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ORIGINAL PAPER

Implementing 360 Video to Increase Immersion, Perceptual Capacity, and Teacher Noticing

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Abstract
Although it is a relatively new innovation, 360 videos have gained commercial and public popularity. Given their novelty, there is a relative dearth of studies on their effectiveness. Most of the existing research is published as technical articles dealing with standards and specifications, as theoretical pieces promoting the potential value, or as descriptive experiences and resulting factors. Such work is arguably needed, but the field lacks deep research basis for justifying and clarifying the implementation of 360 video into practice. This article reports on a study exploring 360 videos for improving elementary mathematics teacher education. The results of the empirical study show improved immersion, presence, and video evaluation from using 360 video. Additionally, participants who viewed the videos on virtual reality headsets demonstrated increased attention to mathematical strategies in the context of teaching, demonstrating the potential usefulness of 360 headsets for perceptual capacity and teacher noticing.

Keywords 360 video · Perceptual capacity · Noticing · Mathematics teacher education

Introduction

A digital innovation called 360 video has emerged that has gained recent commercial and public popularity. The 360 video, also known as an immersive video, records a spherical view of an environment. Unlike traditional videos where the field-of-view (what is being recorded) is pre-set by the videographer, or even new cameras that follow a specific person in the environment, 360 cameras record the event from every perspective. Viewers can then move and change their field-of-view to any direction; they have control over the perspective. Figure 1 provides an example of a traditional professional development video (often taken from the back of the room) with one set view determined by the videographer; it also includes a still shot of a 360 degree video of the same classroom.

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Capturing 360 video is easy and affordable. Decent quality cameras run as low as $150; capturing video is as simple as setting it on a tripod and hitting the record button. Replaying videos is both simple and varied. Viewers can watch through regular two-dimensional (2D) laptops, desktops, and mobile devices using traditional web browsers, controlling the perspective through mouse or finger movements. More immersive options include viewing the video with a low-cost (e.g. *Google Cardboard*) or higher-end virtual reality headset (e.g. *Oculus Rift*). Controlling perspective through such devices is as simple as turning one's head, looking left, right, up, or down. Arguably *Facebook*, *Youtube*, and other social networks' interest in and ability to offer such videos have increased their prominence and adoption in society (TaghaviNasrabadi et al., 2017).

Although there has been a surge of interest in the use of 360 videos (Corbillon et al., 2017), there is a relative dearth of studies on their effectiveness. Most of the existing research is published as technical articles dealing with standards and specifications (e.g. Bao et al., 2016), as theoretical pieces promoting the potential value (e.g. Roche & Gal-Petitfaux, 2017), or as descriptive experiences and resulting factors (Elmezeny, Edenhofer, & Wimmer, 2018). Such work is arguably needed, but the field lacks a deep research basis for justifying and clarifying its implementation. For instance, supplemental

Fig. 1 A traditional back of room view (left) compared to a 360 view of that same classroom (right)

technology-based scaffolds have been found to enhance videos and animations' capacity for facilitating professional knowledge (Brunvand & Fishman, 2007; Herbst et al., 2013), but little is known about the impact of such adaptations and enhancements for immersive video experiences.

Additionally, the field lacks studies that explore the use of 360 videos in context. A specific example, and the purpose of this study, comes from the area of teacher education. Videos have been used in preparing preservice teachers (PSTs) in teacher education programs for the past several decades (Grossman et al., 2009), with demonstrated positive effects on their professional noticing (Barnhart & van Es, 2015; Jacobs et al., 2010), and their demonstrated pedagogical content knowledge (Ball et al., 2008). Much of this research has focused on the elementary level, given that many elementary teachers enter undergraduate study with lower levels of *Mathematical Knowledge for Teaching* (MKT; Ball et al., 2008) in various math domains (Izsák, 2008; Thanheiser et al., 2014). Well-prepared teachers have higher MKT scores (Hill et al., 2008) and also have students with higher mathematics achievement scores (Hill et al., 2007).

Although much has been learned investigating PSTs' engagement with various representations of practice, Stahnke et al. (2016) note that much of the literature is divided into assessing either benefits associated with more explicitly conveyed knowledge (i.e., measures of what they have learned in the PST classroom) or tacitly conveyed aspects of knowledge (i.e., how to handle specific a construct in the scenario). However, "research would highly benefit from combining both a cognitive and a situated perspective" (Stahnke et al., 2016, p. 24).

