comments on the importance of students feeling comfortable with participating.
Student Knowledge and Understanding The PST reflects on students' knowledge or understanding and explains how it affects the lesson.	The students are still working on the same part of the worksheet, isolating the variables and deciding if the equations are equivalent. **They struggled more with this than anticipated and I had to devote more attention than planned to help students successfully complete the steps.** In this moment, a girl who has already completed two [equations] correctly was struggling and because she didn't know the answer called herself stupid. I attempted to quickly redirect this comment as she was actually doing a good job in regard to the fact that **they hadn't done this material in a year.** (Francesca, Video 1, Comment 11:00)	Francesca noticed that students struggled more than she had anticipated, due to insufficient or fragile prior knowledge of the material, which affected the time spent on the task being longer than planned.

For the second round of analysis we reviewed the same set of data tables but with a different lens. In order to respond to our second research question, we developed a set of categories describing learning opportunities of the PSTs afforded by 360 video reflection. To develop these categories we relied on the literature on noticing and reflection.

The first category of learning moments is *making a decision in the moment*, which describes PSTs responding to unexpected events in the classroom which required changing the original lesson plan. This category corresponds to Stockero & Van Zoest's (2013) 'pivotal teaching moment', defined as "an instance in a classroom lesson in which an interruption in the flow of the lesson provides the teacher an opportunity to modify instruction in order to extend or change the nature of student mathematical thinking" (p. 127). The second category of learning - *reflecting on student understanding*, corresponds to noticing students' mathematical thinking, which is gen-

erally considered a central aspect of teachers noticing expertise (cf. Barnhart & van Es, 2015; Santagata & van Es, 2010; Star & Strickland, 2008). Another category of PSTs' learning is *reflecting on one's own teaching in relation to student learning.* This category corresponds to the 'extended' level of noticing in Van Es's (2011) framework for learning to notice student mathematical thinking: "attending to the relationship between teaching strategies and particular students' mathematical thinking" (p. 139). A related category of learning was *critically assessing pedagogical choices*, which is an instance of a PST reflecting on a particular event in the classroom and assessing how his/her handling of the situation affected student mathematical learning. The difference between these two categories is that the latter contains an evaluative stance the PSTs take when making a reflective comment.

Two additional categories of PSTs' learning opportunities are *connecting to a general pedagogical principle* and *contemplating an alternative teaching move*, which are central activities of productive reflection (Davis, 2006; Jay & Johnson, 2002; Moore-Russo & Wilsey, 2014), suggesting that a teacher extends beyond the boundaries of what happened in the classroom to broader contexts and principles. The six categories of learning opportunties are illustrated in Table 2.

Table 2

Categories of PSTs' learning from 360 video reflection

Category & Description	Example	Explanation and Context
Making a decision in the moment The PST reflects on a specific decision they had to make during the lesson, due to an unplanned classroom event. The PST reflects whether their move was productive or not and explain why.	We are working on the first proof of question 1 and I ask students "What happens when I subtract the 5x on both sides?" Students shout you get x, 0, and x2. **Since I was hearing various answers,** I called on each student to tell me what they think you obtain when you subtract 5x-5x. However, students were still thinking about the question and not all students were participating. **I think I made the correct teacher move when I decided** to take a vote to see how many people thought it was x, 0, or x2. . . I separate the 5 and x from itself so students can focus on them separately. All students knew 5-5 was zero. When I wrote x-x students now agreed it was 0 or x. **For the student's level of understanding, I think I made the correct move by** not going into a mini lecture explaining why x-x is 0. Instead, I had them think about plugging a number in and letting x=2. Students understood 2-2 is zero… **It was essential to intervene and assist students** because this led to them being able to prove the conjecture. (Pam, Implementation Report)	Pam was reviewing a problem on the board with the students. When asking about a specific step, the students offered various answers that surprised her, and led her to divert from the original plan. Pam made an in the moment decision to hold a short discussion about subtracting variables. Pam provides the rationale for her decision and explains how it helped students to understand the question.

