# Following a Teacher's Mathematical and Scientific Noticing Across Career Progression from Field Experiences to Classroom Teaching

**Julie M. Amador, Ingrid Carter, Rick A. Hudson and Enrique Galindo**

**Abstract** In this study, we focus on one preservice teacher's noticing of students' mathematical and scientific thinking with an emphasis on how the acts of attending and interpreting can influence decisions about pedagogical actions. The study centers on an innovative field experience approach that incorporates lesson study in order to emphasize students' thinking and its impact. Consequently, we were interested in understanding how one teacher made decisions based on her noticing at three points in her career: preservice field experiences, student teaching, and her first-year teaching. We used a case study approach to focus on one preservice teacher. Findings indicate that scaffolding PSTs to notice students' mathematical and scientific thinking influenced how she noticed and considered students' thinking while teaching. Results further indicate that supporting the development of noticing during field experiences has a positive impact on a teacher when she was in her own classroom. The study provides a unique contribution to the field as it incorporates both the mathematics and science teaching practices of the same PST from her teacher education experience into her career.

**Keywords** Field experience · Lesson study · Student teaching · Mathematics · Science

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J.M. Amador (✉)
University of Idaho, Coeur d'Alene, ID, USA
e-mail: jamador@uidaho.edu

I. Carter
Metropolitan State University of Denver, Denver, CO, USA
e-mail: iweiland@msudenver.edu

R.A. Hudson
University of Southern Indiana, Evansville, IN, USA
e-mail: rhudson@usi.edu

E. Galindo
Indiana University, Bloomington, IN, USA
e-mail: egalindo@indiana.edu



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What teachers perceive about students' thinking during the act of teaching and the subsequent choices about how they respond provide rich insights into the thinking of teachers. Although the benefits of focusing on students' mathematical and scientific thinking have been shown to be an important component of teacher education (Driver, Guesne, & Tiberghien, 2000; Sowder, 2007), relatively few studies have examined the long-term impact of teacher education programs that emphasize the thinking of children. In this chapter, we describe a study that examines a preservice teacher who participated in an experimental field-based course as part of the Iterative Model Building (IMB) project. Using case study methodology, we document the impact of one preservice teacher's noticing on field experiences, her initial practice as a student teacher, and her first-year teaching.

## Noticing Students' Mathematical Thinking

Building on the work of van Es and Sherin (2002, 2008), Jacobs, Lamb, & Philipp (2010) introduced a special type of noticing enacted by teachers, which they termed *professional noticing of children's mathematical thinking*. Jacobs et al. posit that this type of noticing consists of three interrelated steps: (1) attending to children's strategies, (2) interpreting the mathematical understandings of children, and (3) deciding how to respond based on children's understandings.

*Attending* involves how teachers recall the specific details of the mathematical strategies used by children. *Interpreting* refers to the extent to which teachers' attention is consistent with the children's strategies and with research on the development of children's thinking. Finally, *deciding how to respond* describes the extent to which the teacher used her or his knowledge of mathematical thinking to determine how to react to the student. Based on their analyses of prospective and practicing teachers, Jacobs et al. (2010) found that the characteristics of advanced noticing were not as common among prospective teachers as they were among emerging teacher leaders, confirming the work of prior research (Star & Strickland, 2008) that noticing is both learned and can be developed. Our current work is based on the assumption that one's ability to notice can, and does, change over time.

Since Jacobs et al. initial description of the construct of professional noticing, a number of publications have extended their work. To classify *what* and *how* teachers notice students' mathematical thinking, van Es (2011) introduced a framework with four levels for *what* students notice, moving from focusing primarily on behavioral or teacher actions to attending to the particular strategies of students and considering the relationship between these strategies and the teaching practices. Amador, Weiland, and Hudson (2016) extended van Es' (2011) framework by further categorizing the advanced levels of noticing, including the ways teachers detail strategies, analyze evidence, and make suggestions for improvement.

Other researchers have examined the structures necessary to support teachers' development of noticing. For example, when teachers are provided with specific scaffolding questions, teachers notice at a more advanced level (McDuffie et al., 2014; Seidel, Blomberg, & Renkl, 2013). Earlier case study work has also shown that through interviewing elementary students as a formative assessment, a teacher gradually improved her ability to notice children's thinking (Weiland, Hudson, & Amador, 2014). Furthermore, new teacher education materials have been designed to help improve preservice teachers' ability to notice, such as modules designed to increase attention to children's early numeracy concepts (Schack et al., 2013). Although much of this work confirms teachers' ability to notice children's thinking change over time, there are unanswered questions concerning what impact a focus on noticing students' mathematical thinking during preservice teacher education has on the instructional decisions those educators make as practicing teachers.

## The Role of Student Thinking in Teacher Education

Several research studies have shown that when teachers develop strong conceptions of students' mathematical thinking, they are better positioned to assist students by building on their thinking, adapting instructional practices, and consequently impacting student achievement (Fennema et al., 1996; Kazemi & Franke, 2004; Norton & McCloskey, 2008; Schifter, 1998). Furthermore, this type of knowledge of students' thinking is distinct from mathematical content knowledge, and content knowledge is not sufficient in order for preservice teachers to cultivate their students' conceptual understanding of mathematics (Bartell, Webel, Bowen, & Dyson, 2013). Teachers' conceptions of students' thinking may include the typical ways students think about particular problems or the common misconceptions that they employ. For example, the results of a study on Cognitively Guided Instruction showed that when teachers became aware of research-based models of students' thinking, students' achievement in regards to mathematical concepts and problem solving increased significantly (Fennema et al., 1996).