In sum, research is needed that shortens the gap between what pre-service teachers learn about mathematics instruction in the university classroom and what they practice in the field. The use of 360 videos might be able to convey more of the nuance within a classroom scenario, thus providing more support for developing and eliciting both tacit and explicit aspects of professional knowledge. The main rationale for this study was to further explore the positive and negative impact of using 360 video to bridge the gap between theory and practice in mathematics teacher education.

Theoretical Framework

Mathematics Teacher Education

Understanding the professionalized knowledge and skillsets of teachers has been a focus of researchers as early as the 1970s (Borko et al., 2008). Shavelson and Stern (1981) suggested that teachers "make judgments and decisions, and carry them out on the basis of their psychological model of reality" (p. 461), composed of various beliefs about professional practice. Shulman (1987) focused more specifically on a cognitive model of what he described as pedagogical content knowledge. This was later extended upon by Deborah Ball and colleagues in their conception of Mathematical Knowledge for Teaching (MKT: Ball et al., 2008). Specifically, Ball et al.

(2008) suggested that teachers' work requires "coordination between the mathematics at stake and the instructional options and purposes at play" (p. 401).

In developing assessments of elementary teachers' MKT, Ball and colleagues have observed that teachers with higher MKT scores demonstrate higher quality of mathematics instruction than those with lower MKT scores (Hill et al., 2008), and also have students with higher mathematics achievement scores (Hill et al., 2007). Other researchers have developed assessments based on Ball et al.'s (2008) framework, and have observed similar trends in regard to teachers' instructional decision-making (Cengiz et al., 2011; Wahbeh & Abd-El-Khalick, 2014) and their students' academic achievement (Baumert et al., 2010; Kunter et al., 2013).

Unfortunately, various researchers have observed that PSTs' MKT in various domains such as fractions (Stevens et al., 2018) and multiplication/division (Simon, 1993; Thanheiser et al., 2014) is often lacking in sophistication when they initially enter a teacher education program. For example, Stevens et al. (2018) found that many elementary PSTs enter college with part-whole reasoning of fractions, but need focused instruction to engage in more sophisticated reasoning. Likewise, Simon (1993) observed that elementary PSTs typically hold more procedural knowledge and less conceptual understandings of division.

As useful as the literature base is on teachers' professional knowledge, in general, and MKT, particularly, many researchers caution against using such measures as the sole indicator of teacher capabilities (Ball et al., 2008; Hill et al., 2008). Specifically, "the work of teaching, while requiring substantial explicit knowledge (e.g., factual and conceptual mathematical knowledge), also requires important tacit knowledge" (Herbst et al., 2016, p. 79). The literature on PSTs' MKT tends to suggest the importance of *both* explicit attention to their content knowledge (Stevens et al., 2018) *and* practice-based approaches to facilitate their tacit knowledge (Boerst et al., 2011).

Sometimes referred to as situated knowledge (Scheiner, 2016), tacit knowledge is the knowledge that allows individuals to interact in the domain where explicit knowledge must be applied. Consider the example of third-grade students learning multiplication. The teacher must have explicit conceptual knowledge of what multiplication means, as well as the various ways multiplication may be represented, the learning trajectories that students tend to follow developmentally, and so forth. Yet, there is tacit knowledge involved in various situations of teaching multiplication. In a lesson focusing on representing the commutative property with 7×8 is the same as 8×7, a student may suggest that 7×8 is also the same as 14×4, because $7 \times 2 \times 4$. A teacher must rely on their tacit knowledge of mathematics instruction to determine whether they should continue focusing on commutativity, or to take time to discuss the one student's application of the associative property ($7 \times 8 = 7 \times 2 \times 4 = 14 \times 4$).