Category & Description	Example	Explanation and Context
Reflecting on student understanding The PST makes a comment about a student or a group of students' understandings**.**	Funny enough, this is right after the clip I thought went very well. There appears to be **only one student, who admittedly does not understand the jump from solving the linear equation to deciding that the entire statement is false.** In this clip, I am trying to explain this to her, and I attempt to use the example of 8th graders wearing a red shirt. **I'm not sure if she actually understands,** but she agrees anyway. I'm not sure how I could have explained this to her in another way, or if I should have maybe gotten the other students started on something else, while I discussed with her individually what was going on. (Shelly, Implementation Report)	The PST, Shelly, reflects on a student's lack of understanding of the material in her lesson. The comment mentions what the student does not understand and how Shelly tried to address it. She admits not being sure about the effectiveness of her move and contemplates an alternative move
Reflecting on one's own teaching in relation to student learning The PST notices that a specific teaching move either helped or did not support the student learning. The PST provides the rationale for that.	**A student asks for help** on the first problem. **I decided to guide him through it step by step because** I figured he did not remember how to solve for X. The first problem on the warmup was the most simple one so **it was important for this student to understand the process. I guided him through it** by telling him we have to work backwards, and I asked him "what do we have to get rid of first?" He is able to answer my question and move on to the next step. I ask the same question and he knows the right number to get rid of but doesn't know which operation to use. I told him to think about the opposite of the operation he sees. **Eventually we come to an answer together. Overall, I think going over this problem step by step with him really helped him because** then it refreshed his brain of how to solve for x and he now can move on to the other problems. **Sometimes students need a refresher just to get started.** (Wendy, Video 1, Comment 2:33)	The PST, Wendy, reflects on her interaction with a student who does not recall a procedure for solving an equation. Wendy describes her process of helping the student and explains how it helped the student. Wendy makes a general comment, extrapolating the specific event to supporting students in general.
Critically assessing pedagogical choices The PST reflects on a specific teaching move they did, and either praise or critique their own actions.	**I like the way I asked students** why we can say those four sides are all congruent or we have two pairs of congruent sides, because of the radius, **but I don't like the way** I chose to explain why we can't assume the third side is congruent from the start. I kind of made it sound like we can't say it's congruent at all, but we did prove it to be congruent because of CPCTC. I just wish I made this explanation a bit more clear. (Sylvia, Video 2, Comment 7:00)	Sylvia gets students to notice that two sides of a triangle are congruent because they are radii of one circle. She critically evaluates her next move of not sufficiently explaining
Connecting to a general pedagogical principle The PST makes a general pedagogical claim beyond interpreting a particular classroom event.	**I think these kinds of discussions are very important in a math classroom because** it allows students to see what their peers are thinking about, and they are allowed to discuss what they are thinking. **Also, during these types of discussions,** a student may find that they are not the only one thinking about something in a particular way. Students can find similarities and differences in each other's thinking and learn things from other perspectives that could help them. (Wendy, Implementation Report)	Wendy reflects on a class discussion that occurred during the lesson and explains, in general terms, why these types of discussions are important to have in a classroom

Category & Description	Example	Explanation and Context
Contemplating an alternative teaching move The PST reflects on a particular classroom event and contemplates what could have been done differently to support student learning.	I think the students may have been lost at this point because when I asked them to create a universal statement about congruency in translation, right after we wrote them for reflection and rotation, they couldn't do it. **I thought it would have been enough to give them an idea of two, and then have them write another, but it wasn't. I should have thought about how this is a new concept to them and should have done a better job of explaining. As well as encouraging questions.** (Bella, Video 3, Comment 1:55)	Bella asked her students to come up with their own examples of universal statements. When reflecting on why the students were unable to do the task, Bella takes responsibility for her insufficient support of students' learning and thinks of what she should have done differently.

With these categories in mind, we coded the data for identifying the moments of PSTs' learning. We used the same unit of analysis and coding techniques as in the first round of analysis, for consistency. This process generated the total of 173 instances across all PSTs. The average number of codes per PST was 19.22 (SD=3.9, Range 14 to 27).

RESULTS

The following results are presented by research question. The first question was: What do pre-service teachers notice when watching 360 video recordings of their own lesson enactment? Table 3 summarizes the number and percent of categories of noticing by all participants.

Table 3

Distribution of categories of PSTs' noticing in 360 videos

Types of Categories	Categories of Noticing	Number of codes	Percent	Percent of Category Type
Content	Content	13	8.9%	8.9%
Teaching	Teaching of Content	33	22.6%	45.2%
	Interaction between Teacher and Students	33	22.6%	
Students	Interactions between Students	18	12.3%	26.7%
	Student Knowledge and Understanding	13	5.5%	
	Student Participation	8	8.9%	
Interactions	Class Discussion	28	19.2%	19.2%
Total		146	100%	

The categories of noticing fall broadly into four types: *Mathematical content, Teaching, Students and Classroom interactions*. These categories describe who or what was the object of PSTs' noticing and correspond to Stockero's (2021) categories of *agent* (mathematics, teacher, student (group or individual), as well as student – teacher interactions). The two most frequent categories are *teaching of content* and *interactions between teacher and students*; 22.6% each, collectively accounting for 45.2% of instances of noticing. It is natural that the PSTs, who are in the early stage of learning to teach, pay particular attention to their own actions and their own interactions with the material and with students. This result is also consistent with prior literature (e.g., Sherin & van Es, 2005; Stockero, 2021) that documented teachers' tendencies to focus primarily on themselves and their teaching actions.