Although existing literature suggests that teacher education initiatives should focus on the thinking of students, it is less clear *what* teachers should know about students' thinking and be able to do in response to student thinking. Certainly, a commonly agreed upon action is the interpretation of student thinking (Johnson & Cotterman, 2015; Sleep & Boerst, 2012). Jansen and Spitzer (2009) suggested that preservice teachers need to describe the thinking of students with mathematical specificity and differentiate between the thinking of students in order to develop differentiated interventions. Sleep and Boerst (2012) also expected preservice teachers to elicit student thinking, whereas Harlow, Swanson, and Otero (2014) found that teachers restated the students' thinking using content-specific terminology. Furthermore, preservice teachers need opportunities to distinguish between students' conceptual and procedural understandings (Spitzer, Phelps, Beyers, Johnson, & Sieminski, 2011).

A second related question is *when* do teachers begin to truly attend to student thinking. Refuting earlier claims that teachers are unable to attend to student thinking until they begin to identify as teachers, Levin, Hammer and Coffey (2009) contend that preservice teachers can learn to attend carefully to the thinking of students. However, such experiences should be carefully framed to support the preservice teachers' analysis of student thinking. Positive outcomes from engaging teachers in student thinking activities early in the preservice teacher education program have been confirmed by others (e.g., Bartell et al., 2013; Spitzer et al., 2011), and is not dependent upon first learning mathematical content (Philipp et al., 2007).

Although there is strong evidence that teachers' knowledge of student thinking is an important component of preparation for teaching, few studies have examined teachers' longitudinal development to determine how (or whether) their collegiate coursework and field work during their preservice teacher education impact their teaching practice as a student teacher or later as a practicing teacher. This is problematic, given that research on student teaching suggests that student teachers often do not incorporate what they have learned in preservice teacher education during their student teaching semester (Moore, 2003). Santagata and Yeh (2014) found that student teaching experiences that focus on student thinking by prompting preservice teachers to reflect on the impact of their instruction on student progress were more likely to make student thinking visible and use evidence of student learning. Our study addresses the need to examine the longitudinal effects of a similar program, called IMB, by answering the following research question: As preservice teachers become student teachers and practicing teachers, how does their collegiate coursework and related field experiences, that focus on professional noticing, during a teacher education program influence their teaching practice at various points in their career progression?

## Context: Iterative Model Building

The IMB approach to the early field experience includes formative assessment interviews, building models of students' thinking, and lesson study. The purpose of the formative assessment interviews is to provide preservice teachers with direct experience planning, conducting, and analyzing interviews of elementary students related to their mathematics and science thinking on specific topics (see Weiland et al., 2014). Preservice teachers then use videos and notes taken during formative assessment interviews to build models of students' thinking. Finally, preservice teachers engage in an adapted model of lesson study (Lewis, 2002), which includes planning, teaching, reflecting on, and revising lessons based on the models of students' thinking. The current study focuses on the lesson study portion of the IMB approach to gain an understanding of how one preservice teacher, Mikayla, professionally noticed while teaching and while reflecting on and revising the lesson.

The lesson study process began with preservice teachers planning a lesson in pairs. One of these preservice teachers taught the lesson, while the other co-taught or served in a support role. The remaining four preservice teachers assigned to teach in the same classroom took observation notes. Immediately after the lesson was taught, all six preservice teachers met to debrief the lesson with the classroom teacher and a university supervisor (in this case, a doctoral student in science education). This debriefing session, which we refer to as the Lesson Study Analysis Meeting, typically lasted 30 min and included reflective discussion, based on the observation notes, on what went well and what could have been improved in the lesson. The group then discussed how these reflections could inform the teaching of the next lesson (to be taught the following week). Preservice teachers usually engaged in six consecutive mathematics cycles and then five consecutive science cycles of the lesson study process throughout the field experience semester. We refer to this process as Phase One of the IMB cycle.

One year after finishing the field experience, IMB participants completed one semester of student teaching, which we refer to as Phase Two. During Phase Two, preservice teachers were observed teaching two mathematics lessons and two science lessons in their student teaching placements. We then followed the preservice teachers into their first year of independent classroom teaching, Phase Three. We then observed two mathematics and two science lessons during their first-year teaching.

## Participant

For the purpose of this monograph, we focus solely on one preservice teacher, who participated in all three phases of the IMB cycle. At the onset of the study, Mikayla was in her junior year of an elementary teacher education program at a large Midwestern research university. She was concurrently enrolled in a mathematics method course, a science method course, and the associated IMB field experience (Phase One). Prior to taking these courses, Mikayla had successfully taken three mathematics content courses (Number and Operations, Finite Mathematics, and Geometry and Measurement) and four science content courses (Introduction to Scientific Inquiry, Biological Science for Elementary Teachers, Physical Science for Elementary Teachers, and Earth Sciences: Materials and

Processes). As a participant in the IMB field experience, Mikayla was assigned to teach in a first-grade classroom one day a week with her five peers, as described in the aforementioned process for Phase One. Compared to her five peers, Mikayla was above average with regard to motivation and creativity in working with the elementary students. Her assignments for the field experience course (e.g., reflections and lesson revisions) were not always submitted on time; however, she was highly engaged in the entire IMB process while in the field. During the Phase One experience, Mikayla generated a particularly strong connection to the classroom teacher with whom the six preservice teachers worked. During the Lesson Study Analysis Meetings, Mikayla spoke as often as her peers and provided good insights into the students' mathematical and scientific thinking. Therefore, we consider Mikayla to be representative of an average participant in the larger IMB project.

