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What They Notice in Photographs: A Study of Preservice Teachers' Noticing in a Formative Assessment Cycle

Identified as a critical skill, researchers have explored various ways to develop teacher noticing skills within teacher preparation programs (e.g., Amador et al., 2021; Fisher, et al., 2018; Fernández et al., 2020). Learning trajectories/progressions (LT/Ps) are useful tools that can structure teacher noticing (Ivars et al., 2018), and also support formative assessment practices (Ebby & Petit, 2018). This paper explores PSTs' noticing skills by analyzing work samples from a methods course assignment that engaged PSTs in noticing and planning for future instruction with an opportunity to utilize LT/Ps.

Teacher Noticing

Importance of Developing Noticing Skills

The National Council of Teachers of Mathematics (NCTM) (2014) places particular emphasis on teachers' abilities to elicit and use evidence of student thinking and further identifies teacher noticing as, "planning for ways to elicit that information, interpreting what the evidence means with respect to students' learning, and then deciding how to respond on the basis of students' understanding (Jacobs et al., 2010; Sleep & Boerst, 2010; van Es, 2010)" (p. 53). Similar goals have been expressed by the Association of Mathematics Teacher Educators (AMTE, 2017). In order for PSTs to become well-prepared beginning teachers, teacher education programs need to provide opportunities for PSTs to develop the skills of attending, interpreting, and responding to student thinking (AMTE, 2017; Star & Strickland, 2008).

Mathematics teacher educators (MTEs) have utilized a variety of tools to support the development of PSTs' ability to notice, including video clubs (e.g., Mitchell & Marin, 2015; Walkoe, 2015), interviews (e.g., Lesseig et al., 2016), students' written work (e.g., Monson et al.,

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2020), and photographs (e.g., Oslund & Crespo, 2014). Most studies of PST noticing include "some type of written document as evidence of noticing" (Amador et al., 2021, p. 7) and many use video and/or audio. Jacobs and Spangler (2017) indicate that, despite their popularity, video and student written work are not the only means to notice children's mathematical thinking and identify photographs as potential artifacts for studying teacher noticing. While the specific use of photographs in research about PSTs' ability to notice is scant, Oslund and Crespo (2014) demonstrate how photographs of student work, a math lesson, and classroom and community contexts can be used to promote noticing skills by having inservice and preservice teachers engage in conversations about what might or could have happened in the photographs. This work further explores PSTs' ability to notice using photographs as evidence of student thinking.

Mathematics teacher noticing is an evolving body of research (Schack et al., 2017; Sherin et al., 2011a) in which researchers are asking "primal questions of teaching: where do teachers look, what do they see, and what sense do they make of what they see?" (Sherin et al., 2011b, p. 3). Van Es (2011) asserts that the development of teachers' noticing skills is important because "focusing on student thinking and children's learning promotes teaching and learning mathematics for understanding and leads to improved student achievement" (p. 135).

Conceptualizations of Teacher Noticing

Two major frameworks define the literature on mathematics teacher noticing: Learning to Notice (van Es & Sherin, 2002) and Professional Noticing of Children's Mathematical Thinking (Jacobs et al., 2010). Van Es and Sherin's (2002) Learning to Notice framework focuses on three key aspects of learning to notice: (a) identifying important moments; (b) making connections from observations to experience and knowledge; and (c) using context to understand teaching situations. Jacobs et al. (2010) have more specifically defined professional teacher noticing of

children's mathematical thinking to include the three interrelated skills of attending, interpreting, and responding to children's mathematical thinking. This type of professional work requires teachers to be able to identify and interpret the important mathematical ideas in students' verbal, written, or concrete work in order to respond in ways that build upon student thinking.

Later, van Es (2011) proposed a framework that outlines a trajectory of development containing four levels of noticing that measures "two central dimensions: what teachers observe in classroom episodes and how they reason about these features of instruction" (p. 148). Essential to this framework is the relationship between what and how teachers notice and the conclusion that "learning to attend to the particulars of student mathematical thinking may help teachers reason about what they observe" (van Es, 2011, p. 149).

A key difference between the two frameworks is that Jacobs et al. (2010) extend to "responding" and next instructional steps. Because Jacobs et al. (2010) view professional teacher noticing of children's mathematical thinking as happening quickly in the moment, the cognitive skills of attending, interpreting, and deciding how to respond occur almost simultaneously in discursive interactions with students (e.g., listening to a child explain their thinking, making sense of what the child understands mathematically, and making a decision regarding feedback to the child). Whether noticing is outside or inside of the moment, both frameworks have prioritized teacher noticing focused on attending and making sense of student mathematical thinking with the intention to be instructionally responsive.

The Learning to Notice framework coupled with formative assessment extends van Es and Sherin's (2002) noticing framework to the practical and professional work of planning for, collecting, and using formative assessment data to inform instruction. This extension of the

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Learning to Notice framework runs parallel to the ways Jacobs et al. (2010) define professional teacher noticing of children's mathematical thinking to include responding.

Connections between Teacher Noticing and Formative Assessment

"Formative assessment is a powerful instructional tool worthy of every teacher's attention and an important element of effective instruction" (Mills et al., 2018, p. 4) and, is defined by Wiliam (2018), as an assessment through which:

> Evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have made in the absence of that evidence (p. 48).

Teacher noticing is a skill that informs and supports formative assessment practices (Marin et al., 2020; Furtak et al., 2016; Pai, 2018). Specifically, Furtak et al. (2016) synthesized the processes of teacher noticing (N) and formative assessment (FA) to include: "eliciting (FA), attending (N), interpreting (FA, N), deciding (N), and responding (FA, some N)" (p. 4). This merged framework begins to highlight the ways teachers process information in the classroom (attending, interpreting, and responding) and the tools and actions teachers use to elicit student thinking and make future instructional decisions. Likewise, Marin and colleagues (2020) and Pai (2018) present visualizations focused on noticing skills that teachers are cognitively engaged in during formative assessment practices (i.e., attending and interpreting) and the instructional actions a teacher does in response to the student's thinking. Thus, formative assessment is an activity in the work of teaching where teacher noticing skills (attending, interpreting, and responding) can be authentically practiced and developed in teacher preparation.