Variations in Practice

Researchers have attempted to respond to the gap between PSTs' tacit and explicit professional knowledge through various aspects of teaching practice (Boerst et al., 2011; Grossman et al., 2009; Herbst et al., 2016). Grossman et al. (2009) distinguished between three pedagogies of practice: representation, decomposition, and approximation of practice. A *representation of practice* provides PSTs with opportunities to view teaching or evidence of student reason. Common examples include videos of instruction from the Annenberg collection to illustrate teaching of specific topics, or videos of interviews with children from the Integrating Mathematics and Pedagogy (IMAP) collection to illustrate mathematical strategies of students. A *decomposition of practice* engages PSTs in dissecting and analyzing components of teaching. Examples include class discussions of specific videos, as well as annotation technology that allows for the "marking and commenting on" (Herbst et al., 2016, p. 80) videos and animations in an interactive manner. An *approximation of practice* allows PSTs to enact some form of practice in a way that approximates teaching their primary audience, without necessarily engaging them. Variations include rehearsals of teaching (Lampert et al., 2013); written or spoken descriptions (Estapa et al., 2018); and animated representations depicting what happens next (Kosko et al., 2014). For example, Kosko (2014) used a comic-based simulation that engaged PSTs with examining the relationship between a teachers' choice of scaffolding task within a fraction-based task (determining the fraction exactly halfway between 1/3 and 2/3), and how depicted students would react to that task.

A common theme across representations, decompositions, and approximations of practice is the role that technology has taken in enhancing and extending these facets of training professionals. New technology available in the 1950s allowed for the emergence of video representations of practice in teacher education, as a more immersive alternative to written cases (Slingland, 1958). However, producing and locating videos for use in teacher education is expensive in regard to time and resources. This has led to an average of only three videos per course being used by most teacher educators (Christ et al., 2017). In the past decade, comic strips and animations have emerged as an additional representation of teaching practice (Herbst et al., 2013), allowing for representations of practice to be created rather than captured. Although PSTs report a lower sense of immersion when viewing animations instead of videos, they appear to notice more specific details about the mathematics (Herbst et al., 2013). Yet, both mediums incorporate a limited perspective, in that only what the creator has selected is viewable in the representation of practice (Gaudin & Chalies, 2015).

Noticing

Teacher noticing, as an activity, involves identifying aspects in a classroom scenario, relating those aspects to one's professional knowledge and norms, and then applying this interaction "to reason about classroom interactions" at hand (van Es & Sherin, 2002, p. 573). Although the overwhelming majority of research on teacher noticing focuses on what participants interpret or perceive in a scenario, there is a scarcity of research on how to connect PSTs', tacit, situation-specific skills with, explicit, aspects of professional knowledge (Stahnke et al., 2016). Scheiner (2016) noted that many researchers have focused on PSTs' perceptions rather than examining constructs of attention or awareness, suggesting "attention selects certain stimuli of a perceived scene for detailed analysis, while perception goes to build up a certain visual experience" (p. 231). Furthermore, attention is foundational to developing PSTs' awareness in a scenario, and involves coordination between various aspects of one's professional knowledge and contextual resources.

Much of situated awareness involves tacit knowledge of what is occurring in a given context. Endsley (2000) defines situated awareness as understanding what is occurring in your given situation, with the added understanding of what is important in those occurrences. Furthermore, development of situated awareness can be described in three stages. In stage one, individuals develop a basic perception of important information in a scenario. In stage two, individuals begin to integrate and retain information about a scenario in a manner that is relevant to the individual's goals. In stage three, individuals are able to project from a current scenario to anticipate what happens next. These stages correspond with various frameworks for teacher noticing, including Jacobs et al.'s (2010) construct for professional noticing of children's mathematical thinking: attend to children's strategies, interpret children's understandings, and decide how to respond.

The connection between situated awareness and teacher noticing has previously been noted (Miller, 2011), with the current study considering teacher noticing as derived from situated awareness. The main difference in experienced versus novice teachers' professional noticing is the ability to describe specific mathematics and mathematical actions (Jacobs et al., 2010;), Therefore, utilizing technologies and teaching approaches that engage PSTs in more specific and pragmatic professional noticing is essential.

360 Videos

Within the past few years, 360 videos have emerged as a new medium for representing practice, in a manner that allows for a wider range of perspective to be viewed by users (Harrington et al., 2018; Roche et al., 2017; Wereley et al., 2018). Given its relative infancy, many of the published articles on the use of 360 videos address functional aspects from a descriptive perspective (e.g. Ardisara & Fung, 2018), perspectives on their use (e.g. Geng et al., 2018), potential impact (e.g. Reyna Zeballos, 2018), or prototypes for implementation (e.g. Windscheid & Will, 2018).