## Data Collection and Analysis

Data collected for this chapter came from all three phases of the project, Phase One (Field Experience), Phase Two (Student Teaching), and Phase Three (Classroom Teaching). For Phase One, we analyzed Mikayla's written lesson plans for one mathematics lesson and one science lesson, her teaching (video recorded) for one mathematics and one science lesson, the accompanying Lesson Study Analysis Meetings for these lessons, and her written reflections on each lesson. For Phase Two, we analyzed Mikayla's written lesson plans for one mathematics lesson and one science lesson, her teaching for one mathematics and one science lesson based on field notes and lesson observation protocols of two research team members, and conducted post-teaching interviews after each lesson. The interviews were transcribed for analysis. For Phase Three, the data collection mirrored that from Phase Two, including analysis of lesson plans, teaching, and interviews. We intentionally focused on one participant, Mikayla, and one lesson for each subject for each year from her teaching because in Phase One she only led one of each lesson type and we sought similar data across the analyses. Further, we considered the second observed lesson in Phase Two and Phase Three to be more representative of her actual teaching because she was familiar with the observation and interview process.

Data were analyzed according to the Jacobs et al. (2010) framework for professional noticing of children's mathematical thinking. Data were initially analyzed by content area and by phase for attending, interpreting, and responding on the basis of children's thinking. For this analysis, data maps were created for both mathematics and science for each of the three phases. Figure 1 shows an example of a data map for a mathematics lesson for Phase Two.

After data maps were completed for analysis for each of the lessons for both content areas, we analyzed the data across phases for each content area, meaning we

Lesson: Making Ten (Number Sentences) Concept: Groups of Ten

| ATTENDING | INTERPRETING | RESPONDING |
|---|---|---|
| **Lesson Plan:**<br>No evidence of Attending<br>**Field Notes and Lesson Observation:**<br>Teacher asks students questions that are easily answered with yes and no responses. Teacher engages students in counting with their hands and then students complete problems on erase boards. She says, "Alex wrote about the ten frame, circle what Alex should have written. He said two away from ten is seven and that five and two is seven." According to the lesson observation protocol, almost the entire lesson was spent working on skill development, facts, and vocabulary without connections to related concepts. In many instances during the lesson, the teacher indicated that the content was too easy for students, but did not modify the lesson accordingly.<br>**Interview:**<br>Preservice teacher indicated that the lesson went very well and it helped her understand what the students already knew. Indicated that she attends to students' thinking by having them explain answers use manipulatives.<br>"Just and interviewing students, you see that they want to have something to touch, some manipulative or something." | **Lesson Plan:**<br>No evidence of Interpreting<br>**Field Notes and Lesson Observation:**<br>No evidence of Interpreting<br>**Interview:**<br>Preservice teacher makes interpretations about what students learned. She concluded that students learned how to look a given set of objects, line them up and formulate a number sentence based on the number of objects. "I feel like they understood how they could look at something, even if it is chips or cubes and line them up in a certain way to create a number sentence or a story problem if they wanted to. And, they really, really, took a step in that direction." When discussing how she knew student learning occurred, she noted, "When I had a student that created the ten frame and added the circles and she was able to create the number sentence and show me using the cubes and able to explain it to her fellow classmates, just really showed me that in that fifteen minutes she was able to understand what I taught her, so that was a great part."<br><br>She recognized the importance of providing multiple opportunities for students, "I like to allow my students to become teachers. So, instead of just asking them to tell me, have them come up, answer, and explain why they did it and using manipulatives." | **Lesson Plan:**<br>Four main objectives are listed, including, "Students will understand how to solve number sentences under the number 10." She provided an overview, "This lesson will be a combination of a lot of things. I will start off by using cubes and have the students use their fingers to show how to make ten and numbers under ten. Next we will talk about creating number sentences from a ten frame where students will have to tell me 5 + ? = 10. We will go through a lot of problems like that on the dry erase. Then the students will do a page in their work book."<br>**Field Notes and Lesson Observation:**<br>The lesson followed the description provided in the overview on the lesson plan. The teacher recognized the ease of the content for the students during the lesson, but did not make any adjustments to her original plan.<br>**Interview:**<br>Preservice teacher indicated the lesson was easy for students, so she concluded it went well. "I created the lesson plan based on the Envision teacher edition workbook. Changed it up a little bit based on my students and what they learn and how they learn." She notes that she will adjust future lessons for content, but did not make modifications during the lesson. "My follow-up lesson will be with bigger numbers outside of the ten frame, creating their own story problems, and writing their own number sentences, and then moving on from there." |

*Figure 1.* Data map example.

analyzed themes from Phase One to Phase Two to Phase Three for the mathematics lessons and similarly for the science lessons. Finally, we compared analysis for the two content areas to determine similarities and differences. This process supported the intent to understand how one preservice teacher noticed students' mathematical and scientific thinking from field experience to classroom teaching.