Learning to Notice in Mathematics Teacher Education

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Teachers' noticing skills vary with expertise (Berliner, 2001). Evidence suggests that novice teachers find noticing challenging and demonstrate less developed noticing skills than veteran teachers (de Araujo et al., 2015). Therefore, van Es (2011) suggests, "teachers need to learn to notice" (p. 134). As such, learning to notice has become a popular topic of study across research on mathematics teacher education. There is evidence demonstrating that PSTs are able to learn to notice using more specific language and targeted activities in coursework (e.g., Fisher, et al., 2018; Fernández et al., 2020). Iterative assignments utilizing feedback loops have also supported PSTs in "becom[ing] more aware of the relation between students' mathematical thinking and their teaching actions" (Fernández et al., 2020, p. 971). Many teacher educators have taken the approach that teacher noticing can be decomposed into approximations of practice (Grossman et al., 2009). The complex practice of teacher noticing has been deconstructed to noticing in video, live classrooms, and viewing student work samples (Sherin et al., 2011a). Research has also demonstrated the ability to improve teachers' abilities to notice through various approximations of practice that either remove pressures of in-the-moment noticing by allowing teachers to notice outside the classroom moment, or that zoom in on one particular aspect essentially eliminating part of the external stimuli (e.g., Sherin & Star, 2011).

Noticing can happen in the moment and outside the moment, and both have been utilized as ways to investigate teacher noticing skills. Researchers have utilized videos (Mitchell & Marin, 2015; van Es, 2011; van Es & Sherin, 2008) and written lesson elements (e.g., Amador & Weiland, 2015) as ways to capture student mathematical thinking in the classroom, and thus act as an approximation of practice for teacher noticing both in and out of the moment. Less prevalent in the noticing research is the use of photographs. Photographs provide a classroom artifact that can be revisited and interpreted outside of the teaching moment (Roller et al., 2019b,

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2020; Jacobs & Spangler, 2017; Sherin & van Es, 2003). Oslund and Crespo (2014) also promoted teacher noticing skills by leveraging photographs, which do not tell a complete story, but instead encouraged teachers to consider and discuss alternative narratives of what might or could have happened while examining students' math work.

While video is a powerful tool for research on teacher noticing, it is not always a practical option in the day-to-day work of classrooms. Teachers do not often videotape lessons without purpose and in some cases taking video of a lesson could violate students' safety, security, and FERPA rights (U. S. Department of Education, 2022). However, if an interesting moment arises in math class, the teacher could easily capture an image or series of images of a student's thinking in a photograph. These images can be reviewed later as an artifact of student thinking. Photographs are particularly helpful during a task as a means to capture students' work with manipulatives that will disappear at the conclusion of a lesson (Roller et al., 2019b, Tapper, 2012). Photographs can also be used to document student understanding (Krechevsky et al., 2013) and as formative assessment data to inform instructional decisions (Roller et al., 2019a, 2020). Therefore, when PSTs use photographs for noticing, they are honing an important skill and engaged in realistic approximations of practice (Grossman et al., 2009). As Sherin and Star (2011) note, teachers are "bombarded with a 'blooming, buzzing confusion' (James, 1980) of sensory data" (p. 69), which makes it difficult to attend to a specific part of that buzz, namely, students' mathematical thinking. We hypothesize the use of photographs allows PSTs to focus on a single moment with a specific intention of noticing students' mathematical thinking. Additionally, similar to Oslund and Crespo's (2014) work, photographs can also be used in methods courses as ways to develop and extend PSTs' noticing skills when MTEs use the photographs to encourage conversation about alternative explanations of what might or could be

occurring in the photograph. Limited research has been done on the use of photographs as a tool for the development of noticing skills in PSTs.

Learning trajectories/progressions (LT/Ps, Lobato & Walters, 2017) have potential as an instructional tool in mathematics teacher education. The ability to notice students' mathematical thinking is enhanced by the use of learning trajectories (Ivars et al., 2020). NCTM (2014) identifies learning trajectories as "one source for identifying critical indicators of student thinking" with power lying in the description of "how students' mathematical thinking develops over time" (p. 53). Professional development opportunities that utilize LT/Ps with in-service teachers (Clements et al., 2011; Sztajn & Wilson, 2019; Supovitz et al., 2021) have been studied, but few investigate their implementation with PSTs. For example, Ivars et al. (2018, 2020) suggests that PSTs who have experiences with LT/Ps are better able to describe student thinking and Wilson et al. (2013) demonstrated that PSTs using LT/Ps are able to shift their focus from "right" or "wrong" solutions and instead focus on student thinking. However, while this addition of labels is helpful for identification and description (Ivars et al., 2018), it has been noted that in-service teachers may incorrectly use LT/Ps to label the student instead of the work sample (Ebby & Petit, 2018), a problem that could persist for PSTs.

Theoretical Framework

Noticing, regardless of the unit of analysis, is an important skill set for teachers that guides the way teachers gather, analyze, and act upon formative assessment data. We draw on the prevalent conceptions of noticing: Learning to Notice (van Es & Sherin, 2002; van Es 2011) and Professional Noticing of Children's Mathematical Thinking (Jacobs et al., 2010), and formative assessment (Wiliam, 2018). Through those lenses, we used an adapted version of Marin and colleagues' (2020) reimagined cycle of formative assessment drawing on teacher

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noticing skills that utilizes photographs, and displays how learning trajectories can be incorporated at each stage to enhance noticing and promote formative assessment (Figure 1).

[Insert Figure 1]

The cycle includes the teacher noticing skills of attending, interpreting, and responding to student's thinking (Jacobs et. al, 2010, van Es 2011), while extending this work to mirror formative assessment practices of anticipating student thinking prior to the start of a lesson and recommending next instructional steps. The cycle is designed to support teacher noticing and formative assessment practices by giving teachers additional time outside the moment to interpret and analyze the student thinking they captured during math class. The skill of responding is also moved outside the moment to encourage intentional decisions that will build on student thinking. The pulling apart of these constructs aligns the reimagined cycle with the Learning to Notice frameworks (van Es & Sherin, 2002; van Es, 2011).