However, even in its infancy, research on 360 videos have shown promise; Snelson and Hsu (2019) identified 12 studies addressing the topic. For instance, examining the role of 360 video with physical education PSTs, Roche et al. (2017) observed that PSTs appreciated the freedom of changing the perspective of the camera, "as the subject was not constrained by a frame chosen by the video's producer, and so had the possibility to explore the whole situation and understand all the different aspects of the situation" (p. 3423). Choi et al. (2018) examined the use of 360 videos for teaching marine biology; they found increased involvement and engagement. Finally, and perhaps most connected to this study, Walshe and Driver (2019) used 360 video for teacher education. They found "that 360-degree video supports students' reflection of their practice and, as a result, both develops a more nuanced understanding of their microteaching, and supports their self-efficacy. The immersive, embodied experience of watching the 360-degree video footage appears particularly significant as it becomes a proxy for real-life classroom settings through which students are able to re-experience their teaching, emplaced within its space and time, being there in an embodied sense" (p. 103). These studies are promising; however, the field needs additional studies, particularly in teacher education for the ability to bridge the gap between theory and practice. More work is also necessary inside of specific content domains (e.g., mathematics teacher education).

Methods

Participants

Participants included 34 prospective teachers enrolled in an early childhood education program, at a Midwestern U.S. institution of higher education. All participants were first-semester seniors enrolled in the semester preceding student teaching. Participants were solicited from their second mathematics pedagogy methods course, and participated in a 30–45 min session.

Procedures

Participants were randomly assigned to one of three conditions in which they each watched a video of one of three versions of the same third grade lesson focused on informally introducing the Commutative Property of Multiplication. In the first condition (laptop control), participants watched a standard version of the video on a laptop. The viewing perspective in the video was positioned towards the back of the room, and positioned to capture as much of the classroom in one frame as possible. Thus, the viewing perspective was fixed. This matches what is typically recorded and then presented in pre-service classrooms. In the second condition (laptop 360), the video camera was positioned towards the center of the room, but was presented in a 360 video format, so that participants could use a computer mouse to turn the viewing perspective on a laptop or desktop. Thus, the viewing perspective was malleable dependent on a participant's choice. The third condition (headset 360) included the same video as that used in the laptop 360 condition, with participants viewing the video using an *Oculus Go* headset, instead of viewing on a laptop screen.

Prior to watching the video, all participants were given a set of instructional materials used in the video by students (an answer sheet and a set of Cuisenaire rods). They were given these instructions:

This task was provided to students in the video you are about to watch. What pivotal moments do you expect that you may see in the video (list them below)?

After engaging with the materials and recording their response, they watched the entire video (approximately 7 min). Upon completion of the video, they were asked to record any and all pivotal moments they saw in the video. They then watched the full video a second time and then added or updated their list of pivotal moments. The study concluded with participants completing an instrument that was created to measure immersion, presence, and overall evaluation of the video viewing experience.

Measures

Borrowing from Suh and Prophet's (2018) distinctions for cognitive reactions to virtual environments, we created measures for immersion and presence. We adapted items from various studies that sought to measure aspects of immersion and presence involving virtual environments, as well as videos and animations of classroom practice. Inclusion of the latter involved studies comparing regular classroom videos with animated versions of the same episodes, and seemed appropriate for the current study (comparing regular videos with a different medium).

An 18 item survey was created to assess participants' perceived immersion, presence, and evaluation of the video viewing experience (see Table 1). Items were assessed on a six-point Likert scale (*1 = Strongly Disagree; 2 = Disagree; 3 = Somewhat Disagree; 4 = Somewhat Agree; 5 = Agree; 6 = Strongly Agree*). *Immersion*, or a feeling of being in the experience (e.g., Jennett et al., 2008), was assessed with eight items and was found to have sufficient internal reliability ($\alpha = .826$), with item point-biserial coefficients ranging from .38 to .79 providing additional support for the reliability of the measure ($M = 4.86$, $SD = .66$). *Presence*, often described as being in the here and now (Calleja, 2011), was measured with four items focusing on what Suh and Prophet (2018) identified as spatial presence. As with immersion, the presence measure was found to be statistically reliable ($\alpha = .829$), with item point-biserial correlations ranging from .54 to .78 ($M = 5.21$, $SD = .67$).

In addition to immersion and presence, we included six items to assess participants' valuing of the video viewing experience in terms of their professional development. Since the video focused on an episode of third grade multiplication/division, three items included language to assess prospective teachers' perceived valuing of the experience in regard to their professional development. The *video evaluation* measure was found to be statistically reliable ($\alpha = .702$), with item point-biserial correlations ranging from .30 to .62 ($M = 5.07$, $SD = .55$). A complete list of the items, grouped by measure, is presented in Table 1. In general, participants' scores across conditions trend towards agreement. Additionally, statistically significant correlations were observed between immersion and presence ($r = .75$, $p < .001$), immersion and video evaluation ($r = .57$, $p < .001$), and presence and video evaluation ($r = .35$, $p = .041$).

