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ORIGINAL PAPER

Mathematics teacher learning to notice: a systematic review of studies of video-based programs

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Abstract

Teacher noticing has become increasingly acknowledged as a fundamental aspect of teacher professional competence. Teacher education scholars have examined how the development of noticing might be supported both in initial teacher education and in professional development. In mathematics teacher education, several studies have explored the use of video as a supporting tool for teacher noticing. It remains unclear how this body of work builds on the various theoretical perspectives of noticing prevalent in the literature, thus broadening our understanding of noticing. Furthermore, the field has not examined systematically the extent to which research has leveraged the affordances of digital video technologies, and whether scholars have employed different research methods to answer questions that are critical to teacher educators. This survey paper reviews studies published in the last two decades on programs centered on mathematics teacher noticing that used video as a supporting tool for teacher learning. Thirty-five peer-reviewed papers written in English were identified and coded along three dimensions: (1) theoretical perspectives; (2) use of video technologies; and (3) research questions and methods. This review summarizes important findings and highlights several directions for future research. Most studies involved pre-service teachers, and only a few centered on in-service teachers. Developers of the large majority of programs took a cognitive psychological perspective and focused on the attending/perceiving and interpreting/reasoning facets of noticing. Few studies used video-based software and few studies used grouping, and even fewer used randomized grouping. Evidence of program effects on responding and decision making, and on instructional practice, is limited and should be extended in the future.

Keywords Teacher noticing · Teacher professional vision · Mathematics · Video · Teacher education · Teacher professional development

Teacher noticing has become widely accepted as a fundamental aspect of teacher professional competence (Kaiser and König 2019; Scheiner 2016; Sherin et al. 2011; Stahnke et al. 2016). The complex, multidimensional and relational

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nature of the work of teaching requires teachers to process a myriad of information during instruction and decide, sometimes instantaneously, what to attend to, what to ignore, how to make sense of students' actions, their positioning and participation, their written work or questions, and how to move the lesson forward. Scholars have construed this work of noticing as the somewhat "specialized ways in which teachers observe and make sense of classroom events and instructional details" (Choy and Dindyal 2020). Teacher noticing is also often situated within the wider area of study that examines teacher dispositions and teacher performance, seeing it as a set of situation-specific skills that function as in-between processes that translate teacher dispositions (including cognition, affect and motivation) into teaching behaviors (Blömeke et al. 2015).

Parallel to the development of noticing, the field has seen the advancement of video technologies. During the last two decades, video technologies have improved considerably, with the move to digital video and increasingly inexpensive and easier to use camcorders to capture footage. Cost-effective editing software and storage capabilities further allow for timely capturing, editing, and sharing of video. In addition, multimedia platforms allow video to be linked to transcripts and other supplemental materials and to structure video viewing by teachers according to particular sequences and goals for teacher learning.

In this paper, we summarize the findings of a systematic review of empirical studies that have bridged literature on teacher noticing with literature on teacher learning from and with video. Much has been written on the affordance of video. Video allows teachers to slow down instructional interactions and closely examine what happened (Sherin and Han 2004), "break set" (Putnam and Borko 2000, p. 6) with their normal teaching routines and focus on particular student ideas, learning interactions, or teaching moves. Teachers can study video as a way to learn from their own teaching and the teaching of others. These qualities make video an ideal tool to support the development of teacher noticing (Sherin and van Es 2005).

Recently, Gaudin and Chaliès (2015) provided a literature review on video viewing in teacher education and professional development, in which 255 studies were selected (not limited to mathematics teaching and spanning 15 different content areas or topics). Two common objectives for the use of video as a tool for teacher learning were identified: (1) building knowledge of how to interpret and reflect on episodes of teaching and learning; and (2) building knowledge of what to do. In this paper, the authors documented two types of activities teachers are asked to engage in while watching videos, namely, selective attention and knowledge-based reasoning. Although this categorization of the nature of video viewing activities was clearly informed by the notion of noticing, the authors did not limit their publication selection to teacher noticing or professional vision. Instead, they used broader keywords in their searches (i.e., 'video', 'video technology', 'video viewing', 'teacher education', and 'teacher professional development') and then applied a noticing lens to categorize studies. The resulting review thus included papers whose theoretical framework was grounded in a variety of conceptualizations and not every paper framed the research as a teacher noticing study.

In this literature review, we took a different approach to complement these efforts. We selected only papers that summarized studies centered on the development of noticing competencies in pre-service or in-service mathematics teachers. We focused our review on three areas of interest, as follows: (1) theoretical perspectives of noticing that ground the design of video-based activities, measures and analytical approaches; (2) use of video technologies; and (3) research methodologies of video-based studies on noticing. Below we discuss the rationale for these three foci before we introduce the research questions we addressed in this study.

1 Theoretical perspectives on teacher noticing and their conceptualizations of noticing

The first area of interest centers on how video-based studies of development of mathematics teacher noticing have conceptualized the construct of noticing. Specifically, we were interested in examining how different perspectives on noticing informed the program design, measures, and analytical approaches. The field of teacher noticing is not uniform and includes various perspectives that differ in important ways. In a broader review of research on teacher noticing that includes both conceptual and empirical papers and is not limited to intervention studies nor to mathematics teaching (König et al. 2020, under review), we have categorized the theoretical frameworks used in these studies into four main perspectives on noticing, as follows: a cognitive psychological perspective drawing on the work on van Es and Sherin (2002), a socio-cultural perspective drawing on Goodwin's (1994) work, a discipline-specific perspective that builds upon Mason's (2002) work, and an expertise-related perspective that draws upon the novice-expert differences paradigm discussed by Berliner (1988).

Theoretical perspectives drive the design of teacher learning activities, including learning goals and specific tasks teachers are asked to complete. In turn, studies of teachers learning to notice contribute to our interpretations of noticing and enrich our theoretical understandings. A focus on selective attention and knowledge-based reasoning seems to be prevalent in video-based studies of teacher learning (Gaudin and Chaliès 2015); however, it is unclear on what conceptualization of teacher noticing researchers draw, and how

these perspectives inform the design of learning experiences and the kind of outcomes on which researchers choose to focus. Below we introduce the four theoretical perspectives that emerged from our systematic review of the noticing literature and discuss their potential for the conceptualization of noticing and the design of video-based programs.

1.1 A cognitive-psychological perspective: noticing as mental processes

A cognitive psychological perspective characterizes noticing in terms of the cognitive processes in which teachers engage when observing and making sense of videos of teaching (Sherin et al. 2011). Van Es and Sherin (2002), for example, identified three processes: "(a) identifying what is important or noteworthy about a classroom situation; (b) making connections between the specifics of classroom interactions and the broader principles of teaching and learning they represent; and (c) using what one knows about the context to reason about classroom interactions" (p. 573). Jacobs et al. (2010) built on this work and introduced three interrelated skills: attending to the details in children's strategies, interpreting children's understanding reflected in their strategies, and deciding how to respond based on children's understandings. Similarly, Kaiser et al. (2015) proposed that teacher noticing consists of perceiving particular events in an instructional setting, interpreting the perceived activities in the classroom, and decision-making—either as anticipating a response to students' activities or as proposing alternative instructional strategies. In this approach teacher noticing relates to a broad range of teaching aspects going beyond the focus on students' thinking (Yang et al. 2020). The affordance of cognitive-psychological perspective is that it allows teacher educators and researchers to center the design of video-based activities on specific cognitive processes with prompts that direct teacher attention to details of student thinking or teaching practices and that support teacher reasoning. Studies that are grounded in this perspective also contribute to our understanding of the nuances of noticing and provide frameworks and tools that other teacher educators can use to design their own teacher learning activities.

1.2 A socio-cultural perspective: noticing as socially organized and situated

A socio-cultural perspective draws on the work of Goodwin (1994) by focusing on the social and situated nature of teacher noticing. Goodwin (1994) used the term "professional vision" as involving somewhat "socially organized ways of seeing and understanding events that are answerable to the distinctive interests of a particular social group" (p. 606), underscoring the socio-cultural aspects of professional ways of seeing in certain professions (e.g., archeology). While scholars of teacher education have adopted the term professional vision, its usage does not always reflect a socio-cultural framing and research approach. For example, Seidel and Stürmer (2014) used the term professional vision, but adopted a cognitive-psychological perspective in their research design. More recently, a focus on socio-cultural aspects that is more aligned with Goodwin's understanding of professional vision has reemerged in the field to account for issues of power and equity (e.g., Louie 2018).