We find it interesting that the three categories related to *students* (knowledge and understanding, student participation and interactions between students) collectively comprise 26.7% of the data, which is comparable with and somewhat larger than the category of *teaching the content.* This shows that the PSTs noticed various aspects of student engagement with the lesson.

In addition, three of the categories in Table 3 describe various types of interactions: interactions between teacher and students (22.6%), interactions between students (12.3%) and classroom discussion (19.2%). Collectively, the three categories of interactions comprise 54.1% of all data. During the 50-minute lesson, the PSTs engaged students in multiple activities, such as individual and partner work, mini-lecture, students presenting at the board, and group discussions. Thus, multiple interactions among students and between students and the teacher occurred simultaneously and would not be possible to capture with a single-view camera. Positioning the 360 cameras on students' tables allowed for capturing video and audio of the PSTs and the students 'around', and seem to positively affect the PSTs' ability to notice various types of interactions in the lesson.

Our second research question concerned the PSTs' learning from reflecting on the 360 videos of their teaching. Table 4 shows the distribution of the categories of PSTs' learning as found in the data.

Table 4
Distribution of categories of PSTs' learning

Categories of Learning Moments	Number of codes	Percent	Range per PST	Mean (SD) per PST
Reflecting on one's own teaching in relation to student learning	58	33.5%	2 - 10	6.44 (SD=2.55)
Reflection on Student Understanding	37	21.4%	1 – 10	4.11 (DS=3.01)
Critically Assessing Pedagogical Choices	36	20.8%	2 – 7	4.00 (SD=1.41)
Contemplating an Alternative Move	17	9.8%	0 – 5	1.89 (SD=1.62)
Connection to a General Pedagogical Principle	14	8.1%	0 – 4	1.56 (SD=1.51)
Making a Decision in the Moment	11	6.4%	0 – 3	1.22 (SD=1.39)
Total	173	100%		19.22 (SD=3.9)

The most frequent category of learning from reflection was *reflecting on one's own teaching in relation to student learning*, representing about one-third of all learning instances. As mentioned in the methods section, this category is parallel to van Es's (2011) 'extended' level of teacher noticing, where teachers notice the relationship between their pedagogical moves and student mathematical thinking. Our PSTs were novices, with this lesson being only the third they had taught to school students; thus, we do not claim that our PSTs have advanced to an 'extended' level of noticing. Rather, we hypothesize that the ability to view both themselves and how the students react to their pedagogical moves was supported by the 360 video technology allowing the PSTs to engage with this level of reflection. This is how one PST, Francesca, described this feature in her summative essay:

> With the cameras, I was able to go back and see not only how I presented the material but also how students responded. In the moment, it is difficult to process or catch everything that is going on, but the camera allows for my ability to do that, giving me the opportunity to reflect on each individual part of the lesson even when I wasn't able to in the moment.

The other two most frequent categories of PSTs' learning opportunities were *reflection on student understanding* (21.4%), and *critically assessing pedagogical choices* (20.8%) – a category in which PSTs provided critical evaluation of their own pedagogical work. One's ability to reflect critically on their work is necessary for productive reflection (Moore-Russo & Wilsey, 2014), i.e., reflection that has a potential to advance PSTs' pedagogical expertise. Although not represented in all PSTs' reflections and of lower frequency, the categories of *connecting to general pedagogical principles and contemplating an alternative pedagogical move,* were still present in our data, suggesting additional aspects of deep and productive reflection of the PSTs on the 360 videos of their lessons, akin to the reflection-for-action (Wilson, 2008).

In the summative essays the PSTs expanded on how watching the 360 video and reflecting on it in writing helped them to improve from one lesson to another. In particular, the PSTs emphasized the ability to listen to students, notice student discourse, which they missed during the lesson, evaluate their actions, and draw conclusions on how to improve. Wendy's comment illustrates these ideas:

> I thought the video recording was helpful in our reflections, because during the lesson you do not pick up on some of the things you did but watching it back, you can see your good moments and your mistakes. In addition, I found that I could listen to students' ideas even if I did not get to hear them during the actual lesson. The videos also helped me realize what needs to be changed in the next lessons and how to better deal with students and answer their questions. I found that a lot of the time when I was watching my recordings, I would think to myself "Oh I could have done that this way instead."