Results

Immersion, Presence, and Video Evaluation

We performed three Kruskal-Wallis tests to compare the distribution of scores across the three conditions for each measure: immersion, presence, video evaluation. Kruskal-Wallis is often referred to as a nonparametric alternative to a one-way analysis of variance (Siegel & Castellan, 1988), and was used in the present study due to the smaller sample size ($n = 34$).

Median scores for the control group (*Median* = 4.00, *Interquartile Range* = 1.00), laptop 360 group (*Median* = 5.00, *Interquartile Range* = 1.00), and headset 360 group (*Median* = 5.06, *Interquartile Range* = .78) were compared. Differences in participants' immersion scores were found to be statistically significant by condition ($H\ (df = 2) = 9.127$, $p = .004$). A Dunn post hoc analysis indicates that the control group (the standard condition) had statistically significant lower scores than the laptop 360 group ($p = .040$) and the headset 360 group ($p = .011$). However, the laptop 360 and headset 360 groups were not found to have statistically significant scores ($p = .613$).

Differences in participants' presence scores were found to be statistically significant by condition ($H\ (df = 2) = 10.943$, $p = .010$). A Dunn post hoc analysis indicates that the control group (the standard condition) had statistically significant lower scores than the laptop 360 group ($p = .035$) and the headset 360 group ($p < .001$). However, the laptop 360 and

Table 1 Items per construct

Construct	Item	Source*
Immersion	I was so engaged in the lesson, that in some cases I wanted to interact with the students/teacher directly.	Georgiou & Kyza (2017)
	I observed students' mathematics during the lesson.	–
	I felt part of the lesson as if I had been there in the classroom.	Friesen & Kuntz (2018) Seidel et al. (2011)
	I saw how students were thinking about the math in this lesson.	–
	I saw what the teacher was doing in the lesson.	–
	I was so engaged that I felt that my actions could affect what was happening in the classroom.	Georgiou & Kyza (2017)
	I felt immersed in the lesson.	Buttussi & Chittaro (2018)
	I forgot the passing of time.	Buttussi & Chittaro (2018)
Presence	I felt this was a genuine representation of an elementary math lesson.	Herbst et al. (2013)
	I felt like I was in the classroom.	Schuemie et al. (2001)
	The video was so authentic that I sometimes thought I was actually in the classroom.	Georgiou & Kyza (2017)
	The classroom situation appeared authentic to me.	Friesen & Kuntz (2018) Seidel et al. (2011)
Video Evaluation	I would like to watch more of these videos.	–
	The video made me think differently about how to teach multiplication/division.	–
	This video made me think differently about how children think multiplicatively.	–
	Videos like this are useful for teaching teachers about how to teach math.	–
	Videos like this are useful for teaching teachers about how children think mathematically.	–
	The video made me think differently about what multiplication means.	–

*Wording of some items were adapted for the context of the current study.

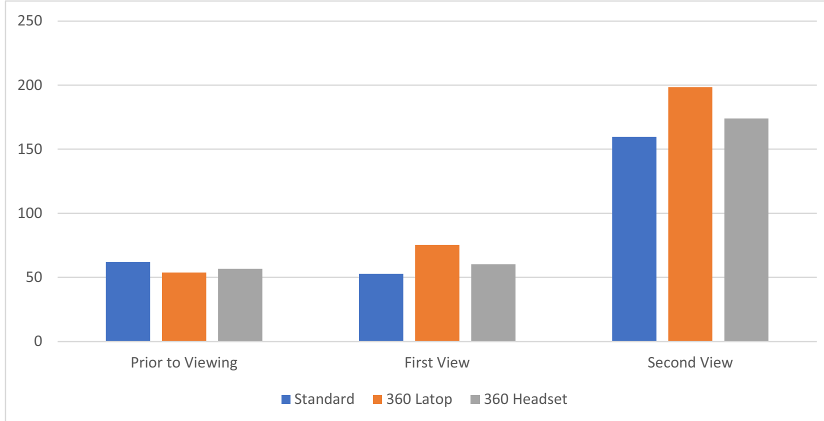
headset 360 groups were not found to have statistically significant differences in scores ($p = .251$). This is reflected in the median scores for the control group (*Median* = 4.50, *Interquartile Range* = .75), laptop 360 group (*Median* = 5.25, *Interquartile Range* = 1.50), and headset 360 group (*Median* = 5.55, *Interquartile Range* = .81).