## Findings

The following presents the findings from the study, initially by content area, and then provides cross content area conclusions.

### *Mikayla's Noticing in Mathematics*

Two main themes were evident across Mikayla's career progression when teaching mathematics. First, she placed an emphasis on students' mathematical understanding by attending to and interpreting their thinking in all three phases, but this occurred to an even greater extent in Phase Three. Second, the extent to which she adapted or modified her teaching in the moment, or her responding, differed across the three phases. The following describes these two themes, based on the three phases.

In Phase One, Mikayla was cognizant of student thinking as she planned her lessons and reflected on her lesson. She designed a lesson plan focused on *greater than* and *less than* around a game called Guess my Number and incorporated questions that would prompt student thinking. For example, in her plan, she wrote that she would ask "What did you learn from the game? Was it a hard game? Was it too easy? Did you figure out a strategy to figure out the number? Was there a better way to play the game?" After the lesson, she was able to talk generally about student understanding, "When it came to doing the game, I felt that mostly all the students understood the whole purpose of the game and that was to use the language of greater than and less than when talking about numbers." She went on to make interpretations about how well the students did with the lesson as compared to her preconceived ideas about their understandings. Although her interpretations were limited, commonly referencing whether or not students understood the concept, she made these interpretations based on what she had attended to in the lesson; however, she lacked specificity when describing students' mathematics thinking.

When responding during Phase One, Mikayla kept to her initial lesson plan and only made one minor change from her plan during the process of teaching. She asked questions that could be answered with simple responses that she deemed correct or incorrect. During the Lesson Study Analysis Meeting following her teaching, she discussed how students used the number line and had some confusion when numbers were less than or greater than other numbers. In the process of discussing her teaching with peers and knowledgeable others, she talked about what she would do to support student understanding in the next lesson. Instead of using a number line, she decided using arrows to indicate if the students' number was greater than or less than the number they were trying to guess would better support students' mathematical understanding. Despite discussing what she would do next after the lesson, it is important to remember that she only made a small change by responding in the moment.

In Phase Two, evidence of attending to and interpreting students' thinking was apparent during the interview. After teaching a lesson on making groups of ten, she indicated that she attended to students' thinking by having them explain answers and use manipulatives. She noted "And interviewing students [during the lesson], you see that they want to have something to touch, some manipulative or something." When asked specifically about student understanding in the observed lesson, she concluded that students learned how to look at a given set of objects, line them up, and formulate a number sentence based on the number of objects.

> I feel like they understood how they could look at something, even if it is chips or cubes and line them up in a certain way to create a number sentence or a story problem if they wanted to. And, they really, really, took a step in that direction.

It is interesting to note that her wording (i.e., "I feel like") suggests that at this point, Mikayla was basing her interpretation on her "sense" of the students, rather than on specific evidence of the students' words or actions. She described how she knew student learning had occurred,

> When I had a student that created the ten frame and added the circles and she was able to create the number sentence and show me using the cubes and able to explain it to her fellow classmates, just really showed me that in that fifteen minutes she was able to understand what I taught her, so that was a great part.

In these examples, Mikayla's attending and interpreting were more specific than what was seen in the evidence from Phase One.

In Phase Two, Mikayla's responding was similar to that in Phase One—she was able to discuss changes she would make after the lesson, but did not make significant changes or deviate from her plan in the moment of teaching. In her lesson plan, she wrote

> This lesson will be a combination of a lot of things. I will start off by using cubes and have the students use their fingers to show how to make ten and numbers under ten. Next we will talk about creating number sentences from a ten frame where students will have to tell me 5 + ? = 10. We will go through a lot of problems like that on the dry erase. Then the students will do a page in their workbook.

The lesson observers noted that she followed this plan with fidelity. Despite the similarity between the plan and the enactment of the lesson, Mikayla showed evidence of basing her lesson plan on past instances of attending and interpreting. For example, when asked about the lesson, she wrote "I created the lesson plan based on the enVision teacher edition workbook. Changed it up a little bit based on my students and what they learn and how they learn." Thus, there was evidence of responding based on students' thinking from lesson to lesson, but not during lesson enactment and without specificity. She went on to confirm this by noting that she would adjust future lessons for content. The present lesson had focused on numbers up to ten, but she noted "My follow-up lesson will be with bigger numbers outside of the ten frame, creating their own story problems, and writing their own number sentences, and then moving on from there." Therefore, the evidence of responding was similar to her actions in Phase One.

In Phase Three, Mikayla's ability to attend and interpret was even more specific to the students' understanding of mathematics. During the interview following the lesson, she noted that she was focused on recognizing students' errors in division with repeated subtraction. She remarked that many students had a difficult time knowing their math facts, which complicated repeated subtraction. In this way, she connected students' prior understanding (about fact families) with the content of the current lesson on dividing with repeated subtraction to come to conclusions about their understandings. This ability to attend to and interpret student thinking about specific mathematical difficulties was also noted by the observers of the lesson. One observer wrote "The teacher noticed some of the struggles the students were having and did some more modeling with the students before having them try it out on their own." The combination of the observer notes and Mikayla's comments during the interview are evidence that she was attending to students' thinking. In Phase Three, she was more specific about the mathematical understanding of the students than she was during Phase One and Phase Two.