Marin et al. (2020) note "the disappearing nature of children's work makes it difficult for teachers to capture data that illuminates children's mathematical understandings, a necessary component in planning future instruction" (p. 135). Photographs are a means of capturing this disappearing data, particularly in early childhood classrooms where work is often built (using manipulatives) rather than written and therefore cannot be collected for later analysis. Collecting this data is a means of formative assessment, which the teacher can use to inform future instruction, and provide an authentic space to slow down and hone teacher noticing skills. The reimagined formative assessment cycle (Figure 1) demonstrates teacher noticing as an essential skill for effective formative assessment practices and offers ways teachers can leverage photographs to scaffold the process of noticing students' mathematical thinking.

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However, as noted by van Es and Sherin (2002), it is possible for teachers (especially novices) to lose focus and attend to moments not about mathematics. In an effort to help teachers maintain focus on the mathematics content and goals, Marin and colleagues' (2020) framework places learning trajectories around the teacher noticing work. Thus, suggesting that learning trajectories can offer teachers a lens and support to help notice and focus on students' mathematical thinking. There is limited research on PSTs use of LT/Ps as tools that may support them to identify important mathematical evidence in student thinking.

Research Questions

This research investigates PSTs' teacher noticing skills within a formative assessment cycle where photographs are utilized to capture children's mathematical thinking (Figure 1). We seek to answer the following questions:

1. To what extent did PSTs attend to students' mathematical thinking in their captions of photographs?
2. How do PSTs interpret children's mathematical thinking in photographic evidence of children's work in math stations as written in their captions?
3. How do PSTs propose responding to children's mathematical thinking in photographic evidence of children's work in math stations?
4. To what extent did PSTs utilize learning trajectories to support their interpreting and responding to children's mathematical thinking?

Research Design

Data collection for this qualitative study took place during Fall 2017 at a small public university in the Southeast. The following sections describe the participants, course context, data collection, and data analysis.

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Participants

Eighteen out of 20 PSTs enrolled in the sole elementary mathematics methods course in their teacher preparation program consented to the study and 17 PST Math Work Station Projects were investigated. One PST's project was dismissed due to a misalignment between the grade level of the content standard and the students (i.e., fifth grade classroom and sixth grade content standard). Typical of elementary teacher preparation programs, the population was predominantly white and female. Participants were in the second or third semester of a four-semester teacher preparation program. Each participant submitted one Math Work Station Project, in the context of the course requirements, that was graded. All participants consented to the use of assignments for research purposes after course grades were submitted.

Course Context

This research was conducted in an elementary mathematics methods course focused on the Effective Mathematics Teaching Practices (NCTM, 2014) and instructional routines promoting number sense development (i.e., number talks and math work stations). Throughout the course, PSTs engaged in assignments aligned to the course goals including: number talk rehearsals and a book study of *Math Work Stations: Independent Learning you Can Count On, K-2.* (Diller, 2011), which provides explicit examples of stations that develop number sense. To further extend PSTs' knowledge of children's development of additive and multiplicative thinking, they were introduced to the Additive and Multiplicative Ongoing Assessment Project (OGAP) learning progressions and used them to classify student strategies from work samples. In this course, PSTs developed and implemented a math work station in a K-5 field placement.

Data Collection

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The Math Work Station Project was assigned in the methods course, following a book study about math work stations. Details about the book study and how the assignment was designed and implemented can be found in *Preparing Teachers of Mathematics with a Math Work Station Project* (Roller, 2019). The assignment was designed to engage PSTs in photographing what they noticed about students' mathematical thinking, interpreting the work captured in the photograph, and responding to each student's thinking in writing by proposing instructional next steps. See Appendix A for the assignment prompts. PSTs had seven weeks to plan and enact the work station they created in their field placement. They observed pairs of students engaged in their work station and took photographs, and then submitted three captioned photographs as part of their completed assignment.

PSTs wrote two-paragraph captions to accompany each submitted photograph. In paragraph one, they attended to and interpreted student thinking by identifying and describing the mathematical thinking present in the photograph. In paragraph two, PSTs responded by suggesting instructional decisions based on the evidence in the photograph. Because PSTs had prior exposure to the OGAP Additive and Multiplicative Frameworks (Hulbert & Ebby, 2017; Petit & Laird, 2017) it was recommended that the learning progressions could be used to support their work. Using an OGAP progression was optional in the course assignment, however, all participants focused on base ten and number operation standards in their assignment, which made the use of OGAP learning progressions possible. In total, the 17 Math Work Station Projects resulted in a collection of 51 captions about corresponding photographs (i.e., three per PST), which were separated from the remaining aspects of the assignment for data analysis.

Data Analysis

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We analyzed the collection of captions about photographs (N = 51) using structural coding (Saldaña, 2009) and drew from teacher noticing literature (Jacobs et al., 2010; van Es, 2011). In a new context using photographs as the artifact from student mathematical thinking, this data analytic process has the potential to confirm earlier research findings that PSTs'can notice (e.g., Amador & Weiland, 2015; Mitchell & Marin, 2015; de Araujo, 2015). Structural coding is "a question-based code that acts as a labeling and indexing device" (Saldaña, 2009, p. 67). It is useful in analyzing narrative work samples, such as those collected in this study, because it "generally results in the identification of large segments of text on broad topics" which provide a starting point for more in-depth analysis within or across topics (Saldaña, 2009, p. 68). This data set was broadly coded by category and then further analyzed in smaller, more focused subcategories (See Figure 2). Following a review of the literature, we chose a coding protocol influenced by van Es (2011) that focused on what and how teachers notice and added interpreting and responding aspects from Jacobs et al. (2010) to address formative assessment practices. This resulted in the categories: topic, level of evidence to make sense of student thinking, and use of evidence for responding and making instructional choices. Within each category, codes and subcodes were established and defined, and a codebook was created prior to coding. We individually coded 51 captions and reconciled differences.