A comparison of participants' video evaluations was also conducted. Differences in median scores for the control group (*Median* = 4.91, *Interquartile Range* = .91), laptop 360 group (*Median* = 5.20, *Interquartile Range* = .67), and headset 360 group (*Median* = 5.08, *Interquartile Range* = .67) were not found to be statistically significant ($H\ (df = 2) = 1.188$, $p = .552$).

Teacher Noticing

Two aspects of teacher noticing were examined: a) total word count in describing what PSTs noticed; and, b) type of pedagogy noticed by PSTs. For word count, prior to viewing the video, PSTs examined the task students in the video used and described what they expected to notice in the video. This occurred across all three conditions (standard video, 360 laptop, and 360 headset). Average word count was analyzed. Prior to the watching the video the standard condition had a mean of 62.00 words (SD = 9.98), the 360 laptop condition had a mean of 53.73 words (SD = 8.66), and the 360 headset condition had a mean of 56.64 words (SD = 7.94). After the first viewing, participants selected and wrote about what they saw as pivotal moments (what they saw as important in the teaching/learning of math). Both the 360 laptop condition (M = 75.36, SD = 10.63) and the 360 headset condition (M = 60.29, SD = 7.96) outpaced the standard condition in total number of words (m = 52.75, SD = 7.13). After the second viewing, they modified their list and picked two most important moments (and described why those moments were pivotal). Once again, the 360 laptop condition ((M = 198.55, SD = 17.39) and the 360 headset condition (M = 174.00, SD = 24.93) were higher than the standard condition (M = 159.63, SD = 16.77). Figure 2 presents mean word counts across all three conditions.

Fig. 2 Length of description (number of words) in what preservice teachers noticed in the video



Response data were also analyzed thematically. Data were coded to look for student discussion of pedagogy, particularly related (in this case) to mathematics pedagogy. Results suggest that a higher percent of PSTs in the 360 headset condition discussed multiple strategies for solving mathematics (57.1%) compared to the 360 laptop condition (54.5%) and the standard video condition (50.0%). Moreover, students using the 360 headsets consistently identified more specific mathematical strategies. There were higher portions of 360 headset participants who noticed students' reasoning with the commutative property (92.9%) than in the 360 laptop (54.5%) and standard conditions (75.0%). However, participants in the 360 headset condition were the only ones to name the property explicitly. We discuss analysis of this data in a separate study (see Author et al. 2019). Additionally, participants using the headsets were quicker to identify alternative strategies with 35.7% noticing some students' use of 28×2 to solve for an 8 by 7 array after the first viewing of the video (only one student outside of the 360 headset condition wrote about this after the initial viewing).

Discussion

One challenge in preparing current and future teachers is addressing lower levels of explicit professional knowledge, particularly in fractions and multiplication/division (Izsák, 2008; Simon, 1993; Thanheiser et al., 2014). A second challenge is bridging the gap between explicit knowledge (i.e., MKT) and tacit knowledge (i.e., teaching in the classroom). Existing research projects have demonstrated success, particularly with the use of innovative technologies. Unfortunately, most of these projects focus solely on explicit or tacit knowledge, failing to address a combined approach (Stahnke et al., 2016).

An innovative technology known as the 360 video has demonstrated early evidence of its potential to increase involvement, engagement, and perspective-taking. Given this promise, a study was created to test pre-service teacher immersion, presence, video evaluation, and noticing. Participants were separated into three groups that watched a classroom practice video in a traditional format (two-dimensional with a fixed perspective), in a 360 format (using a two dimensional laptop screen), or in a 360 immersive format using a virtual reality headset. There were two important lessons.