The socio-cultural perspective broadens our examination of noticing by focusing the attention on communities of practice, use of artifacts, as well as social and cultural norms that frame and inform teacher noticing. Studies that draw on this perspective might conceive of learning to notice as a socialization process through which teachers, by participating in communities of practice, gradually learn to adopt a professional lens to make sense of the work of teaching. These studies might also examine closely how artifacts, such as video, extend teachers' noticing capabilities and how cultural assumptions and norms inform teacher noticing, sometimes by perpetuating existing inequities (Louie 2018).

1.3 A discipline-specific perspective: noticing as a collection of discipline-specific practices

Mason (2002) proposed the notion of a discipline of noticing and the importance of raising teachers' presence, awareness, and sensitivity of students and their understanding of the subject matter. For Mason (2011), teacher noticing is a "collection of practices designed to sensitize oneself so as to notice opportunities in the future in which to act freshly rather than automatically out of habit" (p. 35). Although Mason's conceptualization of noticing is centered on individual teachers and the mental processes they engage in, we distinguished it from the cognitive-psychological perspective to highlight its focus on sensitized awareness and the necessity for teachers "to be methodical without being mechanical" (Mason 2002, p. 61). Teacher education programs that draw on Mason's conceptualization might emphasize and include in the design of video-based activities opportunities for teachers to become aware of ways of seeing that they bring to classroom interactions, that might limit their ability to act freshly by attending to students' in-the-moment contributions.

1.4 An expertise-related perspective: expert-novice differences in noticing

Finally, scholars also draw on research on expert-novice differences (e.g., Berliner 1988) and, similarly to the cognitive-psychological perspective, conceive of noticing as teachers' ability to attend to important elements of teaching events, create coherent interpretations, and ignore other elements

that might distract from consequential instructional decisions. Unpacking expert teacher noticing allows the highlighting of skills that novices need to develop and this can inform the design of video-based learning experiences. A focus on expert-novice differences might also invite teacher educators to structure programs around the interaction between novices and experts and/or the design of sequences of activities that might support teachers' gradual engagement in more sophisticated noticing processes according to a pre-defined progression.

2 Use of video technologies

As mentioned above, digital video is an ideal tool to engage in noticing activities, largely because it allows the teaching and learning process to be slowed down, and thereby makes visible details of interactions or viewing perspectives not readily available while teaching. Recent advances in digital and multimedia technologies have further amplified the potential of video by allowing teacher educators to utilize various tools, such as time stamps and annotation software, to support the development of teacher noticing. We were interested in documenting systematically how teacher educators use video in their programs, the extent to which they take advantage of the affordances of video-based technologies, and whether there exist untapped directions for future research.

3 Research methodologies of video-based studies

In the broader field of education, studies that examine learning processes and outcomes of programs and interventions include various methodological approaches. The use of different methods typically strengthens scholarship around a particular topic, providing opportunities for the investigation of a multitude of complementary questions. Initial studies of teacher noticing tended to be explorative and qualitative, involving small groups of teachers. The novelty of the construct in the early 2000s indeed warranted exploratory research. Nearly twenty years have now passed; in this review, we were thus interested in examining the types of research methods represented in the existing literature, identifying potential shortcomings, and providing the research community with directions for future studies.

4 Research questions

The three areas of interest discussed above inform the research questions of this study:

1. Which theoretical perspectives of mathematics teacher noticing (cognitive-psychological, socio-cultural, discipline-specific, and expertise related) form the focus or focal points of video-based studies on teacher noticing, and how do these conceptualizations of noticing inform the design of noticing programs and the choice of noticing outcomes?
2. How do mathematics teacher educators use video in their programs, and to what extent do they leverage the affordances of video-based digital technologies?
3. What research methods were used to investigate (a) to what extent, and (b) how, a video-based program supported the development of teacher noticing?

Together, answers to these questions provide an overall picture of existing research on video-supported mathematics teacher education in the context of teacher noticing, identify patterns and trends in the existing studies, and provide a critical synthesis to advance the field and suggest future directions for research. Given that the fields of research on teacher preparation and professional development tend to be separate and teachers at different stages of the professional continuum typically learn in different settings and have different immediate needs, we report findings separately for pre-service and in-service mathematics teachers when meaningful differences between the groups emerged.

5 Method

We followed the guidelines and recommendations by Cooper (2017), Cooper et al. (2019) and Siddaway et al. (2019) to structure the literature review. Here we summarize the steps we took to select the publications, develop the coding scheme, and code the database of articles.

5.1 Selection process

As the initial search included publications on teacher noticing not restricted to intervention studies, video, or mathematics, we conducted the search by using the terms "teacher* AND notic*" as well as "teacher* AND professional vision*".[1] Both the term noticing and professional vision are utilized in the literature, sometimes as synonyms, other times to refer to different conceptualizations of teacher

[1] By using a truncation symbol at the end of the search terms (*), it was specified that the search algorithms of the databases include all possible word-endings, particular plural forms or gerund (e.g., notice or noticing; teacher or teachers). The term "professional vision" instead of "vision" was chosen, as the term "vision" was too broad and ensnared too many references, especially ones that were not relevant to this review.

noticing as discussed above. We thus decided to include both terms in our search.[2]

Five online databases (i.e., ERIC, PsycINFO, ScienceDirect, Scopus, and Web of Science) were accessed to conduct the search across the publications' titles, abstracts, and keywords. No restrictions were applied regarding the publication type and publication year during the search. In total, these database searches, carried out in June 2019, produced 7,205 publications after removing duplications. Next, we chose the following three criteria to select publications for review: (1) published in a peer-reviewed journal (to include only publications that were subjected to rigorous peer review); (2) published in English-language (to have a high degree of accessibility); and (3) explicitly focused on noticing of teachers. A total of 226 publications matched these selection criteria. Figure 1 below summarizes the selection process and identifies the number of publications that were excluded based on each criterion.

The full-text version of each article was then reviewed for relevance to the current study according to three additional criteria: (a) teacher noticing was central to the empirical investigation; (b) the article focused on a program or intervention that was designed to develop teacher noticing (most articles that were excluded here examined teachers noticing skills at one point in time only, sometimes with other aspects of teacher competence, but not as part of an intervention study or of a teacher preparation course intended to improve noticing); and (c) the study used video as a tool for teacher learning and was focused on mathematics teaching. This final selection resulted in 35 publications. Figure 1 reports the number of articles that were excluded based on each criterion.

5.2 Coding

The first phase of code development and of the coding process were conducted on the entire database of articles that focused on teacher noticing or professional vision ($n = 182$). Code development was structured around three dimensions of interest, namely, (1) theoretical perspectives, (2) research methods, and (3) design of programs centered on developing teacher noticing. The coding scheme was developed through a three-step iterative process of revision and refinement. A sub-sample of articles ($n = 20$) was reviewed to develop a first draft of the codes, and then codes were applied to twenty additional articles, revised if necessary, and finalized. Finally, all articles were coded, and twenty percent were double coded to test for interrater reliability. Individual codes within each dimension were dichotomous and coders were asked to identify whether a certain approach or characteristic applied or not to a given study. The average interrater reliability across codes for dimension 1 (i.e., theoretical perspectives) and dimension 2 (i.e., research methods), calculated through Cohen's κ, can be regarded as good ($M\kappa = 0.72$; min. = 0.35, max. = 1.0, $SD = 0.19$). The interrater reliability for codes of the third dimension (i.e., design and findings of professional development program) can be regarded as excellent ($M\kappa = 0.97$; min. = 0.86, max = 1.0, $SD = 0.05$). Cases of disagreements were resolved through discussion. For articles that were coded by only one researcher, the coding team discussed ambiguous coding decisions until consensus was reached.

Following the selection process outlined above, 35 articles were identified as relevant for the purpose of this systematic literature review. Descriptive statistics for the codes along the three dimensions listed above were computed for the entire selection of articles, separately for programs involving pre-service, in-service, or both groups of teachers, and, in some cases, by examining the studies across two or more codes from different dimensions. All coding dimensions and codes are listed and defined in the Appendix.