In Phase Three, Mikayla demonstrated a notable difference in responding, as compared to Phase One and Phase Two. During classroom teaching, Mikayla modified her lesson content in the moment of teaching based on student understanding. One observer of the lesson noted

> She gave them the problem 10 divided by 5 and asked the students to show their work on their board using repeated subtraction. When the students were struggling she decided to go through another problem with the students on the board.

Following the lesson, Mikayla talked about how a few students did not meet the objective of the lesson, so she planned to repeat portions of the lesson and work with smaller groups on dividing and repeated division. She also talked about making plans to work with struggling students on their fact families because she considered this to be directly related to their difficulty with repeated subtraction. The difference distinguishing Mikayla's responding in Phase Three from Phase One and Phase Two was her ability to make changes to the lesson content during the lesson and to consider future instruction on the basis of students' thinking from the lesson.

## *Cross Mathematics Conclusion*

Considering attending, interpreting, and responding across the three phases, Mikayla demonstrated increased ability with all three interrelated skills during Phase Three of the data collection. During Phase One and Two, she attended to students' mathematical thinking, but noted how she would make changes to future lessons on that basis. During Phase Three, she made changes from her plan in how she responded during the lesson and was able to discuss how she would respond in future lessons, based on students' mathematical understanding.

## *Mikayla's Noticing in Science*

As in Mikayla's mathematics teaching, her ability to notice her students' scientific thinking progressed across all three phases. In Phases Two and Three, she began to attend to and interpret her students' thinking more deeply, and began to respond to students' thinking as she planned her lessons. The following describes the development of Mikayla's ability to notice in science, and how this development compares to her noticing in mathematics.

Similar to Mikayla's noticing in mathematics, in Phase One she included written question prompts to elicit students' thinking about Oobleck, for example, "How would you describe Oobleck? What are the properties that make it a liquid? What are the properties that make it a solid?" When Mikayla taught the lesson, she roved around the room, asking students to describe their observations of the Oobleck. After students explored Oobleck in small groups, she brought the students back to the carpet and asked them what they observed. One student responded that Oobleck melts, and Mikayla asked probing questions, such as "Why do you think it melts? What makes you think Oobleck is a liquid?" Through these question prompts, Mikayla attended to her students' thinking by asking them specific questions about how they were thinking about Oobleck. Some of these questions were preplanned (in her lesson plan), yet others were included in the moment of teaching. Mikayla was then able to make general interpretations of that thinking in the Lesson Study Analysis Meeting, for example, "I feel like this lesson gave them the opportunity to find both sides [solids and liquids]." As was the case in Phase One of teaching mathematics, Mikayla made general interpretations of students' thinking and began her interpretation with the phrase "I feel like," rather than citing specific evidence of the students' words or actions. However, Mikayla did connect what she observed of students' thinking in prior science lessons that semester (taught by her peers) to the lesson she taught. She began to interpret why students had been having difficulty connecting their prior knowledge of solids and liquids (i.e., how mixtures and solutions are formed) to Oobleck:

> When I asked [the student] she said, 'The sugar is a solid and when we put it in water and mix it together, it creates a liquid.' So some of them are getting that point and that's why [with the Oobleck] it was hard for them to figure out what to write about what's the same [between Oobleck and solids/liquids] without an example like water and ice, because what would you say?

In response to Mikayla's interpretation that students were having difficulty finding similarities between Oobleck and solids or liquids, she suggested that students would better comprehend the difference between states of matter if more time were spent on each lesson in the Solids and Liquids unit. The last portion of the above quote also suggests that Mikayla herself struggled to differentiate properties of solids, liquids, and Oobleck, and was confusing those properties with those of mixtures and solutions. She then responded to this interpretation when she stated

> If I were really teaching this I would have broken it down way more, the lessons on solids and liquids, and this lesson would have been way later because I feel like they got a little confused like, 'Ok, but you told me that solids are this and liquids are this, so why are these both the same?' I feel like them not really realistically knowing what are specific solids and what are specific liquids, so this changed it up a bit …but it gave them the opportunity to play a bit.

Mikayla therefore responded to her interpretation by providing a general suggestion to slow down the unit and teach each concept (properties of solids, properties of liquids, and properties of mixtures and solutions) much more thoroughly and explicitly.

Thus, in Phase One Mikayla attended to student thinking in both mathematics and science through direct questioning and probing. In the case of science, she continued to notice by interpreting students' actions and words while remaining focused on the lesson objective, which was to compare the properties of Oobleck to those of solids and liquids. While these instances of noticing were indeed related to the objective, the concept discussed within the three components of noticing was inconsistent. More specifically, the concept Mikayla attended to (i.e., students explored “both sides,” or the properties of solids and of liquids) did not provide evidence for her interpretation pertaining to mixtures and solutions. Her response did connect somewhat back to her observations of her students (attending) as she suggested that discussing “both sides” may have confused her students and therefore instruction should be “broken down.” Finally, Mikayla did not make in-the-moment changes to her lessons in order to respond to her students’ thinking.

In Phase Two of teaching science, Mikayla began to attend to student thinking during her lesson on the water cycle in multiple ways. In addition to asking students questions related to their explorations during active inquiry, she stated that she observed students interact with the content through various modalities. More specifically, she stated in her post-lesson interview that she attended to student thinking as they engaged in technology, video, a craft [making paper snowflakes], and hands-on movements. As she did in Phase Two of mathematics, in science Mikayla connected her observations to her interpretations of the students’ thinking, supporting interpretations with evidence of students’ actions and words. For example,

> I looked at how they used their hands to do [the water cycle], having them tell me what it is before I told them what it is. It helped show me that they understood … them telling me things that I even forgot we had talked about shows me that they remember. They are using the hand movements, which is fun and helps them to remember. And the journals help me to see what they learned.