[Insert Figure 2]

Coding Schema

Codes were developed in three groups: Attending, Interpreting, and Responding. Within each of these groups there were categories, codes, and subcodes. Each category is discussed in the remainder of this section. Appendix B contains abbreviated examples of each of the codes.

Attending codes

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Like van Es (2011), the coding category of Topic was used to identify what the PST attended to in each photograph based on the caption. We were interested to see if PSTs would attend to students' mathematical thinking, which van Es (2011) identified as a higher level of noticing than general observations and is also aligned with Jacobs and colleagues' (2010) professional teacher noticing of children's mathematical thinking. Since novice teachers are less likely than experienced teachers to focus on noticing mathematics content (Star & Strickland, 2008), we used the category "Mathematics" to code captions that mentioned mathematics. Subcodes "Specific" and "General" were then applied to the captions in the "Mathematics" category. Captions that referenced a specific strategy/model and discussed the mathematical meaning were coded as "Specific." Captions that identified a procedure or described steps without discussing the mathematical meaning were coded as "General." For example, Riley specifically described how "the student had tried another method before beginning to write the repeated addition problem; he said he needed to 'count by seven, nine times.'" We coded this caption as "Mathematics-Specific." See Table B1 in Appendix B for additional abbreviated examples of the attending codes.

Interpreting Codes

To investigate PSTs' interpreting skills (Jacobs et al., 2010; van Es, 2011), three coding categories were used: (a) level of evidence to make sense of student mathematical thinking; (b) the type of evidence utilized to make sense of student thinking; (c) whether or not a LT/P was used to help make sense of students' mathematical thinking.

The first interpreting coding category was the level of evidence to make sense of student mathematical thinking, which is similar to van Es (2011) and Jacobs et al. (2010). PSTs often have limited experience and therefore may struggle with using language that Jacobs and

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colleagues (2010) used to classify as "robust evidence, limited evidence, and lack of evidence" (p. 179). As such, we used codes from van Es's (2011) first three levels of learning to notice student thinking: specific evidence (e.g., verbatim quote, or pointing to a specific spot in math work), general evidence (e.g., identifying a strategy but not connecting to student work), and no evidence (e.g., not pointing to mathematical thinking or work).

The second interpreting coding category named the type of evidence the PSTs utilized to make sense and interpret student mathematical thinking. Coding categories included photograph, conversation, prior knowledge about students, and combinations of these. For example, Jordan wrote, "I knew that this group of students does not fully comprehend long division yet, so that is why I incorporated long division practice in this math work station." We coded this caption as "prior knowledge about students." The captions were further coded for evidence of PSTs' use of LT/P to make sense of student thinking. Captions that mentioned the OGAP progressions or included language from OGAP were coded as "Uses LT/P." Captions that did not mention OGAP progressions were coded "Does not use LTP." See Table B2 in Appendix B for additional abbreviated examples of the interpreting codes.

Responding codes

Jacobs et al. (2010) identify the third component of professional noticing of children's mathematical thinking as "deciding how to respond on the basis of children's understandings" (p. 173). This act of making intentional instructional decisions that build on students' mathematical thinking is also a key component to formative assessment (Wiliam, 2018). The main category identified for coding was "responding" and focused on the level of evidence PSTs were using to decide how to respond. The second category was "Responding with LT/P" and was used to identify LT/P use to justify next instructional steps. Like Jacobs et al. (2011), we chose not to

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evaluate whether the suggested responses were the best moves. Instead, we focused on the level at which evidence was used in deciding how to build on children's thinking, and whether an LT/P was utilized to decide how to respond.

We extended our van Es (2011) inspired interpreting codes regarding level of evidence to responding. These codes were used to analyze the second paragraph of the caption which addressed how the PST planned to respond to the student's mathematical thinking. A caption including a quote from the student or pointing to a specific place in the student's work when making decisions about how to respond was coded "Specific Evidence." A caption referencing a general procedure or name on the progression, but lacking detailed description of student thinking was coded "General Evidence." Captions describing a next instructional step without a connection to the student work or the mathematics, or without any decision about how to respond was coded as "No Evidence".

Finally, we used the coding category "Responding with LT/P" to identify if the PST used an LT/P to justify or assist them in deciding their next instructional move. Captions citing a stage/strategy on the LT/P as a next instructional step were coded "Responding with LT/P." For example, Emerson wrote, "I would also have the student practice their skip-counting. I would also have the student show me their thinking with drawings to ensure that they are truly on the Additive stage of OGAP Multiplication Progression." We coded this caption as "Responding with LT/P." See Table B3 in Appendix B for additional abbreviated examples.

Results

The results section is organized according to the research questions. The results include relative frequencies identified in the data analysis (Appendix C).

PSTs' Attending Skills

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PSTs attended to mathematics in approximately 84% of the captions and not mathematics in approximately 16% of the captions. Of the 43 captions focused on mathematics, 72% (31) discussed specific mathematics content, strategies, or models that students used at the math work station, whereas the other 27% (12) discussed mathematics in general ways. Therefore, analysis of the captions suggests PSTs were typically able to capture and discuss student mathematical thinking in a photograph when prompted to do so in an assignment.

PSTs' Interpreting and Responding Skills

We coded the captions for evidence of how PSTs interpreted and proposed responses to the student's mathematical thinking captured in photographs of children's work in math stations. An investigation of relative frequencies for the level of evidence in the captions was used to interpret and to respond to students' mathematical thinking, and suggests PSTs typically included more detailed levels of evidence while interpreting students' work than when responding to students' mathematical thinking. Furthermore, it was only on rare occasions that a PST's caption would include more evidence to respond than to interpret a student's thinking.