6 Findings

Of the 35 articles included in this literature review, 25 articles involved pre-service, eight in-service, and two both pre-service and in-service teachers (Sherin and van Es 2005; Star and Strickland 2008). These studies summarized a variety of programs that engaged teachers in viewing and analyzing videos of mathematics teaching in order to develop noticing competencies. Studies involving pre-service teachers were most frequently embedded in mathematics methods courses and focused on developing noticing of student thinking about a specific mathematics content (e.g., fraction concepts; algebraic thinking) or across multiple mathematics topics. Some studies aimed to develop pre-service teacher noticing of mathematics teaching practices or to foster their self-reflection. Articles involving in-service teachers were authored by a total of six research teams. They included studies that experimented with new technologies, such as student head-mounted cameras and animations, and most were structured as video clubs, in which groups of teachers came together to view and discuss videos of one another's teaching.

Below we highlight trends and patterns from our analysis of the papers, distinguishing between pre-service and in-service studies when we found meaningful differences.

[2] In this paper, we use the term professional vision only when its use is necessary to highlight a socio-cultural perspective on noticing. In all other cases, we use the term noticing.

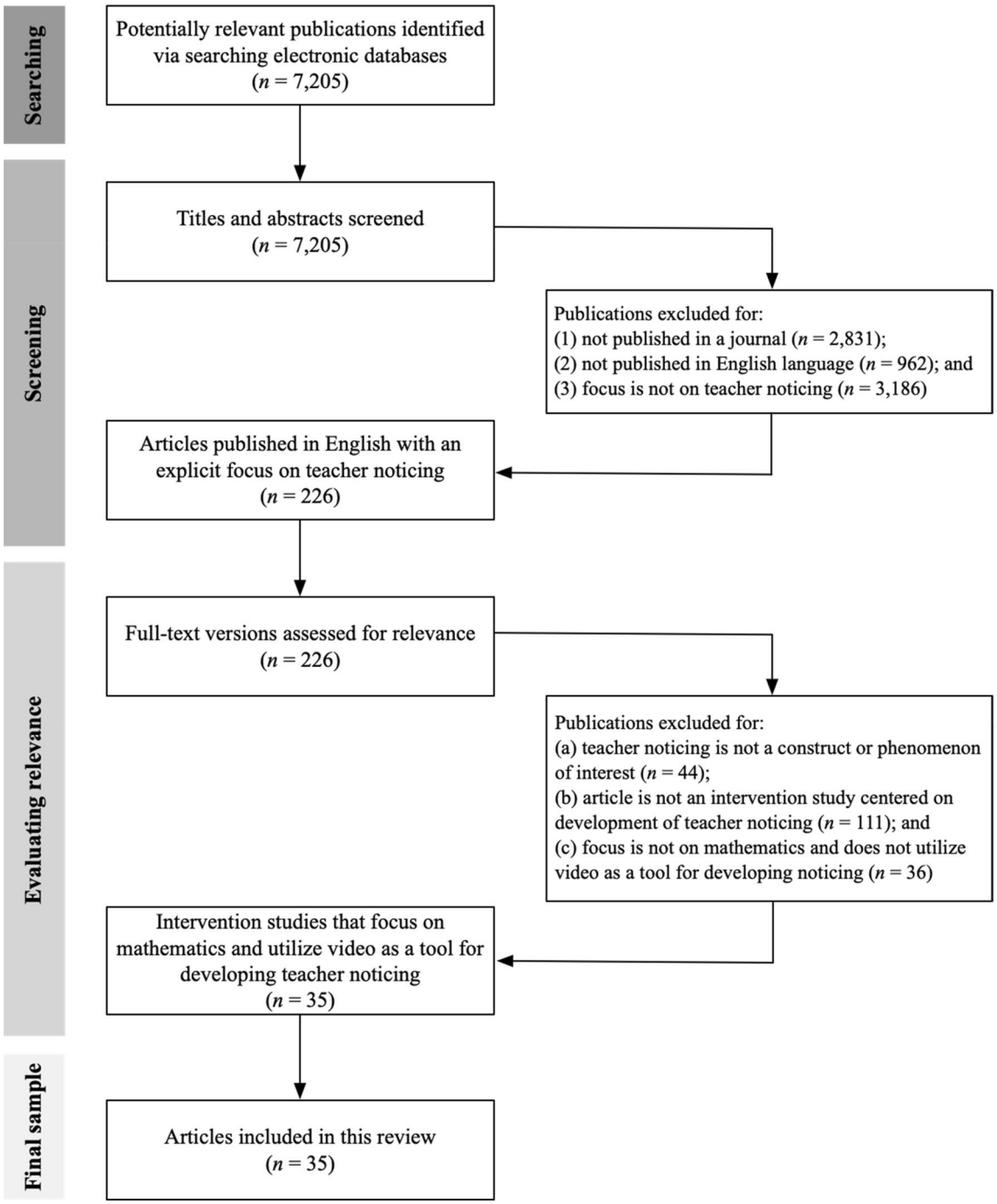

Fig. 1 Search and selection process of publications

6.1 Theoretical perspectives of teacher noticing

6.1.1 Results

To capture the theoretical basis of the video-supported programs, we examined both the terminology authors used to describe the program's focus and the theoretical perspectives they drew on in their description and operationalization of teacher noticing. In addition, we categorized the goals that teacher educators had for teacher development of noticing in terms of focus (i.e., student thinking, equity, instructional practices, and mathematics) and the outcomes on which they reported positive findings.

A vast majority of studies drew from a cognitive-psychological perspective (91%) and used the term teacher noticing (86%, $n = 30$). The other three perspectives—socio-cultural,

discipline-specific, and expertise-related—were less prevalent, and were found in 14% ($n=5$), 9% ($n=3$), and 11% ($n=4$) of articles respectively.

In line with the cognitive-psychological perspective, studies distinguished between facets or sub-processes involved in noticing, mostly focusing on attending/perceiving (89%, $n=31$) and interpreting/reasoning (80%, $n=20$). Only 37% ($n=13$) of studies included a focus on responding/decision-making (the percentage was larger for in-service than pre-service teachers) and even fewer included a focus on making connections between an element of instruction that was noticed in a video and existing theories on teaching and learning or theoretical frameworks from mathematics education (e.g., Alsawaie and Alghazo 2010).

The large majority of studies were designed to support the development of teacher noticing of student thinking (83%, $n=29$) and/or noticing of particular instructional practices and classroom discourse (57%, $n=20$). A smaller group of papers (20%, $n=7$) centered and/or focused on noticing aspects of the mathematics or the mathematics tasks, while only one study included a focus on noticing for equity (3%, $n=1$; i.e., McDuffie et al. 2014).

Finally, we reviewed the findings and discussion sections of publications and coded for aspects of teacher noticing that authors reported as improved as a result of teachers participating in video-supported programs. The focus on different facets of noticing in findings sections of papers aligned with the design of the programs and with the aspects of noticing on which the program activities centered. The most frequently reported improvement was for "attending" (83%, $n=29$). The second was for "reasoning" (66%, $n=23$) and then "responding" (23%, $n=8$). Only a few studies reported changing of teachers' classroom practices and ability to reflect on their instruction (17%, $n=6$ in each category). Studies varied in what they considered as improvement. Most studies coded participants' noticing according to categories that reflected different levels of sophistication and documented changes over time (e.g., Stockero et al. 2017). Some studies created profiles of teachers who noticed in different ways to document variation among teachers (Ivars et al. 2018). Finally, other studies used standardized measures to quantify improvement (e.g., Fisher et al. 2019).

6.1.2 Discussion

The prevalent cognitive-psychological framing of existing research on noticing and the focus on student thinking most likely reflects the impact of the highly-cited work by Sherin and van Es (2005) and van Es and Sherin (2002). Together the reviewed studies provide evidence that video-supported programs can offer valuable and meaningful opportunities for teachers along the professional continuum to develop their noticing competencies in the context of mathematics instruction. The differentiation between the processes of attending/perceiving and interpreting/reasoning prevalent in most studies confirms the conclusions by Gaudin and Chaliès (2015) that video is an effective tool to support teachers' development and improvement of these noticing facets. Conversely, a large number of studies (80%) included interpreting/reasoning in their introduction, and only 66% reported that their program supported the improvement on this facet of noticing. This discrepancy raises questions of whether studies failed to align their theoretical framing with the design of their video-supported activities and/or with the outcomes they chose to capture.

As with the broader literature on the use of video as a tool for teacher learning (Gaudin and Chaliès 2015), still very little work exists that examines the extent to which, and how, developing teacher noticing has also implications for the improvement of classroom practice.