In this quote, Mikayla was interpreting her students’ thinking based on her observations of their hand movements and what they told her about the water cycle. She then began to interpret this thinking by suggesting that hand movements that coincide with the content help students to remember the science concepts. However, her interpretations in science did lack specificity, as they were often limited to whether or not the students understood or remembered the content. The following example coincides with her lesson objective, “Students will learn about different types of precipitation” (from Mikayla’s science lesson plan). With regard to responding to students’ thinking, the following quote demonstrates how Mikayla described her response based on her interpretation of their thinking, yet she did not explicitly connect her interpretation to what she attended to, or observed her students saying and doing.

> I changed up the lesson from what I wrote, I added a hands-on activity, with the snowflakes, because I like to do things that are fun **(responding)**. So I added that at the last minute. *I can tell that they understand based on the one water cycle lesson last time, asking them questions and things like that, so I think it went well* **(interpreting)**. I wanted them to get a hands-on creative way to actually see what was going on—the four types of precipitation rain, snow, sleet, and hail. I can’t really make it rain in here, so I know [a snowflake] would be pretty simple to do **(responding)**.

While Mikayla stated she had observed students' hand gestures while acting out the water cycle to assess their understanding, her response during the lesson was actually based on what she had attended to in prior lessons. In this case, Mikayla had previously observed and interpreted that hands-on activities support students' science learning; she therefore responded to this interpretation by adding a snowflake activity to her water cycle lesson that focused in part on the four types of precipitation (rain, snow, sleet, and hail). Mikayla added a hands-on activity that was appropriate for first graders that allowed them to consider one type of precipitation: snow. While this response may not directly indicate a deepening of students' understanding of precipitation, Mikayla does engage in connecting the processes of interpreting and responding to students' thinking. She does this at a level that could be expected of a new teacher, as well as one who may be limited by content knowledge or knowledge of how the concept builds. This finding that Mikayla responded based on students' thinking from lesson to lesson, but not during lesson enactment, was also evident in Phase Two of her mathematics teaching. While planning this lesson, Mikayla had interpreted from a previous lesson that students effectively understood the content through this kinesthetic modality. She then responded to students' thinking by incorporating another hands-on activity (making paper snowflakes) to demonstrate one of the four types of precipitation.

In Phase Three, Mikayla again attended to her students' science understanding using various formative assessment strategies. She taught the same lesson she had taught during student teaching, relating the water cycle and precipitation. She stated

> I had students read aloud altogether so that I knew they are engaged in the reading, I used partners to discuss so that I knew what they got, I had them write down on their worksheets, and then [I had them do] the [cotton ball] activity.

Mikayla also noted that in this lesson she included yet another modality to support students' learning—a song about the water cycle. She provided a rationale for using this song, although did not directly ground this rationale in specific supporting evidence of students' thinking.

> I like to use songs because they become catchy, and the student doesn't know that they might be repeating the song over and over and basically you are learning something … songs really do help them, well my class at least.

In this quote, Mikayla suggested that, in addition to modifying the lesson by incorporating hands-on activities, she also responded by including a song, which she had previously observed "helps" her class learn. It is unfortunate that she did not state specifically how she knew songs were effective; therefore only implying (not directly linking) her interpretation to observations.

Finally, Mikayla responded to students' thinking by explicitly focusing on the four types of precipitation and incorporating instructional resources beyond the curriculum. She again noted that this response was based on her previous experience, in this case having taught the lesson as a student teacher in Phase Two.

Mikayla responded in advance of the lesson to general learning difficulties she had previously observed. She stated

> I taught this same lesson last year when I student taught, but I taught it differently this time by breaking it down a little more than I did last year. [Last year] we talked about the water cycle, precipitation, and how clouds form all in one big unit rather than breaking it down and discussing each one, we have more time this year.

Because Mikayla's changes were based on her previous experience teaching this lesson, she made changes to the planned lesson, which were not specific to her particular group of students, nor to various levels of her students. In Phase Three, Mikayla did demonstrate one example of making broad changes in the moment of teaching science, "Students are also having a hard time explaining how clouds are formed so Mikayla has the students go back to their book and reread what it says about how clouds are formed" (Researcher Field Notes). This quote demonstrates how Mikayla observed that her students were struggling to understand the content, and therefore asked students to repeat the planned activity (i.e., reading the passage). This finding correlates with Mikayla's Phase Three mathematics teaching, when she responded to students' difficulties by repeating the activity (i.e., modeling another problem on the board).

## Discussion

Mikayla's noticing in mathematics and science across the phases shifted as she attended, interpreted, and responded along her career progression. The following sections are organized by the interrelated skills of noticing, and bring together the disciplines of mathematics and science (Jacobs et al., 2010). Following these sections, further discussion extrapolates the findings more broadly to relate noticing to mathematics and science content. The discussion concludes by making connections between the IMB approach for field experiences and the study findings.