Another PST, Pam, emphasized how the combination of 360 video recording and writing a reflective report contributed to her learning:

> The reflection reports allowed me to think about the video and my teaching and develop a greater understanding of my lesson. It was a learning experience to teach the lesson, but a great deal of learning occurred watching the videos because I could analyze my lesson in depth. I am now more aware of my actions and the ability to self-critique.

DISCUSSION

In our study, we provided PSTs with a unique, 360 video-mediated teaching experience intended to support their self-awareness and professional growth through reflection on their own practices (Borko et al., 2008). The results of our study support the multi-layered nature of the reflective noticing described in the literature (e.g., Moore-Russo & Wilsey, 2014). As the PSTs taught their lessons, they engaged in reflection-in-action, noticing certain things in the moment, from the point of view of a teacher. This is evidenced by some PSTs deciding to adjust their plans during the lesson, with respect to student responses (Tables 2 & 4). Naturally, as Stockero (2021) alluded, the visually accessible aspects of the lesson for the PSTs were the students, their interactions among themselves and with the mathematical content of the lesson. The temporality and the intensity of the events were at their maximum. Thus, it is not surprising that despite teaching only small groups of students, the PSTs admitted their inability to capture every aspect of student thinking, interactions, or behavior. Some PSTs wrote in their reflections that even though they were aware of certain aspects of their lessons as they occurred, they were not able to reflect on them in-depth, in the moment. This illustrates the difficulty of the novices to reflect-in-action (Anderson, 2019; Schön, 1987) and the need to support their learning from teaching. The most important opportunity for reflective noticing occurred, therefore, when the PSTs watched the 360 videos of their lesson, pausing every few minutes to write a reflective comment, as required by the reflection report guidelines. The combination of reduced temporality and the ability to watch 'simultaneously' themselves and the students, necessarily led the PSTs to notice additional and somewhat different things than they did while teaching the lesson. This is evidenced in the PSTs' summative reflections on the utility of 360 video, and in the variety and richness of categories of noticing revealed in our data.

It is important to point out an inherent limitation of relying on written comments, as opposed to, for example, using think-aloud protocols, as PSTs watch their video in real time (Cowan, 2019; Walshe & Driver, 2019). Given that the PSTs watched the 360 videos on their own, we only have access to what they chose to comment on in writing, making the data self-selected, affected by the PSTs' personal writing styles and the open nature of the LMS video annotating tool. On the other hand, it can be argued that even though the PSTs may have noticed more than they chose to write about, their choices indicate what they deemed worthwhile to reflect upon.

Our data, illustrated in Tables 1 and 2 suggests that the PSTs went beyond merely describing the classroom events, but analyzed and reflected on

them. Although purely descriptive comments were present in our data, they were infrequent, with most comments containing the two aspects of noticing: attending and interpreting (Davis, 2006; Goldsmith & Seago, 2011). The data presented in Table 3 show that PSTs attended to and interpreted various aspects of their lessons, such as types of classroom interactions, student understanding, and the relationship of pedagogical moves to student learning. These categories of PSTs' noticing resemble the categories reported in the literature on prospective teachers' noticing in the video of others (Star & Strickland, 2008; Stockero, 2021) as well as categories of noticing of in-service teachers analysing their own videos (Sherin & van Es, 2005). In other words, the PSTs noticed aspects of teaching pertaining both to their own teaching and to their student learning. We attribute this to the affordances of the 360 video technology and the unique opportunities for noticing that it provides.

Of particular interest are what we called 'categories of learning' (Table 4), which are the instances of the PSTs' productive reflections. As noted in the theoretical perspectives section, productive reflection entails attending to multiple aspects of classroom environment (students, teaching, subject matter, and the interactions between them), interpreting these aspects and connecting them to past experiences, theoretical principles, and future actions (Davis, 2006; Jay & Johnson, 2002). The PSTs' categories of learning in our study match the characteristics of productive reflection, both on-action and for-action (Moore-Russo & Wilsey, 2014; Wilson, 2008). In addition, the results of our study concur with those of Walshe and Driver (2019) who showed that the use of 360 video supported PSTs' reflection on their practice, and contributed to developing more nuanced understanding of their teaching and a sense of self-efficacy.