As Fisher et al. (2019) and Sherin and van Es (2005) noted, additional research is also needed to understand how teachers engage in in-the-moment noticing during instruction. Understanding the nuances of these processes might help us to support the transfer of noticing competencies that teachers develop in video-supported environments, to their instructional practices.

Additionally, the more recent extension of noticing to include responding/decision making (Jacobs et al. 2010; Kaiser et al. 2015) is limited to only 8 studies in this review and more evidence could be collected that video can be used productively to develop this facet of noticing as well. Whether scholars consider responding/decision making as part of noticing or not (only 37% of articles included this facet in their conceptualizations), it is important to understand how the elements that teachers notice during their teaching is consequential for how they decide to respond and move instruction forward. In other words, responding and decision-making seem to be the natural next steps towards examining the impact of noticing-centered programs on teacher instructional practices (Table 1).

An area of overall concern is that the evidence for in-service mathematics teachers is limited to a few studies conducted by a small group of research teams from the USA. This reflects a limitation of the larger literature on teacher noticing, which is similarly dominated by research on pre-service teachers (König et al. 2020, under review).

Concerning the theoretical perspectives, very few studies embraced a socio-cultural approach and designed their programs with the goal of developing teacher professional vision (McDuffie et al. 2014; Michalsky 2014; Osmanoglu 2016; Sherin and van Es 2009).

A socio-cultural focus might enrich research on teacher noticing. A cognitive lens allows researchers to operationalize and measure teacher noticing processes with relative simplicity. Yet, the risk is to reduce noticing to mental

Table 1 Terminology, facets of noticing, theoretical perspectives, noticing focus, and improved noticing competencies

	All ($n=35$)	Pre-service ($n=25$)	In-service ($n=8$)	Both ($n=2$)
	% (n)	% (n)	% (n)	% (n)
Terminology				
Predominantly "Teacher noticing"	86 (30)	88 (22)	75 (6)	100 (2)
Predominantly "Professional vision"	11 (4)	12 (3)	13 (1)	0 (0)
Both noticing and vision	3 (1)	0 (0)	13 (1)	0 (0)
Facets of noticing/vision				
Holistic	9 (3)	12 (3)	0 (0)	0 (0)
Attending/perceiving	89 (31)	88 (22)	88 (7)	100 (2)
Interpreting/reasoning	80 (28)	80 (20)	88 (7)	50 (1)
Responding/decision-making	37 (13)	36 (9)	50 (4)	0 (0)
Making connections	14 (5)	12 (3)	13 (1)	50 (1)
Theoretical perspectives				
Socio-cultural	14 (5)	12 (3)	25 (2)	0 (0)
Disciplinary-specific	9 (3)	12 (3)	0 (0)	0 (0)
Expertise-related	11 (4)	0 (0)	25 (2)	100 (2)
Cognitive-psychological	91 (32)	88 (22)	100 (8)	100 (2)
Noticing focus				
Student thinking	83 (29)	84 (21)	88 (7)	50 (1)
Equity	3 (1)	4 (1)	0 (0)	0 (0)
Instructional practices	57 (20)	52 (13)	63 (5)	100 (2)
Mathematics/mathematics tasks	20 (7)	24 (6)	0 (0)	50 (1)
Improved noticing competencies				
Attending/perceiving	83 (29)	80 (20)	88 (7)	100 (2)
Interpreting/reasoning	66 (23)	60 (15)	88 (7)	50 (1)
Responding/decision-making	23 (8)	24 (6)	25 (2)	0 (0)
Alternatives	6 (2)	8 (2)	0 (0)	0 (0)
Instruction	17 (6)	12 (3)	38 (3)	0 (0)
Reflection	17 (6)	20 (5)	13 (1)	0 (0)

Codes for 'facets of noticing' and 'theoretical perspectives' are not mutually exclusive; thus, percentages are larger than 100 when multiple codes applied to a given publication

processes that resemble technical conceptualizations of teacher competence as a set of skills to be trained. Scholars have argued for moving beyond reductionist views of teacher noticing (Scheiner 2016; Sherin and Star 2011), to include more explicitly cultural-historical and embodied-ecological approaches to study teacher noticing (Scheiner 2021). Such approaches call for a more complex view of teacher competence that highlights the situated, social, and distributed aspects of teacher cognition. This, in turn, might promote more research on the cognitive processes of attending and interpreting as situated within teachers' broader vision of effective instruction, as shared among communities of practice, and as supported by tools such as video and frameworks, with a unit of analysis that is larger than the individual teacher. In the broader literature on teacher noticing, others have argued for the importance of these socio-cultural aspects (Herbst et al. 2016; Lande and Mesa 2016; Santagata and Yeh 2016). How this conceptualization may inform the design of video-supported mathematics teacher education programs remains an open question. Perhaps even more challenging is the development of shared measures and research protocols that document teacher professional vision and how it changes over time across settings (Osmanoglu 2016; van Es et al. 2017).

6.2 Use of video and video-based digital technologies

To answer the second research question, we documented the type of video that was used, whether viewing was supported through software and/or guiding frameworks, and whose videos were utilized. To provide contextual information about programs, we also documented program participation structure and duration in terms of contact hours and time span. We share this information in Table 2 for readers to see the variety of participation structures present in the

Table 2 Use of video and digital technologies, participation structure and program duration

	All ($n=35$)	Pre-service ($n=25$)	In-service ($n=8$)	Both ($n=2$)
	% (n)	% (n)	% (n)	% (n)
Video type				
Whole lesson	34 (12)	36 (9)	25 (2)	50 (1)
Video clips	63 (22)	60 (15)	75 (6)	50 (1)
Unclear	3 (1)	4 (1)	0 (0)	0 (0)
Video viewing support				
Open ended	23 (8)	8 (2)	63 (5)	50 (1)
Structured	77 (27)	88 (22)	38 (3)	100 (2)
Video object				
One's own video	26 (9)	20 (5)	38 (3)	50 (1)
Other teachers' video	51 (18)	60 (15)	13 (1)	100 (2)
Students working on math tasks	40 (14)	28 (7)	75 (6)	50 (1)
Unclear	3 (1)	4 (1)	0 (0)	0 (0)
Software technology and animations				
Video-based software	26 (9)	32 (8)	0 (0)	50 (1)
Animations	14 (5)	8 (2)	38 (3)	0 (0)
Participation structure				
Individual	57 (20)	68 (17)	13 (1)	100 (2)
Pairs	9 (3)	8 (2)	13 (1)	0 (0)
Small groups (< 6 teachers)	43 (15)	32 (8)	75 (6)	50 (1)
Large groups	29 (10)	28 (7)	25 (2)	50 (1)
Unclear	3 (1)	4 (1)	0 (0)	0 (0)
Program duration (time span)				
1–2 months	6 (2)	4 (1)	13 (1)	0 (0)
Semester/course	51 (18)	60 (15)	13 (1)	100 (2)
7–12 months	17 (6)	12 (3)	38 (3)	0 (0)
1–2 years	0 (0)	0 (0)	0 (0)	0 (0)
2–3 years	9 (3)	0 (0)	38 (3)	0 (0)
Not stated	17 (6)	24 (6)	0 (0)	0 (0)

literature and the time span devoted to noticing activities. It is noteworthy that the majority of articles (63%, $n=22$) did not state clearly the number of hours teachers spent in activities focused on noticing, most likely due to the fact that activities focused on noticing were often interspersed with other teacher education activities, making it hard to delineate precise time frames. When contact hours were mentioned (37%, $n=13$), they ranged from 3 to 150 h, with an average of a little over 30 h and a large standard deviation ($M=32.50$; $SD=40.72$).

6.2.1 Use of video

The majority of programs used video clips (63%, $n=22$) to engage pre-service and in-service teachers in noticing tasks, and 34% ($n=12$) included whole lesson videos. In most cases, videos portrayed other teachers' classroom practices (51%, $n=18$), 26% of studies ($n=9$) included teachers' own videos, and 40% ($n=14$) included video clips that focused only on students solving a mathematical problem.