### *Attend*

While teaching both mathematics and science, Mikayla's basis for attending shifted across the varying stages of the career progression. During Phase One, for both mathematics and science, she wrote specific questions in her lesson plans and attended to the responses of those questions. As she progressed through Phase Two and Phase Three, her formats for understanding student thinking, and the related attending, shifted. In the later phases, Mikayla incorporated other forms of assessment, such as journals in science, to elicit what students were thinking. She then attended to students' understanding by focusing on what she discovered from these assessments. This shift is possibly the result of increased experience teaching and recognition that simply asking questions, as she did in Phase One, does not always provide a clear understanding of students' thinking. In the interviews for Phase Two and Phase Three, Mikayla noted that she ascertained information about students' understanding in multiple ways and she sought input about how students were thinking that extended beyond asking questions. Thus, as she progressed through the phases, her approach to gain the information she gathered, that to which she attended, developed.

## *Interpret*

At the onset of her career progression, when Mikayla was asked about her interpretations, or what students understood, she began her responses in mathematics and science with the phrase, "I feel the students …". This terminology expressed hesitancy or uncertainty in her commitment to knowing what students understood. Furthermore, she lacked connections to evidence of student thinking. This is not surprising, given that van Es (2011) characterizes connecting interpretations with evidence as mixed or focused noticing (level 2 and level 3), which is distinguished from baseline (level 1) noticing. During Phase One, Mikayla was a preservice teacher, so it is understandable that her noticing would be at novice level and mirror that of the baseline description (van Es, 2011).

Recall that in Phase Two and Phase Three, Mikayla attended to more than just question responses to try to understand students' thinking. Despite multiple inputs for attending, Mikayla's interpretations in Phase Two and Three remained limited to what students understood or did not understand. For example, in science, she made an interpretation about what students understood, but did not ground the interpretation in evidence, and assumed an evaluative position. When she worked to interpret student thinking, the emphasis was on correct or incorrect responses, as opposed to understanding the nuances of students' thinking. One distinguishing component in Phase Two and Phase Three was rare instances when Mikayla provided information on how she knew something was correct or incorrect. Occasionally, she would evaluate what she had attended to and would then provide an explanation for how she arrived at that conclusion. This distinguished her interpreting across the career progression as she began to ground her interpretations in her observations of her students' thinking. Therefore, similar to attending, there were slight developments among interpretations across the three phases.

## *Respond*

With attending and interpreting, the shift in Mikayla's noticing was most notable between Phase One and Phase Two, with Phase Three, in most instances, mirroring the attending and interpreting of Phase Two. In contrast, marked changes in responding were noted between Phase Two and Phase Three for both mathematics and science, distinguishing responding during classroom teaching from responding during the field experience and student teaching. In the Lesson Study Analysis Meetings following teaching in Phase One, Mikayla was able to talk about what she would do differently if she were teaching the lesson again and discussed the next lesson, or how she would respond on the basis of what happened. During her Phase Two interview, she again discussed changes she would make to the lesson post-teaching, but did not demonstrate making these changes while teaching. In contrast, during Phase Three lesson observations, Mikayla was able to deviate from her written lesson plan and make adjustments on the basis of students' thinking. Thus, Phase Three was the first instance, both in mathematics and science, where she made significant in-the-moment responses on the basis of students' understanding. These responses came after Mikayla recognized that students were misunderstanding or not comprehending the topic she was teaching, at which point, Mikayla gave students additional problems in mathematics or had students reread in science. We recognize that both of these responses do not enhance the lesson or provide students multiple entry points to the content, they simply have students repeat what was problematic (i.e., rereading or repeating problems). This provides insight into Mikayla's noticing—namely her responding. She seemed to be more cognizant of her awareness about how the lesson was progressing (Mason, 2011). Perhaps in Phase Three, Mikayla reached the point that she was able to attend, interpret, and decide how to respond in the moment of teaching and then made changes to her instruction. Jacobs et al. (2010) note that "before the teacher responds, the three component skills of professional noticing of children's mathematical thinking—attending, interpreting, and deciding how to respond—happen in the background, almost simultaneously, as if constituting a single, integrated teaching move" (p. 173). It is possible that Phase One and Phase Two provided the structured supports for Mikayla to attend, interpret, and decide how to respond and the actual first instances of responding in the moment first manifested in Phase Three. We recognize that Mikayla's responses were aligned with those of a novice and not yet an expert, but these findings suggest that she may be integrating Jacobs et al. (2010) three interrelated skills in Phase Three.

When Mikayla responded in Phase Three by adjusting her lesson in the moment of teaching, she seemed stifled or restricted to the process, format, and content she was already pursuing. For example, when students struggled with using subtraction as repeated addition, she gave them additional problems of subtraction as repeated addition instead of attending to and interpreting their understandings. There was some discrepancy between what she was attending to and how she was deciding to respond. Perhaps, the lack of interpretation (extending beyond students being correct or incorrect) constrained her ability to implement changes in instruction that would address actual content needs. Likewise in science, when students were struggling with understanding a passage they had read, Mikayla adjusted her lesson plan by asking students to reread the same passage. As teacher educators, if we expect preservice teachers and those along the career progression to be able to respond with content-specific instruction, they need to be supported to do this.

In the case of Mikayla, we recognize that an even stronger connection to the content (mathematics and science) may have supported knowledge that would result in these types of changes. It is interesting that in the case of science, she did not paraphrase or teach the content in some other way other than reading. However, we recognize that directing students back to the textbook may not be surprising if her science content knowledge is a factor and if she is unsure of other avenues for supporting students' understandings.