The majority of captions (31) cite specific evidence used to interpret the student's mathematical thinking in the photograph, and typically both a photograph and conversation (19 of 31). This mirrors the authentic practice of teaching, where teachers gather information from observing students engaged in a learning activity and by investigating the assessment artifact. In the captions that included specific evidence for interpreting, there was rarely specific evidence (9 of 31) used to describe responding and decision making for future instruction. Typically captions included general evidence (18 of 31). A promising finding is that the PSTs' captions including specific evidence used to interpret rarely (4 of 31) included no evidence when used to respond.

Contrastingly, ten captions included the use of general evidence for interpreting. Of these

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10 captions, the most common types of evidence cited are again: photograph (4 captions) and photograph and conversation (4 captions). Like the trends in those captions including specific evidence, captions that included general evidence to interpret demonstrated a decline in the use of evidence to respond. Next instructional steps were justified with either general (4 captions) or no evidence (5 captions). In captions where no evidence was cited to interpret students' mathematical thinking, typically there was also no evidence cited to respond (8 of 10).

PSTs Use LT/Ps for Interpreting and Responding

An extension of research questions two and three was to explore how/when PSTs used an LT/P and in what ways the use of this tool supported PSTs to interpret and respond to student thinking in photographs of children's work at math stations. One-third of the captions (17) referenced an LT/P - an OGAP progression (Hulbert & Ebby, 2017; Petit & Laird, 2017) - to interpret the strategies captured in the photographs. Nine of the 17 captions where an LT/P was utilized for interpreting also used the LT/P to justify their next instructional steps. Additionally, in captions without a reference to an LT/P to interpret student thinking (34 captions), there was often a lack of justification for the instructional response (33). Further investigation of the 17 captions that used a LT/P to make sense of the students' mathematical thinking revealed that the topics of these observations were predominately about mathematics. Additionally, 14 of the 16 captions that focused on mathematics attended to specific mathematical thinking. Thus, suggesting when PSTs utilize a LT/P they tend to focus more on specific mathematical ideas and strategies in the student work.

In reviewing captions that utilized an LT/P, we noticed PSTs had a tendency to label the student or identify a student's level, versus labeling the student's strategy and where that strategy would appear on a LT/P. An example of this language is displayed in Sidney's narrative:

> "The next step for this student would be to work on finding equal fractions by using multiplication. Without the manipulatives, this student is in the non-fractional stage of the OGAP fraction progression."

In this example, Sidney's narrative displays a common mistake teachers and PSTs make when using LT/Ps, where they place students on the learning progressions instead of placing the specific mathematical strategy on the learning progression (Ebby & Petit, 2018). MTEs will likely want to explicitly address this with PSTs, as well as the notion that the strategies a student uses may move forward and backward in complexity on a LT/P depending on the student's familiarity with the problem type or the numbers.

Discussion

Upon analysis of the data, we had four main takeaways with regards to PSTs' noticing and photographs. PSTs can: (a) notice students' mathematical thinking; (b) notice students' mathematical thinking in photographs they captured; (c) attend to and interpret the mathematics in photographs, but need additional support to consider how to respond to the mathematical thinking; and (d) use LT/Ps to help them notice (specifically attend and interpret), but there is less evidence of them using LT/Ps as a tool to respond to students' mathematical thinking. We will unpack each of these takeaways and discuss their implications for mathematics teacher education practices and further research.

PSTs Can Notice

This study confirms prior findings that PSTs can notice (e.g., Amador & Weiland, 2015; Mitchell & Marin, 2015; de Araujo, 2015), in the new context of using photographs. Given that there is evidence in captions that PSTs can notice, MTEs need to consider ways to leverage and develop noticing skills when planning instruction for future teachers. This implication is

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important because while PSTs notice, and have shown that they sometimes notice mathematical thinking, they do not always do so to the extent of the levels described by van Es (2011) or in the robust ways that Jacobs et al. (2010) discuss.

Noticing in Photographs

While many researchers have shown evidence that PSTs can notice students' mathematical thinking in various mediums, the findings in this study show evidence in captions that PSTs were able to use photographs to capture and notice students' mathematical thinking. Studies of PST noticing often use video (e.g., Mitchell & Marin, 2015) or written lesson elements (e.g., Amador & Weiland, 2015) as their medium. What the findings in this research indicate is that photographs can also be used to assist PSTs in practicing their noticing skills in ways that align with formative assessment practices of documenting student learning (Krechevsky et al., 2013; Tapper, 2012). Photographs are a promising medium for teacher education practices focused on noticing because they decompose the practice of noticing within the authentic context of formative assessment and allow PSTs to focus on one aspect of noticing at a time. For example, PSTs focus on attending when taking the photographs and can shift to interpreting the photograph outside of the teaching moment. Additionally, photographs can be taken without identifying the student and can be easily displayed in teacher education courses, where alternative interpretations and responses may be explored (Oslund & Crespo, 2014).

PSTs' Noticing Skills with a Formative Assessment Cycle

The findings show that PSTs can attend to and interpret students' mathematical thinking in a scaffolded assignment mimicking the formative assessment cycle, where they take photographs and caption them. Since the majority of the captions focused on mathematics (84%), there is evidence to suggest that the majority of PSTs in this study did notice the mathematics in

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photographic evidence of student work. The data also show that when PSTs notice mathematics they often attend to specific mathematical ideas (e.g., content, strategies, models) versus general mathematical ideas (e.g., procedures). Since the assignment was embedded in a classroom enactment, the majority of PSTs' captions pointed to specific evidence when interpreting students' thinking, and used a variety of evidence to make sense of the students' work, including photographs, conversations observed during the implementation of the station, and prior knowledge about the class or student. However, the findings also indicate even when PSTs' captions included specific evidence for interpreting the students' mathematical thinking, the captions typically did not continue to include specific evidence for making decisions about how to respond or plan for next instructional steps. The decline in use of evidence may be a result of a course focus on using trajectories to attend and justify interpretations, and less on how to respond. It is also possible that this decline is evidence of PSTs beginning to develop responding skills. This has implications for the effectiveness of formative assessment where teachers make instructional decisions built on students' mathematical thinking.