The large majority of programs (77%, $n=27$) used structured frameworks or viewing guides to support teachers in learning to notice, while only 23% (8 papers) used open-ended prompts. Frameworks were specific to each program and included prompts to guide pre-service or in-service teachers' analysis of videos. Some frameworks were grounded in research on student learning of specific mathematics concepts (e.g., Fisher et al. 2019); other frameworks guided participants to attend to the details of classroom interactions (e.g., Walkoe and Levin 2018). Two studies engaged teachers in video analysis using analytical tools that were developed for research purposes (Barth-Cohen et al. 2018; Mitchell and Marin 2015). Studies that engaged teachers in video clubs used open-ended prompts, such as "What do you notice?" (van Es and Sherin 2008). The ways video was used did not vary greatly between the studies that involved pre-service and in-service teachers (see Table 2).

6.2.2 Use of software technology and animation

Only 26% of studies ($n=9$; 8 of which involved pre-service teachers) utilized software to support teachers' noticing. The majority of studies involving software used an online interface to lay out the instructional activities, for example, to assign the videos for teachers to complete noticing activities and to introduce the noticing prompts (Fisher et al. 2018; Johnson et al. 2019; Michalsky 2014; Sherin and van Es 2005; van Es and Sherin 2002). Four studies used video annotation software, where participants could pause the instructional videos and attend to specific moments of instruction (Sherin and van Es 2005; Stockero et al. 2017; van Es and Sherin 2002; Walkoe 2015). Finally, five studies (14%) included animation in addition to video. One study employed cartoon sketches based on participants' perceptions of instructional practices as prompts for noticing (Walkoe and Levin 2018). The remaining studies used animation to depict hypothetical classroom interactions (González 2018; González and DeJarnette 2018; González and Skultety 2018) or to help teachers record their noticing in animated forms (de Araujo et al. 2015).

6.2.3 Summary of Findings and Discussion

The authors of the studies we reviewed highlighted the benefits of using video as a tool, particularly for anchoring discussions of teaching and learning around specific evidence. They also noted that viewing frameworks offer essential guidance, and the nature of the prompts matters and is consequential for teacher learning (Diamond et al. 2018; Stockero et al. 2017; van Es and Sherin 2002; Walkoe 2015). A few authors also commented on how video allows for rich discussions and for supporting the development of an appreciation for the complexity of ambitious mathematics instruction (Estapa et al. 2016; González and DeJarnette 2018; van Es and Sherin 2006).

Authors also called for more research on the specific affordances of program designs, including a closer examination of viewing frameworks, prompts and facilitator moves (McDuffie et al. 2014; Walkoe and Levin 2018). From our analysis of this literature, it was evident that it is the combination of video with well-structured frameworks supported by well-prepared facilitators that optimizes video-supported programs. Studies including software and structured teacher collaboration also shed light on the potential of technology and of shared reflection and sense-making. Yet, the extent to which program designs have been unpacked in published articles to highlight design principles, theories of learning that inform decisions, conjectures that guide specific choices of video, prompts, feedback, and so on, is still limited.

Similarly, despite the advances of digital video technologies in the last one or two decades, this review made apparent that video software was rarely used, video annotation features were seldom utilized, and the potential of technology for supporting the development and for studying mathematics teacher noticing was under-examined.

An additional question that remains open in relation to the use of video in teacher education courses or professional development is the optimal duration in terms of contact hours and time span. Recent discussions in the context of research on the impact of professional development call for skepticism in considering the effect of duration separately from a consideration of program goals and *how* time is spent (Kennedy 2016). Nonetheless, practical considerations demand that we learn more about the amount of time that is necessary to develop meaningful noticing competencies that are consequential for teacher practices. We owe this to teacher educators who struggle to fit multiple learning goals into already packed teacher education courses and professional development programs (Santagata et al. 2018).

6.3 Research Methods

6.3.1 Results

Researchers should make methodological decisions based on the questions their studies intend to answer. For this reason, before documenting the types of research methods used in the studies, we examined their research questions. Scholarly inquiry differed across studies predominantly along two types of research questions. Forty-three percent ($n=15$) of studies examined *the extent to which* a program or intervention affected teacher noticing, and over half of the studies (57%, $n=20$) examined *how* a program or intervention supported the development of teacher noticing. A few studies ($n=4$) mentioned interest in examining the design features of programs. However, none of the studies reported using a design-based research (DBR) approach to investigate fully how specific features of program design impacted teacher learning. Studies ranged widely in the number of participants, $M=51.91$, $SD=68.94$, range (2, 296) with studies with in-service teachers including fewer participants than those with pre-service teachers [in-service $M=6.9$, $SD=4.3$, range (2, 13); pre-service $M=69.2$, $SD=75.7$, range (2, 296)].

We further examined the intersection of data collection approaches and study design, in relation to question types. Figures 2 and 3 illustrate the research methods by question types for studies involving either pre-service or in-service teachers ($n=33$). There were some differences between empirical approaches used in pre-service and in-service teacher studies. Studies with pre-service teachers that inquired about *how* an intervention facilitated the