## *Mathematics and Science Content*

When considering the content and Mikayla's subject matter knowledge related to noticing, it is important to note differences between mathematics and science. When Mikayla was teaching mathematics and discussed the next lesson, it was typical that she would describe larger numbers as way to further challenge students. For example, in one lesson, she was focused on numbers up to ten and said the next day she would focus on numbers up to fifteen. She demonstrated some understanding of a hypothetical learning trajectory, recognizing that students progress with numbers in a somewhat linear form (i.e., learning numbers to ten before numbers to twenty) (Clements & Sarama, 2004). In contrast, when Mikayla discussed her science plans for subsequent days, she typically focused on "breaking the concept down." To think about what students needed to know next, she thought about all of the pieces or components of a larger unit. In this way, she perceived science as more recurrent and mathematics as more linear. For example, to understand how clouds form, students would not only need to understand the tenets and phases parts of the water cycle, but would need to know about convection. From this knowledge base, students could then explore a variety of concepts to build their understanding of clouds and how clouds form (e.g., temperature). Thus, Mikayla sometimes faltered with knowing how to provide students with a variety of entry points into the science concept being taught, and simply asked students to reread the same informational passage. Perhaps Mikayla was limited by her content knowledge, as well as by her understanding of the nature of science. The nature of science is such that concepts are continually being developed and built upon [i.e., science is tentative (Lederman, 2007)], perhaps exhibiting more fluidity with the order in which topics should be taught as compared to mathematics. We recognize that our data collection did not include a specific assessment of Mikayla's knowledge, but data sources we have indicate that her knowledge level may be a factor in our findings. Thus, these discrepancies between mathematics content and science content may somewhat relate to Mikayla's choices with responding when planning lessons.

### *Iterative Model Building Process*

Considering these findings in light of the modified field experience process used in Phase One raises questions about the incorporation of content knowledge and mathematics and science knowledge for teaching (i.e., pedagogical content knowledge) into the lesson study process (Ball, Thames, & Phelps, 2008). During Phase One there were several instances during both the mathematics and science Lesson Study Analysis Meetings in which other members of Mikayla's group raised topics related to the mathematics or science content that would support responding in future lessons. For example, in the mathematics lesson taught in Phase One, Mikayla used a number line when students were not understanding less than or greater than in that context. After discussion about multiple representations and what it meant to be greater than or less than, Mikayla considered that she might incorporate a hundreds chart into her next lesson to help students further understand the concept. We argue that these conversations and moments are important for developing the understanding and ability to attend to students' mathematical (or scientific) thinking and that experiences thinking deeply about content may be necessary for teachers to fully interpret and respond on the basis of students' thinking. This process would support the interrelated skills that Jacobs et al. (2010) deem necessary for being able to make in-the-moment teaching decisions. Moreover, the supports provided to Mikayla in Phase One through the lesson study may account for the similarities in her noticing in Phase One and Phase Two. In Phase Two she had more extensive teaching experiences, but still demonstrated noticing that mirrored that of Phase One, when it came to responding in the moment. This is reasonable given that she no longer had the collaborative support of lesson study following her teaching, as student teachers were placed in various schools that did not incorporate lesson study as a professional tool. Perhaps added collaborative supports during the student teaching portion of Phase Two, specific to mathematics and science content knowledge and how students learn these topics (Ball et al., 2008) would be helpful in supporting the development of noticing, specifically responding.

Despite the suggestions for further supporting noticing throughout Phase Two, the notion that Mikayla, as a preservice teacher, was able to attend, interpret (to some extent), and consider responding (for future lessons) during a field experience on the basis of students' mathematical and scientific thinking is notable. The structure of the IMB program provided opportunities for preservice teachers to consider that to which they attended, scaffolded interpretation through a collective group setting in lesson study, and prompted discussion about next steps and teaching that should occur on the basis of what was discovered during the lesson about students' mathematical and scientific thinking. This structure afforded Mikayla opportunities to consider these components of teaching and to practice the interrelated skills of attending, interpreting, and responding (Jacobs et al., 2010). It is possible that the scaffolded support she received in Phase One through the IMB process influenced her ability to notice in later phases.

Likewise, the post-teaching questions during the interviews in Phase Two and Phase Three likely prompted Mikayla to further consider her noticing to an even greater extent, raising awareness of awareness, which could have influenced her noticing during her teaching (Mason, 2011). More specifically, knowing that she would be asked about students' thinking following her lessons may have prompted her to consider students' thinking to a greater extent during her teaching. One could argue then that the noticing Mikayla reported is simply a feature of the structure of the data collection process; however, we propose that the opportunities for reflection built into the IMB process provide valuable time for considering noticing. We recognize that the data reported in this chapter are limited to that which we were able to ascertain from documentation (i.e., lesson plans) and data that came from observations, lesson study, and interviews, and we cannot fully describe the extent to which Mikayla was noticing. However, we do have evidence that Mikayla attended, interpreted, and responded in all three phases of the project and these skills manifested differently at different points along her career progression. She then was able to simultaneously integrate these components into a single teaching move when she decided to respond (Jacobs et al., 2010). Therefore, we argue that the IMB process supported the development of Mikayla's noticing by emphasizing students' mathematical and scientific thinking and through providing scaffolds to encourage the development of attending, interpreting, and responding.

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