PSTs' Use of LT/Ps to Notice

PSTs in this study had a brief introduction in their coursework to the OGAP Additive and Multiplicative Progressions (Hulbert & Ebby, 2017; Petit & Laird, 2017) - LT/Ps that feature a trajectory of developmentally appropriate additive and multiplicative strategies. There was not a requirement for PSTs to use the LT/P in their analysis of their photographs, but some PSTs did choose to use the LT/Ps to guide their work on the assignment, as noted in the captions that used LT/Ps. When PSTs used LT/Ps they overwhelmingly noticed the mathematics and used specific evidence in the photograph to make sense of the mathematics they captured, suggesting LT/Ps could have an influence on PSTs' ability to attend to and interpret students' mathematical

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thinking. However, there is only limited evidence to suggest that the PSTs used LT/Ps when constructing their instructional responses to student thinking, and could be the result of PSTs using language from given documents without understanding of their meaning - a caution about providing guiding documents to PSTs noted by Norton and Kastberg (2011). Typically, if a PST's caption did not include an OGAP progression to interpret the student's mathematical thinking, the PST also did not use it to justify their next instructional steps. Thus, the first step in supporting PSTs' noticing skills is making sure that PSTs have tools for interpreting the student's mathematical thinking. So, it appears that LT/Ps supported PSTs' attending and interpreting but were utilized less so for responding to students' mathematical thinking. This finding has implications for MTEs who need to not only teach PSTs how to use LT/Ps to attend and interpret student thinking but they also need to spend instructional time working with PSTs to use an LT/P when developing instructional responses to student thinking.

Limitations

Sherin et al. (2011b) describe the process of attending as what a teacher does or does not pay attention to in the classroom. Through this lens, a limitation of the study is that data were not collected regarding what PSTs photographed or did not photograph while students engaged at a math work station. Nor was data collected on how PSTs selected or deselected photographs for the assignment. It is also unknown if PSTs used additional resources, such as textbooks, peers, or mentors, nor if they truly made sense of guiding documents provided in the course to make sense of the student thinking in the photographs for their captions (see Norton & Kastberg, 2011). Thus, the teacher noticing skills investigated in this study might be more scaffolded versus entirely independent. A final limitation is that the participants in this study were exposed to one type of LT/P (Lobato & Walters, 2017), which makes it difficult to generalize how they might

utilize other LT/Ps or what the affordances or limitations might be of each tool.

Implications

Implications for Mathematics Teacher Education

These findings support the belief that PSTs can notice students' mathematical thinking. Their ability to notice and the ways in which they notice are often less sophisticated than in-service teachers (Berliner, 2001). However, this study suggests providing PSTs with the opportunity to investigate student thinking out-of-the-moment gives them an opportunity to practice their noticing skills. What this means for mathematics teacher education is that PSTs are capable of doing this work in their coursework and should be supported in learning to notice. MTEs can and should be providing opportunities for PSTs to notice, provide instruction around what and how to notice, along with supporting the development of noticing using LT/Ps and creating opportunities to use LT/Ps in guided tasks in class and on assignments. These types of activities in mathematics teacher education support the recommendations from the Standards for Preparing Teachers of Mathematics (AMTE, 2017). MTEs should consider ways to support the development of PSTs' noticing skills in coursework and during field experiences.

Another implication for mathematics teacher education is the consideration of the types of artifacts illustrating students' mathematical thinking. Many studies (see Amador et al., 2021) have demonstrated the value of video, and written work (e.g., Monson et al., 2020) as artifacts of students' mathematical thinking. This study corroborates Roller and colleagues' (2019a, 2019b) and Marin and colleagues' (2020) work indicating that photographs are valuable artifacts of students' thinking. In this research, there is evidence that photographs taken during work with students in field experiences, proved to be useful artifacts of student thinking and provided evidence that informed PSTs' noticing of students' mathematical thinking. Photographs allow

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PSTs to experience the context of the artifact, as well as independent focused time to make sense of the captured work. We argue that photographs are useful and meaningful in coursework for PSTs with specific regard to the development of PSTs' noticing skills.

The final implication is evidence to support the use of LT/Ps in coursework. LT/Ps are useful for identifying a student's strategy on a continuum of understanding, but the heavy lift for teachers is understanding how to help move that students' thinking forward, which is a critical component of formative assessment. This is a sophisticated teacher move and one that PSTs often do not yet have the experience, knowledge, and/or skill set to do. This is a space in which MTEs can develop opportunities for PSTs to engage in this challenging work. What these opportunities look like and/or how they are integrated into coursework is a topic ripe for investigation in studies of mathematics teacher education practices.

Implications for Research

There is a sizable body of research on the noticing skills of in-service teachers (see Walkoe, 2015; van Es & Sherin, 2008) and a growing body of research on the noticing skills of PSTs (see Amador et al., 2021 for examples). But what is seemingly unknown is how PSTs develop noticing skills. Additionally, it would be beneficial to focus new work on exploring how photographs and learning trajectories can be utilized to support the development of preservice teacher noticing skills, both in semester courses, as well as longitudinally across teacher preparation programs and during induction years. More nuanced coding of iterative evidence (e.g., narratives), similar to Fernandez et al. (2020), might also illuminate the ways preservice teachers are noticing in photographs and the ways in which they are leveraging LT/Ps to support their attending, interpreting, and responding. That leaves us with the question: what do well-prepared beginning teachers notice about students' mathematical thinking and when would we

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say that PSTs are skilled "enough" in noticing to be well-prepared to teach? This is an interesting line of inquiry that should continue to be explored.

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Appendix A

The Prompts Guiding PSTs' Teacher Noticing in the Math Work Station Project

Task 3: Implement math work station

Collaborate with your cooperating teacher to find a time when you could watch some students (at least six) engage with your math work station. Remember, students are supposed to work with a partner at a math work station and should be able to do the work independently of the teacher.