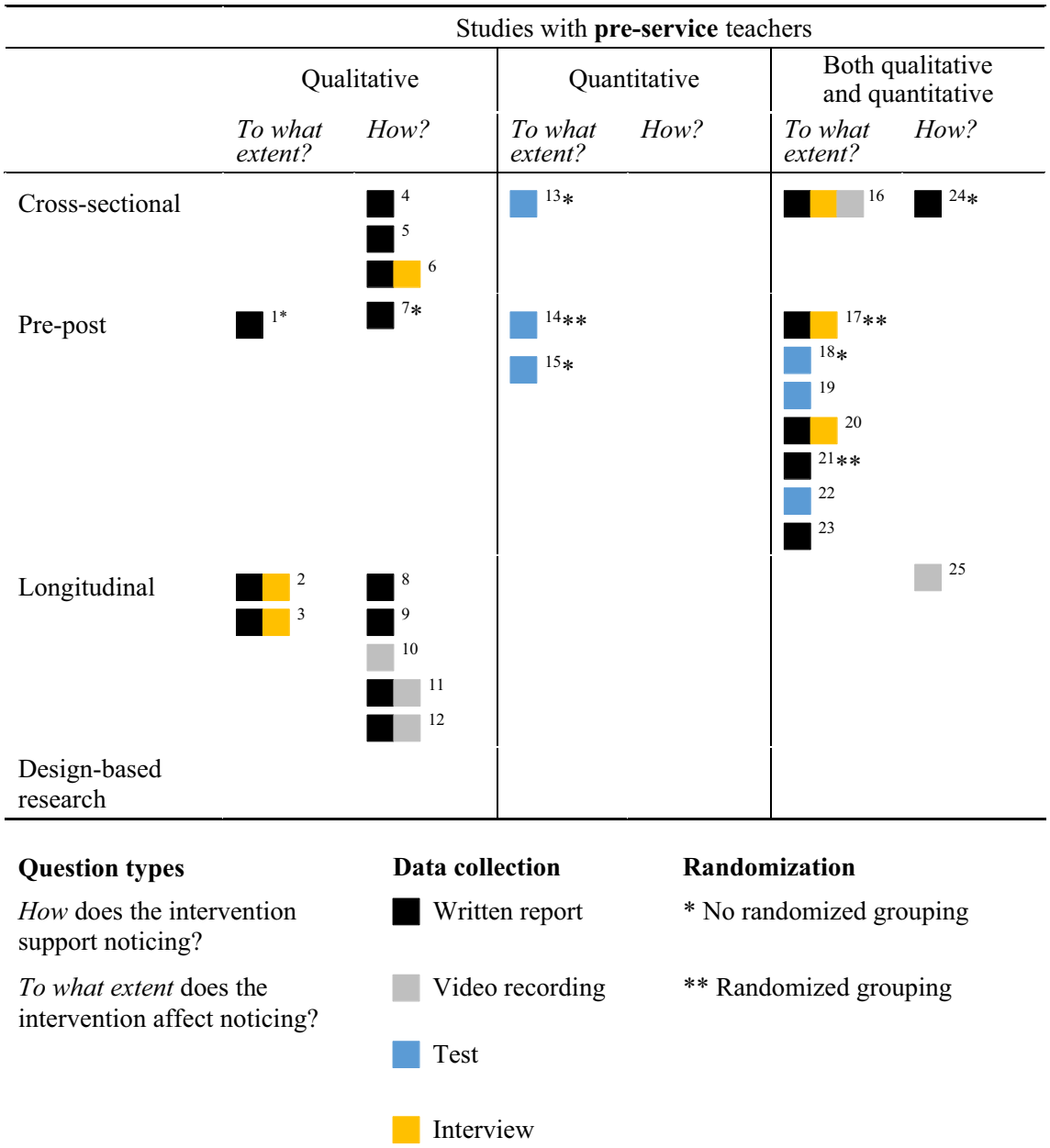

Fig. 2 Research methods for studies with pre-service teachers ($n=25$). Qualitative studies: [1]Diamond et al. (2018), [2]Osmanoglu et al. (2015), [3]Ulusoy and Çakıroğlu (2018), [4]Barth-Cohen et al. (2018), [5]de Araujo et al. (2015), [6]Roller (2016), [7]van Es and Sherin (2002), [8]Ivars et al. (2018), [9]Llinares and Valls (2010), [10]McDuffie et al. (2014), [11]Stockero et al. (2017), [12]Walkoe (2015). Quantitative studies: [13]Johnson et al. (2019), [14]Fisher et al. (2019), [15]Kaendler et al. (2016). Both qualitative and quantitative studies: [16]Osmanoglu (2016), [17]Alsawaie and Alghazo (2010), [18]Fisher et al. (2018), [19]Michalsky (2014), [20]Mitchell and Marin (2015), [21]Prediger and Zindel (2017), [22]Schack et al. (2013), [23]van Es et al. (2017), [24]Walkoe and Levin (2018), [25]Superfine et al. (2019)

development of noticing most frequently employed qualitative approaches (82%, $n=9$), while studies with in-service teachers were about evenly split between qualitative and use of both qualitative and quantitative approaches (qualitative: 43%, n = 3; both approaches: 57%; n = 4).

The majority of studies asking about the impact of an intervention (*to what extent*) involved pre-service teachers (93%, $n=14$). For pre-service teachers, these studies drew from a range of empirical approaches, most notably using both methods (57%, $n=8$), qualitative (21%, $n=3$), and quantitative (21%, $n=3$). The one study that investigated the extent to which an intervention influenced in-service teachers' noticing used a qualitative approach.

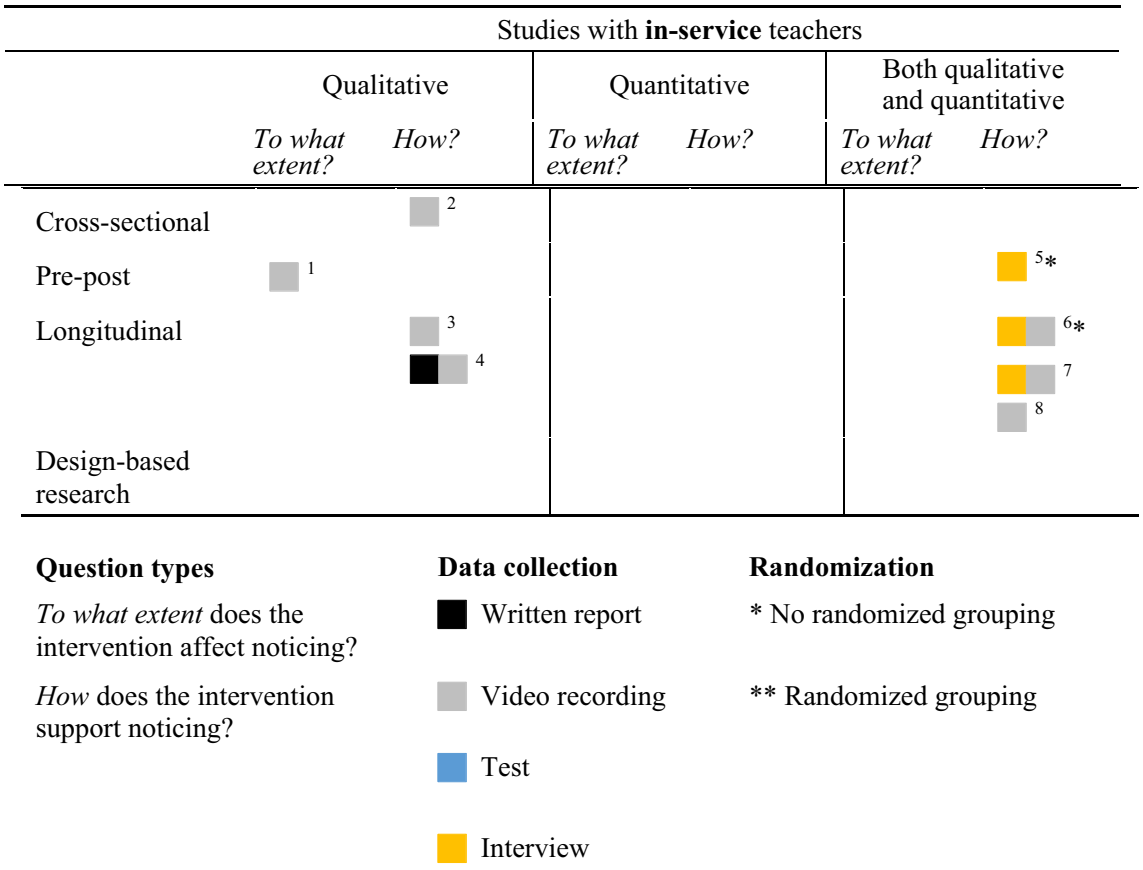

Fig. 3 Research methods for studies with in-service teachers ($n=8$). Qualitative studies: [1]González (2018), [2]González and DeJarnette (2018), [3]Estapa et al. (2016), [4]Meadows and Caniglia (2018); both qualitative and quantitative studies: [5]van Es and Sherin (2006), [6]van Es and Sherin (2008), [7]Sherin and van Es (2009), [8]González and Skultety (2018)

The figures also represent the various data collection methods through different colors. Studies that employed some mechanisms for grouping were noted with asterisks (*non-randomized; **randomized). The figures reveal that studies that examined *how* an intervention supported noticing mostly drew from cross-sectional and longitudinal designs. Meanwhile, studies that employed quantitative approaches to answer *to what extent* questions, exclusively relied on test data, independently from whether the study was cross-sectional (1 time point), pre-post (2 time points), or longitudinal (3 or more time points). Studies with both methods to answer *to what extent* questions, tended to draw from a broader range of data (i.e., interview, written report, video recording, and test), with some studies drawing from two or three data sources.

Only a few studies used grouping, and even fewer used randomized groups (Alsawaie and Alghazo 2010; Fisher et al. 2019; Prediger and Zindel 2017; Sherin and van Es 2005). Studies with grouping most often employed quantitative and qualitative-quantitative approaches to answer *to what extent* questions. Most studies used a control group that did not experience the video-based intervention (e.g., non-randomized grouping, Fisher et al. 2018, Kaendler et al. 2016, van Es and Sherin 2002; randomized grouping, Alsawaie and Alghazo 2010, Fisher et al. 2019, Sherin and van Es 2005). Only two studies used grouping to examine the impact of different intervention designs or noticing prompts (Walkoe and Levin 2018; Prediger and Zindel 2017).

6.3.2 Discussion

Both discussion sections of reviewed publications and our own evaluation of studies led us to the conclusion that although the evidence is clear that engaging teachers in video-supported activities leads to meaningful changes and improvement in their noticing competencies, more attention

is needed to investigation of specific elements that make programs successful. The use of grouping, particularly randomized experiments, could be leveraged to examine the potential impact of different program design features (e.g., materials, prompts, procedures, duration). Grouping could also be employed to answer *how* different program features may facilitate noticing. In addition, only a few studies (e.g., Llinares and Valls 2010) commented on design elements and purposely analyzed the affordances for teacher learning of specific prompts or facilitator moves. Evidence pertaining to in-service teachers is even more limited by the small number of existing studies. The absence of design-based research studies is discussed in our conclusion as a suggested direction for future research.

7 Limitations of this study and directions for future research

As with most reviews, the findings presented above are limited by the criteria we chose to identify relevant publications. Specifically, in an effort to include the most rigorous research in this review, we chose to focus on peer-reviewed journal articles. Books and book chapters vary in the extent to which manuscripts undergo a systematic review process, thus we chose not to include them. Nonetheless, it is important to acknowledge that doing so has potentially excluded relevant research and findings. In particular, DBR studies might be more easily summarized in book chapters that allow for lengthier texts. In addition, emerging lines of research sometimes appear first in book chapters. It is thus possible, for example, that we missed studies that adopted a socio-cultural lens and a focus on equity. Finally, limiting the review to articles in the English language has undoubtedly left out many studies conducted by non-English speaking researchers.