First, participants in the 360 groups (using either a laptop or an immersive headset) showed significantly higher results for immersion and presence. This was not surprising given results by other researchers who demonstrated similar outcomes (e.g., Choi et al., 2018; Geng et al., 2018). This study adds to the literature documenting the promise of such work. The study is able to strengthen those findings, however, because data was also examined that measured the evaluation of the videos. The findings suggest there were *no statistically significant differences* in the evaluation of the videos. In other words, regardless of how videos were viewed, participants considered them useful in their teacher education at a similar level. Considering there is ample evidence that standard video is generally viewed as useful for teacher education (Christ et al., 2017; Herbst et al., 2013), these findings suggest that, despite adding complexity to the video-viewing experience, 360 video is similarly valued. Taken together, these results suggest the added complexity of 360 video, via laptop or headset, does not negatively effect the perceived value of such video for teacher education, but yields a higher sense of immersion and deeper sense of presence than traditional video.

One could assume a major implication is that 360 video works, but with little reason to encourage the expense of head mounted displays (e.g. *Oculus Go* headsets). However, the second major finding is that there was a difference between all three groups in noticing. PSTs who used the 360 headsets were more likely to explicitly notice mathematics pedagogy like the commutative property. Moreover, several students in the standard video explicitly noted they could not perceive everything that happened in the lesson, while no 360 video participants reported such a limitation.

Although there are some potential advantages to narrowing the amount of information provided in certain representations, Endsley (2000) notes that there are times when such narrowing is a disadvantage. Rather, there are numerous subtle cues that videos and animations attempt to approximate, but may fail to engage. One subtle cue is the ability of the teacher in a classroom to turn and move toward a table they consider as potentially worthwhile to notice. Even when a video or animation attempt to include the entire classroom in a particular frame, the physical position of the camera perspective advantages events closer to the camera and disadvantages events further from it (Gaudin & Chalies, 2015). We hypothesize that, in certain contexts, such privileging of perspective has the potential to decrease a PSTs' access to the subtle cues described by Endsley (2000). In other words, 360 videos have a higher degree of *perceptual capacity*, or the potential amount of a scenario that can be viewed by a user, than standard videos.

Furthermore, by increasing the range a video's perceptual capacity, we conjecture that PSTs using 360 videos may operationalize more tacit resources described by Endsley (2000), such as moving one's head to look left or right, in a manner that approximates *attending*. Figure 3 provides a single image of six PSTs from our study while wearing the VR headset to view a lesson on multiplication/division. Juxtaposed with the typical nature of viewing a video (i.e., facing straight ahead), an apparent difference is the physical positioning a PST must engage to view specific points in the classroom. We hypothesize that by engaging in such positioning, PSTs operationalize a tacit form of purposefulness in what is within their field of view and what is not. By contrast, a PST viewing a video on a standard monitor does not engage in such physical positioning, even if viewing a 360 video on a monitor. By engaging PSTs in this tacit purposefulness, we believe that viewing the 360 video with a VR headset facilitates PSTs' integration of tacit and explicit knowledge—something we typically see from expert rather than novice teachers.

Implications for Practice

Research has provided evidence that videos are often only used a few times a semester, they tend to be implemented differently based on the discipline, and often represent only one perspective (Christ et al., 2017). Therefore, an obvious implication for practice is the inclusion of 360 videos for teacher education to address such issues. There is enough evidence presented in this study and related empirical projects to suggest that even watching 360 videos in a two-dimensional perspective (e.g. a laptop or desktop screen) adds additional value if head mounted displays (HMDs) are too costly. This would also be true for scenarios where teacher educators or professional developers felt they lacked the technology savvy to implement head mounted displays.

Given the novelty of 360 video in professional education, it is tempting to apply similar pedagogical practices that have been found effective in using standard video (see Grossman et al., 2009 and Christ et al., 2017 for summary descriptions of such practices). However, we believe the perceptual capacity that 360 video offers also introduces a unique challenge to facilitating discussions about such videos. In traditional video, a teacher educator may point to a specific student in the video frame that all viewers were expected to be able to see. By contrast, viewing 360 video increases the number of students in view and allows for the possibility that something is unseen simply by looking in a different direction. Specific students at particular timecodes can be pointed out as examples in 360 video discussions, but should be used either as an endpoint for a discussion of multiple noticings of future teachers or as an illustrative example for opening discussion of similar observations (of other students in the same recorded classroom).