As the students work, you will take photographs that capture the students' mathematical thinking. These could be pictures of the manipulatives, drawings, or even their hands. Essentially you are "zooming in" on the math in these photographs, so these photos should NOT include the face of students. You may also decide you want to audio record the speech students are using, so that you can transcribe or quote students later for your project.

Task 4: Analyze students' mathematical thinking and engagement

A. Three Photographs with 2 Paragraph Captions

After teaching, select three photographs that demonstrate the various ways that students engaged and thought about the mathematics. These pictures may also highlight misconceptions or progressions of learning. For each photograph, write a paragraph caption describing why you selected this photograph. Be sure to focus on the mathematics and mathematics learning that is occurring. What is the student demonstrating they can do or understand? What is there not evidence of? If it is helpful, you might also include a quote from the student.

As a teacher, you will need to observe students' mathematical thinking and make decisions about how to differentiate instruction particularly for that student. Based on your analysis of the mathematical thinking, write a second paragraph that describes what the next step would be for this child. You might draw from the OGAP progressions for this section of your project.

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Appendix B

Table B1

Abbreviated Examples of Topic Codes

Name	Code	Example
Riley	Mathematics-Specific	From what you can see on the notecard… The student had tried another method before beginning to write the repeated addition problem; he said he needed to "count by seven, nine times."
Blake	Mathematics-General	The student has demonstrated an understanding of how to set up this problem by first acknowledging that it is a multiplication problem, first, then, he sets up the word problem in a standard algorithm format by knowing what the problem is asking when he places the 159 above the 96. This picture presents that the student understood how to decontextualize a word problem into a strategy that he was most comfortable with using...
Harper	Not Mathematics	I chose this picture because I think that it is a great display of the student's use of both the math talk card and the manipulatives. I think this picture really shows how students rely on tools such as math talk cards to help them begin thinking about how they should approach a difficult problem.

Table B2

Abbreviated Examples of Interpreting Codes

Name	Codes	Example
Riley	Specific Evidence, Photograph & Conversation, Uses LT/P	These students were demonstrating that they could model with mathematics (MP4) using an array, but they did not attend to precision when doing so. Based on the conversations I heard, and how students counted the circles into their array after it was made, I would say they are still in the additive phase of the OGAP multiplication progression. These two students only considered one dimension of the array model, and counted down each column to find out how many circles made up their array. Since the students did know to use an array, they are heading towards the early transitional phase of the progression.
Jordan	General Evidence, Photograph & Prior Knowledge, Does not use LT/P	I selected this photograph, because it shows one of the students working and persevering in problem solving. The student is working on long division, and he is making progress towards the correct answer. I knew that this group of students does not fully comprehend long division yet, so that is why I incorporated long division practice in this math work station. In math class, the students also estimate the quotient, so for a future math station I could incorporate estimating too.

Shannon	No Evidence, No Evidence, Does not use LT/P	I chose this picture because I liked seeing how the students were all working together even if they weren't working on the same task card at that exact time. You can't see the worksheets very well but you can see a lot of task cards and manipulatives on the tables. I love that there is a lot of action happening. Since you can't see faces, you can't see how engaged they look, but they really enjoyed this activity and they did talk about mathematics along with discussing their task cards and their plans.

Table B3

Abbreviated Examples of Responding Codes

Name	Code	Example
Sidney	Specific Evidence, Does not use LT/P	Since Lyra struggled to count in groups of two's or five's, I believe Lyra falls under the early counting section of the OGAP. Lyra struggled to count by twos because she was adding two plus two plus two and she was constantly losing track of how many counters she had counted. Lyra needs extra help to construct the meaning of numbers and to better make sense of numbers. Lyra would benefit from working with the teacher one-on-one to build her counting fluency. Once Lyra was able to visually see her counters, she was able to identify one more and one less, with the help of her partner.
Emerson	General Evidence, Uses LT/P	I believe that this student is in the Early Transitional Stage of OGAP Multiplication Progression. Although it cannot be seen in the picture, while solving the equations the student was using skip counting to determine the product of the equation. There were times where she used non-multiplicative strategies and used the procedure incorrectly by skip counting incorrectly, but the student was able to recognize their errors and try again. As a way to help this student progress I would begin working with them on solving multiplication equations using an open area model. I would also have the student practice their skip-counting. I would also have the student show me their thinking with drawings to ensure that they are truly on the Additive stage of OGAP Multiplication Progression.
Rowan	No evidence, Does not use LT/P	When it comes to differentiation for this student I would implement more number sense workstations to assist with her number fluency. I believe that if she had a chance to practice counting, and being exposed to numbers above ten then she would become more fluent. Overall, this student really enjoyed working with this station and being able to collaborate with her peers.