We attribute the results of our study to the unique design features of the PSTs' teaching experience. The most important feature was the use of the innovative, 360-degree video technology, which afforded the possibility to examine one's teaching from multiple perspectives and attend to aspects of classroom practice that otherwise, would not be visible. Another design feature was that the PSTs taught a group of students, as opposed to a whole class, making the teaching experience more intimate and manageable for novices. This type of setting was also more conducive to the use of 360 video cameras, which captured the PST and all the students they taught. Other design features included the use of the full-length, 50-minute videos and the recording of the PSTs' own teaching. The majority of studies on reflective noticing of prospective teachers use videos of practicing classroom teachers and/or shorter video clips, and almost never have both of these

features (Blomberg et al., 2013; Brophy, 2004; Gaudin & Chaliès, 2015). Stokero (2021), for example, had PSTs analyze videos of a full classroom period, but those videos were "recorded from a front-of-classroom teacher perspective, since that is the perspective from which teacher noticing takes place" (p. 77). While our study also used a whole-class-length video, we extended the range of pesrpectives of teacher noticing to include both the students and the teacher – the PST – by utilizing the 360-degree video cameras.

The results of our study concur with Ferdig and Kosko's (2020) finding that watching 360-degre videos, even on a two dimensional computer screen, adds additional value to PSTs' noticing abilities over watching a standard, single perspective video. Although the nature of our research is such that it does not involve a control group, we assert that providing similar viewing (learning) opportunities, without the 360 technology would be close to impossible. Capturing the teacher, the board and the students would require using multiple single view cameras per PST or a videographer who could move the camera to focus on individual students. This would be costly, impractical and potentially stressful for the PST and the students. Whereas in our study, the PSTs set the cameras and recorded the lessons themselves, keeping the unwanted interactions to a minimum; some PSTs even indicated their surprise by how quickly their students became indifferent to the presence of the cameras on the tables.

IMPLICATIONS AND FUTURE DIRECTIONS

The ability to notice (attend and interpret) multiple aspects of classroom interactions, and the ability to engage in productive reflection on teaching are associated with teachers' professional growth (Dindyal et al., 2021; Jacobs et al., 2010; Sherin & van Es, 2005; Tripp & Rich, 2012). The results of our study suggest that the unique 360 video mediated teaching experiences afforded the PSTs rich opportunities to engage in refelctive noticing on their own teaching contributing to their professional learning. Thus, one implication for teacher education programs would be to utilize 360-video technology during practice-teaching experiences, thus affording the PSTs unique opportunities for reflection and noticing.

Although our study is small scaled and localized to a particular course, it illustrates the possibilities and advantages of 360 video mediated field experiences and their potential to promote teacher learning. By this our study helps to expand the body of knowledge on the use of video in practice-based

teacher education in general, and contributes to the novel branch of applications of extended reality in teacher education.

The affordances of 360 video technology open interesting avenues for future research. For example, what cognitive mechanisms underline teacher learning in the extended reality environments? A situated learning perspective on teacher learning (e.g., Borko et al., 2000; 2008) and embodied cognition (e.g., Fugate et al., 2019; Ibrahim-Didi, 2015) suggest promising directions to exploring this question. For us, as mathematics education researchers, this innovative 360 technology opened new avenues to study PSTs' reflective noticing and learning in general. In this paper, we focused on the analysis of the PSTs' own perspective on their learning. However, having access to all the 360-degree views of the classrooms, we can analyze PSTs' teaching and the corresponding student learning (or the lack of therof) from the observer perspective (see Buchbinder & McCrone, 2020 for an example of such analysis) and then compare and contrast the two perspectives.

Other important implications of our study pertain to the specific design elements of 360 video mediated learning environments. For example, in our study, the PSTs reflected on their own videos by using the commenting feature of the LMS tool. However, there are other, more advanced video commenting tools (see Rich & Hannafin, 2009 for an overview). Using video annotating tools that allow recording audio comments or tools that synchronize the video with the lesson plan could support PSTs' reflection in additional ways. This can enrich learning opportunities for PSTs and generate richer research data.

In our study, each PST reflected on their own video individually. In addition, we asked the PSTs to choose two short clips from each lesson for instructor feedback. During portfolio presentations in the final week of the course, we asked the PSTs to share some of these clips with their peers. Future uses of this technology in teacher education programs should explore opportunities to expand this model, for example by including peer-reflection, and/or group analysis of 360 videos akin to the video analysis strategies used with standard single perspective video (e.g., Blomberg et al., 2013; Santagata et al., 2005; van Es & Sherin, 2008). Such experiences supported by 360 technology may bear unique learning potential for future teachers.

Finally, the study reported in this paper examined one out of four lessons taught by PSTs in the capstone course. As we continue to analyze the rest of the videos, we ponder whether it is possible to trace how the PSTs' reflective noticing abilities evolved over time. The noticing literature (e.g.,

Jacobs et al., 2010; Simpson et al., 2018) has mixed results on whether the teaching experience, targeted interventions or some combination of those contribute to the development of professional noticing. Future studies should examine this question as well as the question of the long-term implications of 360 video mediated field experiences on developing teaching expertise.

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