There was an important practical component to this study regarding participants' viewing experiences. During the first iteration of using the *Oculus Go* headsets, there was very little participant movement. They moved their heads slightly left or right, but movement was very limited. There are two hypotheses that deserve further exploration. First, we wondered if this was an experience issue. Most of the participants had never worn an HMD. After watching the first few students, we adapted our instructions to model the ability to move in all directions. This seemed to work as later participants showed more movement. This can fondly be referred to as *mucking around* (Ferdig, 2003). Users new to technology need to be given opportunities to explore the tool prior to attempting to explore the content with the tool. This is very similar to a well-

Fig. 3 PSTs viewing 360 video while looking in different directions (arrows added for emphasis)

known practice of letting students use a discussion forum to introduce themselves (i.e., something they know), rather than having them use it for the first time to discuss Shakespeare.

A second theory, however, is that the HMD was *too immersive*. The camera was set in the middle of the room. It was so immersive that participants suggested they felt like they were actually in the classroom. Visitors to classrooms, particularly if they are seated in the middle, typically have slow and infrequent movements as to not distract the class. This is simply a hypothesis at this point, but a larger question looms about the positive and negative outcomes of being virtually immersed in the classroom. Regardless, students should be given time to muck around with the HMDs.

Future Research and Development

There are three key additional areas of future research. First, we need to be able to expand the field's understanding of how PSTs' tacit and explicit professional knowledge for teaching content can be facilitated through 360 video. Such an objective would allow for the empirical testing of perceptual capacity and improvement in practice over time. Although this was not the goal of this study, examining long-term improvement on practice is a necessary goal. Such 360 research would have significant potential to transform the field's understanding for facilitating PSTs' engagement with representations of practice and to improve PSTs' professional knowledge for teaching.

Second, this research study used one camera. As such, although participants could view a 360 perspective, future studies should explore the ability to *move around the classroom*. This would include the use of multiple cameras and links between videos (multi-perspective 360 video). This would also allow a deeper exploration of the impact on immersion in a classroom setting and measuring fears of interrupting the class.

A third area of future research relates to teacher noticing. This study provided evidence that perceptual capacity was increased by those using an HMD, as noted by the data indicating explicit awareness of the commutative property. Future research and development needs to find a way to easily capture and display noticing data for teacher educators. Figure 4 presents a 360 video screenshot as well as a hypothesized *noticing heat map*. Future research could examine the use of such heat maps with PSTs to self-assess their own teacher noticing. Alternatively, research could examine the pedagogical affordances and challenges of using these displays from the perspective of teacher educators in face-to-face or online assignment settings.

Finally, future 360 work needs to address the im*pact of scaffolds and annotations within 360 videos*. By providing PSTs with the opportunity to comment on specific timepoints on a video, to view the comments of others, respond to quizlets at key moments in the video, or otherwise engage interactively in a scaffolded manner with the medium, PSTs have been observed to attend to more specific elements of practice (Brunvard & Fishman, 2007; Stockero et al., 2017). For example, Stockero et al. (2017) engaged PSTs with using Studiocode to analyze classroom scenarios for particular instructional moments, and found that PSTs began to focus on more particular aspects of practice. Similarly, Chieu et al. (2018) used LessonSketch to examine PSTs' evaluations of key moments they could pin when viewing a representation of practice.

There is extensive literature to suggest using annotation technology to facilitate PSTs' ability to attend to student strategies and interpret their understandings is effective (Boerst et al., 2011; Stockero et al., 2017). Thus, annotation technology is useful in addressing explicit professional knowledge, but research and development are needed to better understand how such technologies apply to, and make use of, 360 video's perceptual capacity. In using the VR headset, we have argued that PSTs are able to engage in a tacit form of attending to particular points in a lesson, thus allowing for facilitation of more tacit forms of professional knowledge. A simplistic view would be that combining the use of annotation technology with viewing 360 videos via a VR headset would allow for facilitation of both explicit and tacit professional knowledge.

However, we conjecture that there is a tension between the tacit and explicit, such that incorporating annotations in video viewing may, in certain cases, reduce the tacit purposefulness. For example, in our own pilot, PSTs using the VR headsets were given autonomy to move their head and look at any point in the classroom. In examining video capture of where PSTs

Fig. 4 Side-by-side comparison of stretched 360 video and example heat map of noticing

looked within the 360 scenario, PSTs tended to split their focus on two student tables. If we had included annotations for one table but not the other, attention could be skewed in a way that reduces the tacit purposefulness a PST chooses to position their viewpoint. In sum, the implementation of annotations in 360 video require more detailed exploration.

Compliance with Ethical Standards

Disclosure of Potential Conflicts of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed Consent Informed consent was obtained from all participants included in the study.

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