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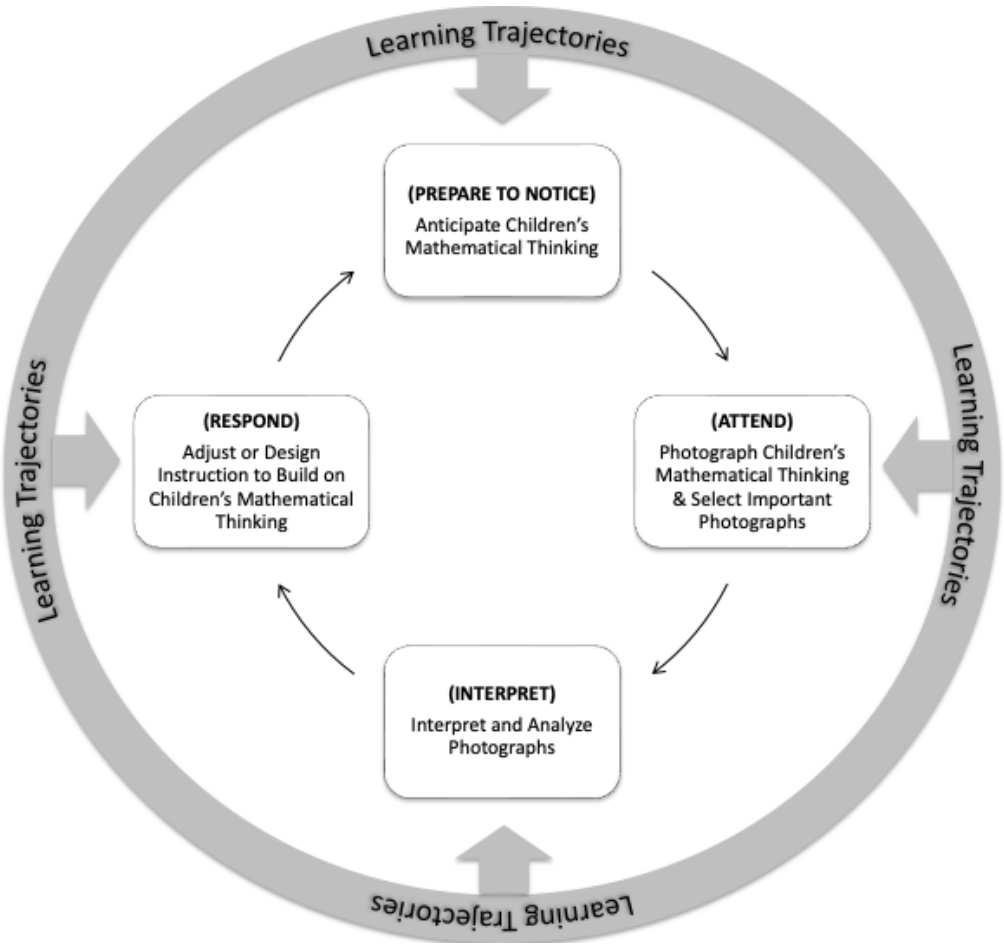
Appendix C

Frequency and Percentage of Codes in Each Category (N = 51)

Categories	Codes	Attending Code Count	Interpreting Code Count	Responding Code Count
Focus	Mathematics-Specific	31 (60.8%)		
	Mathematics-General	12 (23.5%)		
	Not Mathematics	8 (15.6%)		
Level of Evidence to Make Sense of Student Mathematical Thinking	Specific Evidence		31 (60.8%)	
	General Evidence		10 (19.6%)	
	No Evidence		10 (19.6%)	
Type of Evidence	Photograph		16 (31.4%)	
	Conversation		2 (3.9%)	
	Prior Knowledge about Student		0 (0%)	
	Photograph & Conversation		27 (52.9%)	
	Photograph & Prior Knowledge about Student		3 (5.9%)	
	No Evidence		3 (5.9%)	
Making Sense of Student Thinking with LT/P	Uses LT/P		17 (33.3%)	
	Does not use LT/P		34 (66.7%)	
Use of Evidence for Deciding How to Respond	Specific Evidence			10 (19.6%)
	General Evidence			24 (47.1%)
	No Evidence			17 (33.3%)
Responding with LT/P	Uses LT/P to Justify Next Steps Based on Framework			10 (19.6%)
	Does not use LT/P			41 (80.4%)

Figure 1

Formative Assessment Cycle Incorporating Teacher Noticing, Photographs, and Learning Trajectories

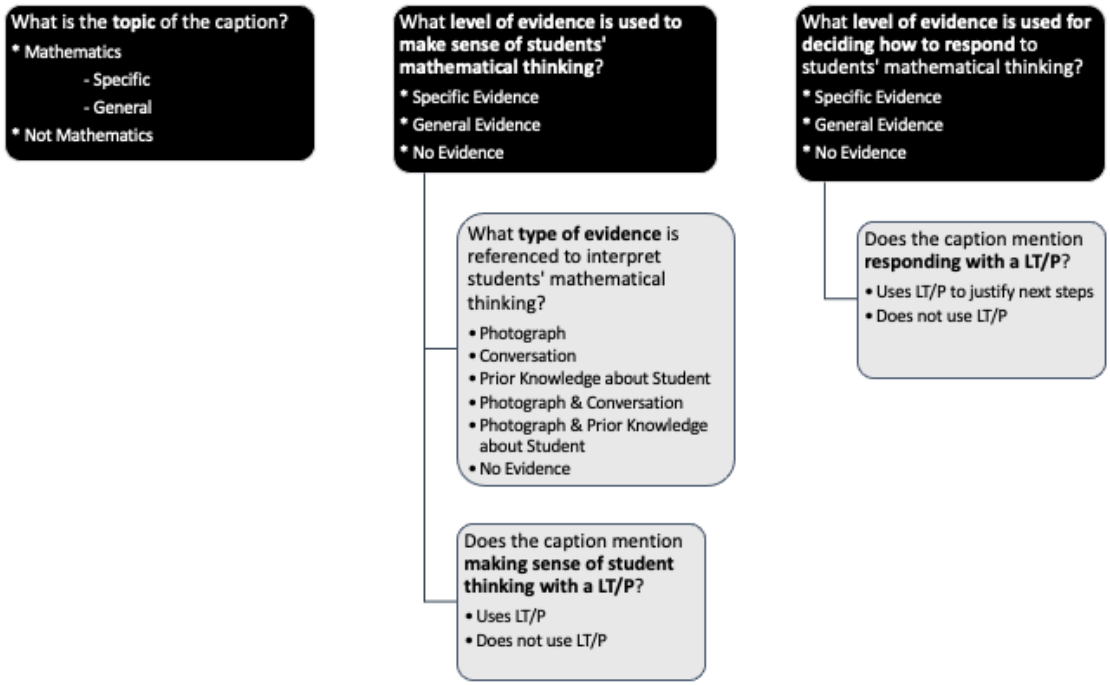


Note. Adapted from *"Using photographs and learning trajectories to enhance teacher noticing to support formative assessment"* by Marin, K. A., Roller, S. A., & Cunningham, E. P., in C. Martin, D. Polly, R. Lambert (Eds.), *Handbook of Research on Formative Assessment in PreK through Elementary Classrooms,* 2020, IGI Global (DOI: 10.4018/978-1-7998-0323-2.ch007*)*.

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Figure 2

Illustration of Coding Process



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