With these limitations in mind, we conclude by suggesting three priorities for future research, as follows:

Drawing on socio-cultural perspectives A socio-cultural approach to the study of noticing would allow researchers to examine closely other elements external to individual teachers' cognitive processes that might support the development of noticing competencies. For example, a focus on learning communities or video as a cultural artifact could improve our understanding of noticing as a socio-cultural practice, unveiling both its potential and the challenges inherent in existing societal power structures and inequities.

Leveraging new technologies Video-based software could be leveraged both to support the development of noticing—by allowing video tagging, online video-based discussions before meetings, and so on—and the design of comparison or DBR studies. Building on existing studies included in this review (e.g., Estapa et al. 2016; González and Skultety 2018; Michalsky 2014; van Es and Sherin 2006; Walkoe and Levin 2018), research could utilize video software to support the design of different conditions, activities, and prompts that can easily be tested and revised over time. Research could also examine the adaptation of technology-supported programs for teachers at different stages of the professional continuum, adding particularly to the current limited evidence involving in-service teachers.

Video-based software also facilitates the collection of data on teacher noticing competencies allowing the capturing of nuances in teacher abilities to highlight, interpret, and respond to noteworthy events and to document how these might improve over time as teachers participate in video-based programs.

Sharing frameworks, protocols, and outcomes The field would benefit from studies conducted in different settings, across instructional contexts, time span, teacher career stage, and student age groups (e.g., Osmanoglu 2016; van Es et al. 2017), that use the same viewing frameworks or facilitation protocols and utilize shared outcome measures to facilitate the gathering of evidence that is generalizable (e.g., Fisher et al. 2018). This limitation of the existing literature is part of a greater weakness in studies of teacher education and professional development that often are situated at one institution and/or conducted by course instructors or programs' original developers, thus contributing to questions about the generalizability of findings and scaling up of programs (Cochran-Smith and Villegas 2015).

This systematic literature review indicates that the use of video has been proven to meet important needs in mathematics teachers' learning to notice. Against the background of the knowledge gained in this review, we consider these priority areas crucial for advancing the field into promising new research directions and exploring new ways in which teachers learn to notice.

Appendix

See Tables 3, 4, 5 and 6.

Table 3 Categories and codes for dimension 1: theoretical perspectives

Category	Code
Terminology	Teacher noticing
	Professional vision
Facets of noticing/vision	Holistic (authors do not distinguish between facets of noticing)
	Attending or perceiving
	Interpreting or reasoning
	Responding or decision-making
	Making connections to underlying theoretical frameworks
Theoretical perspectives	Socio-cultural
	Discipline-specific
	Expertise-related
	Cognitive-psychological

Table 4 Categories, subcategories, and codes for dimension 2: research methods

Category	Subcategory	Code
Research question		How
		To what extent
Methodology	Empirical approach	Qualitative (non-numerical data are used)
		Quantitative (numerical data are used)
		Both quantitative and qualitative (both numerical and non-numerical data are used)
	Study design	Cross-sectional: 1 time point
		Pre-post-design: 2 time points; repeated measures
		Longitudinal: 3 or more time points; repeated measures
		Non-experimental design without randomized grouping
		True experimental design with randomized grouping
		Design-based-research
	Data collection	Interview (dyadic or group interview, narrative, biographical)
		Written report (essay writing, narrative writing)
		Observation
		Video recording
		Test (standardized test, including psychometric testing of noticing)
	Participants	Pre-service teacher
		In-service teacher
		Number of participants

Table 5 Categories and codes for dimension 3: design of programs

Category	Code
Teacher noticing focus	Student thinking
	Equity/diversity
	Instructional practices
	Mathematics
	Other
Artifact and technology	Video[a]
	Video-based software
	Animations
Participation structure	Individual independent work
	Pairs
	Small groups (3–10)
	Large groups (> 10)
Duration	Contact hours
	Span (1–2 months; semester/course; 7–12 months; 2–3 years; not stated)
Improved noticing competencies	Attending/perceiving
	Interpreting/reasoning
	Responding/decision-making
	Alternatives/suggestions for improvement
	Instruction
	Reflection

[a]If the study uses video to support teacher learning, then additional codes were used for capturing information about the types of videos teachers viewed and the viewing support (see Table 6)

Table 6 Video categories and codes

Category	Code
Video type	Whole lesson(s)
	Video clips
Video viewing support	Open ended (e.g., no instruction or broad prompt "what do you notice")
	Structured (e.g., multidimensional viewing guide or multiple specific questions to answer)
Video object	Own video
	Other teachers' video
	Students working on math tasks

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References

References marked with an asterisk indicate publications included in the literature review

Alsawaie, O. N., & Alghazo, I. M. (2010). The effect of video-based approach on prospective teachers' ability to analyze mathematics teaching. *Journal of Mathematics Teacher Education, 13*(3), 223–241.*

Barth-Cohen, L. A., Little, A. J., & Abrahamson, D. (2018). Building reflective practices in a pre-service math and science teacher education course that focuses on qualitative video analysis. *Journal of Science Teacher Education, 29*(2), 83–101.*

Berliner, D. C. (1988). *The development of expertise in pedagogy*. Washington, DC: American Association of Colleges for Teachers.

Blömeke, S., Gustafsson, J.-E., & Shavelson, R. J. (2015). Beyond dichotomies: Competence viewed as a continuum. *Zeitschrift-fürPsychologie, 223*(1), 3–13.

Choy, B. H., & Dindyal, J. (2020). Teacher noticing, mathematics. In M. Peters (Ed.), *Encyclopedia of teacher education* (living). Singapore: Springer.

Cochran-Smith, M., & Villegas, A. M. (2015). Framing teacher preparation research: An overview of the field, part 1. *Journal of Teacher Education, 66*(1), 7–20.

Cooper, H. (2017). *Research synthesis and meta-analysis: A step-by-step approach* (5th ed.). Thousand Oaks, CA: Sage.

Cooper, H., Hedges, L. V., & Valentine, J. C. (Eds.). (2019). *The handbook of research synthesis and meta-analysis* (3rd ed.). New York: Russell Sage Foundation.

de Araujo, Z., Amador, J., Estapa, A., Weston, T., Aming-Attai, R., & Kosko, K. W. (2015). Animating preservice teachers' noticing. *Mathematics Teacher Education and Development, 17*(2), 25–44.*

Diamond, J. M., Kalinec-Craig, C. A., & Shih, J. C. (2018). The problem of Sunny's pennies: A multi-institutional study about the development of elementary preservice teachers' professional noticing. *Mathematics Teacher Education and Development, 20*(2), 114–132.*

Estapa, A., Pinnow, R. J., & Chval, K. B. (2016). Video as a professional development tool to support novice teachers as they learn to teach English language learners. *The New Educator, 12*(1), 85–104.*

Fisher, M. H., Thomas, J., Jong, C., Schack, E. O., & Dueber, D. (2019). Comparing preservice teachers' professional noticing skills in elementary mathematics classrooms. *School Science and Mathematics, 119*(3), 142–149.*

Fisher, M. H., Thomas, J., Schack, E. O., Jong, C., & Tassell, J. (2018). Noticing numeracy now! Examining changes in preservice teachers' noticing, knowledge, and attitudes. *Mathematics Education Research Journal, 30*(2), 209–232.*

Gaudin, C., & Chaliès, S. (2015). Video viewing in teacher education and professional development: A literature review. *Educational Research Review, 16,* 41–67.

González, G. (2018). Understanding teacher noticing of students' prior knowledge: Challenges and possibilities. *The Mathematics Enthusiast, 15*(3), 483–528.*

González, G., & DeJarnette, A. (2018). Design perspectives for making animated stories of instruction: The case of promoting teacher noticing of students' prior knowledge. *Journal of Technology and Teacher Education, 26*(1), 79–102.*

González, G., & Skultety, L. (2018). Teacher learning in a combined professional development intervention. *Teaching and Teacher Education, 71,* 341–354.*

Goodwin, C. (1994). Professional vision. *American Anthropologist, 96*(3), 606–633.

Herbst, P., Chazan, D., Kosko, K. W., Dimmel, J., & Erickson, A. (2016). Using multimedia questionnaires to study influences on the decisions mathematics teachers make in instructional situations. *ZDM-Mathematics Education, 48*(1), 167–183.

Ivars, P., Fernandez-Verdu, C., Llinares, S., & Choy, B. H. (2018). Enhancing noticing: Using a hypothetical learning trajectory to improve pre-service primary teachers' professional discourse. *EURASIA Journal of Mathematics, Science and Technology Education, 14*(11), 1–16.*

Jacobs, V. R., Lamb, L. L., & Philipp, R. A. (2010). Professional noticing of children's mathematical thinking. *Journal for Research in Mathematics Education, 41*(2), 169–202.

Johnson, H. L., Dunlap, J. C., Verma, G., McClintock, E., DeBay, D. J., & Bourdeaux, B. (2019). Video-based teaching playgrounds: Designing online learning opportunities to foster professional noticing of teaching practices. *TechTrends, 63*(2), 160–169.*

Kaendler, C., Wiedmann, M., Leuders, T., Rummel, N., & Spada, H. (2016). Monitoring student interaction during collaborative learning: Design and evaluation of a training program for pre-service teachers. *Psychology Learning & Teaching, 15*(1), 44–64.*

Kaiser, G., Busse, A., Hoth, J., König, J., & Blömeke, S. (2015). About the complexities of video-based assessments: Theoretical and methodological approaches to overcoming shortcomings of research on teachers' competence. *International Journal of Science and Mathematics Education, 13*(2), 369–387.

Kaiser, G., & König, J. (2019). Competence measurement in (mathematics) teacher education and beyond: Implications for policy. *Higher Education Policy, 32*(4), 597–615.

Kennedy, M. M. (2016). How does professional development improve teaching? *Review of Educational Research, 86*(4), 945–980.

König, J., Santagata, R., Scheiner, T., Adleff, A.-K., Yang, X., & Kaiser, G. (2020). Teacher noticing and teacher professional vision: A systematic literature review on conceptualizations and research designs **(under review, manuscript submitted)**.

Lande, E., & Mesa, V. (2016). Instructional decision making and agency of community college mathematics faculty. *ZDM-Mathematics Education, 48*(1), 199–212.

Llinares, S., & Valls, J. (2010). Prospective primary mathematics teachers' learning from on-line discussions in a virtual video-based environment. *Journal of Mathematics Teacher Education, 13*(2), 177–196.*

Louie, N. L. (2018). Culture and ideology in mathematics teacher noticing. *Educational Studies in Mathematics, 97*(1), 55–69.

Mason, J. (2002). *Researching your own practice: The discipline of noticing*. London: Routledge.

Mason, J. (2011). Noticing: Roots and branches. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 35–50). New York: Routledge.

McDuffie, A. R., Foote, M. Q., Bolson, C., Turner, E. E., Aguirre, J. M., Bartell, T. G., et al. (2014). Using video analysis to support prospective K-8 teachers' noticing of students' multiple mathematical knowledge bases. *Journal of Mathematics Teacher Education, 17*(3), 245–270.*

Meadows, M. L., & Caniglia, J. (2018). Co-teacher noticing: Implications for professional development. *International Journal of Inclusive Education, 22*(12), 1345–1362.*

Michalsky, T. (2014). Developing the SRL-PV assessment scheme: Preservice teachers' professional vision for teaching self-regulated learning. *Studies in Educational Evaluation, 43,* 214–229.*

Mitchell, R. N., & Marin, K. A. (2015). Examining the use of a structured analysis framework to support prospective teacher noticing. *Journal of Mathematics Teacher Education, 18*(6), 551–575.*

Osmanoglu, A. (2016). Prospective teachers' teaching experience: Teacher learning through the use of video. *Educational Research, 58*(1), 39–55.*

Osmanoglu, A., Isiksal, M., & Koc, Y. (2015). Getting ready for the profession: Prospective teachers' noticing related to teacher actions. *Australian Journal of Teacher Education, 40*(2), 29.*

Prediger, S., & Zindel, C. (2017). Deepening prospective mathematics teachers' diagnostic judgments: Interplay of videos, focus questions and didactic categories. *European Journal of Science and Mathematics Education, 5*(3), 222–242.*

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4–15.

Roller, S. A. (2016). What they notice in video: A study of prospective secondary mathematics teachers learning to teach. *Journal of Mathematics Teacher Education, 19*(5), 477–498.*

Santagata, R., & Yeh, C. (2016). The role of perception, interpretation, and decision making in the development of beginning teachers' competence. *ZDM-Mathematics Education, 48*(1), 153–165.

Santagata, R., Yeh, C., & Mercado, J. (2018). Preparing elementary school teachers to learn from teaching: A comparison of two approaches to mathematics methods instruction. *Journal of the Learning Sciences, 27*(3), 474–516.

Schack, E. O., Fisher, M. H., Thomas, J. N., Eisenhardt, S., Tassell, J., & Yoder, M. (2013). Prospective elementary school teachers' professional noticing of children's early numeracy. *Journal of Mathematics Teacher Education, 16*(5), 379–397.*

Scheiner, T. (2016). Teacher noticing: Enlightening or blinding? *ZDM-Mathematics Education, 48*(1–2), 227–238.

Scheiner, T. (2021). Towards a more comprehensive model of teacher noticing. *ZDM-Mathematics Education* **(this issue)**.

Seidel, T., & Stürmer, K. (2014). Modeling and measuring the structure of professional vision in preservice teachers. *American Educational Research Journal, 51*(4), 739–771.

Sherin, B., & Star, J. R. (2011). Reflections on the study of teacher noticing. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 66–78). New York: Routledge.

Sherin, M. G., & Han, S. Y. (2004). Teacher learning in the context of a video club. *Teaching and Teacher education, 20*(2), 163–183.

Sherin, M. G., Jacobs, V. R., & Philipp, R. A. (Eds.). (2011). *Mathematics teacher noticing: Seeing through teachers' eyes*. New York: Routledge.

Sherin, M., & van Es, E. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education, 13*(3), 475–491.*

Sherin, M. G., & van Es, E. (2009). Effects of video club participation on teachers' professional vision. *Journal of Teacher Education, 60*(1), 20–37.*

Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to do a systematic review: A best practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. *Annual Review of Psychology, 70,* 747–770.

Stahnke, R., Schueler, S., & Roesken-Winter, B. (2016). Teachers' perception, interpretation, and decision-making: A systematic review of empirical mathematics education research. *ZDM-Mathematics Education, 48*(1–2), 1–27.

Star, J. R., & Strickland, S. K. (2008). Learning to observe: Using video to improve preservice mathematics teachers' ability to notice. *Journal of Mathematics Teacher Education, 11*(2), 107–125.*

Stockero, S. L., Rupnow, R. L., & Pascoe, A. E. (2017). Learning to notice important student mathematical thinking in complex classroom interactions. *Teaching and Teacher Education, 63,* 384–395.*

Superfine, A. C., Amador, J., & Bragelman, J. (2019). Facilitating video-based discussions to support prospective teacher noticing. *The Journal of Mathematical Behavior, 54,* 100681.*

Ulusoy, F., & Çakıroğlu, E. (2018). Using video cases and small-scale research projects to explore prospective mathematics teachers' noticing of student thinking. *EURASIA Journal of Mathematics, Science and Technology Education, 14*(11), 1–14.*

van Es, E. A., Cashen, M., Barnhart, T., & Auger, A. (2017). Learning to notice mathematics instruction: Using video to develop preservice teachers' vision of ambitious pedagogy. *Cognition and Instruction, 35*(3), 165–187.*

van Es, E. A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Journal of Technology and Teacher Education, 10*(4), 571–596.*

van Es, E. A., & Sherin, M. G. (2006). How different video club designs support teachers in "learning to notice." *Journal of Computing in Teacher Education, 22*(4), 125–135.

van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Education, 24*(2), 244–276.*

Walkoe, J. (2015). Exploring teacher noticing of student algebraic thinking in a video club. *Journal of Mathematics Teacher Education, 18*(6), 523–550.*

Walkoe, J., & Levin, D. M. (2018). Using technology in representing practice to support preservice teachers' quality questioning: The roles of noticing in improving practice. *Journal of Technology and Teacher Education, 26*(1), 127–147.*

Yang, X., Kaiser, G., König, J., & Blömeke, S. (2020). Relationship between pre-service mathematics teachers' knowledge, beliefs and instructional practices in China. *ZDM-Mathematics Education, 52*(3), 281–294.

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