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Categorizing mathematics teachers' questioning: The demands and contributions of teachers' questions

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ABSTRACT

We conducted a review of literature to answer the following research questions: (1) What types of questions do teachers pose in mathematical discussions? (2) What evidence exists of the effects of different types of questioning on students' learning and participation? (3) What are the implications of existing research for teacher preparation? Existing literature can broadly be categorized according to studies that distinguish between higher order and lower order questioning, studies that characterize and distinguish probing questions, and studies that address teacher questioning in technology-rich environments. The demands of different types of questions need to be considered in light of the broader contributions that such questions make to students' mathematical learning.

1. Introduction

The importance of teacher questioning as a component of classroom discourse is well understood among mathematics education researchers and practitioners ([NCTM], 2014; National Research Council, 2005). Research on teacher questioning in math classrooms has helped articulate how questioning is part of a broader practice of scaffolding (Jadallah et al., 2011), how teachers make decisions about when to ask questions versus when to tell information (Baxter & Williams, 2010; Chazan & Ball, 1999), and the types of questions teachers might pose to facilitate classroom discourse (Boaler & Brodie, 2004; Chapin & O'Connor, 2007; Herbel-Eisenmann & Breyfogle, 2005). Knowledge of the different types of questions that teachers pose has potential to serve as a valuable resource for teacher education and professional development. However, the studies that constitute this area of research tend to draw upon a range of frameworks and schema for categorizing teacher questioning. There is an opportunity to improve research, practice, and teacher education by synthesizing this literature in a way that helps explain different types of teacher questions in terms of the contributions they make to students' learning and participation in classroom mathematics activity.

The purpose of this study is to review research literature published between 2000–2020 documenting the different types of questions teachers pose in K-12 mathematics classrooms and, where possible, the impact of teachers' questions on student learning and participation. This review will focus on the following research questions: (1) What types of questions do teachers pose in mathematical discussions? (2) What evidence exists of the effects of different types of questioning on students' learning and participation? (3) What are the implications of existing research for teacher preparation? Taken together, the answers to these questions should inform a framework for training and professional development around how to effectively pose questions in math classrooms.

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2. Sociocultural perspectives and teacher questioning

Studies of classroom discourse are aligned with sociocultural perspectives of student learning, emphasizing learning as participation in shared practices (Forman et al., 1993; Rogoff, 1997; Vygotsky, 1978). On an international scale, curriculum standards have emphasized the importance of classroom mathematics as a social activity in which students could develop skills to formulate questions, make arguments, and justify their ideas (e.g., Australian Association of Mathematics Teachers, 2006; NCTM, 2000). Across a variety of contexts researchers have documented how teachers can use questions to establish classroom communities that are rich with mathematics discourse, conceptual learning, and shared authority among teacher and students (e.g., Huffered-Ackles et al., 2004; Imm & Stylianou, 2012; Kazemi & Stipek, 2001). However, this does not imply that all classrooms meet these ideals.

Teachers pose a range of questions in math classrooms, ranging from straightforward questions to gather information to more complex questions such as probing students' thinking or encouraging justification (e.g., Boaler & Brodie, 2004; NCTM, 2014). The questions that teachers pose can provoke patterns of interaction among students and teachers. Most notably, Mehan (1979) described a typical pattern of classroom interaction known as initiation-response-evaluation (IRE) which has also been referred to as the initiation-response-feedback (IRF) pattern (Cazden, 2001; Lemke, 1990; Wells & Mejía-Arauz, 2006). Others have expanded the IRF pattern to describe funneling patterns and focusing patterns of interaction (Herbel-Eisenmann & Breyfogle, 2005; Wood, 1994, 1998). Categories of teacher questions can be helpful for understanding how teachers use classroom discourse to establish classroom mathematical norms and set expectations for math talk within a classroom. However, taking a sociocultural view of classroom mathematics activity, it is necessary to extend conceptualizations of teacher questioning to consider how teacher questions are part of the broader range of shared practices within a classroom. Development towards a theory of teacher questioning should account for the ways in which teachers' questioning practices overlap with other teaching practices, with the needs of students and their learning, and with the mathematical work of a classroom. This review of literature contributes to such an effort, with a goal of making explicit some of the tacit rationales for teachers' in-the-moment decision making with respect to posing questions.

3. Method

In this literature review, we use the phrase *categories of teacher questioning* to describe literature that sorts teacher questions according to the types of responses questions elicit. Sometimes categories of teacher questioning are mutually exclusive (e.g., higher-order versus lower-order questions), but it is possible that they may sometimes overlap (e.g., factual questions might serve as guiding questions). We conducted a search for peer-reviewed articles containing clearly defined categories of teacher questioning from 2000 to 2020. We began our search in 2000 for a combination of reasons. First, the early 2000s was a time of international interest in clarifying not only what content students should learn in school mathematics, but also how students should learn school mathematics. Additionally, there was a small collection of studies in the early 2000s that have strongly informed later research in this area (e.g., Boaler & Brodie, 2004; Huffered-Ackles, Fuson, & Sherin, 2004; Kazemi & Stipek, 2001), and therefore we expected that beginning our search in 2000 would yield a coherent body of literature.

3.1. Databases and search terms

Our literature search followed three interrelated branches. We began with a database search using the following databases: Education Resource Information Center (ERIC), Education Full Text, Education Research Complete, Web of Science, and Scopus. We searched these databases simultaneously using the initial search terms *teacher question** (all text), *mathematics* (subject term), and *NOT undergraduate or college students* (subject term). We set our results to include only peer-reviewed academic journals, eliminating technical reports as well as book chapters and conference presentations so that we could maintain consistency in the extent to which our reviewed research had been vetted. Our initial search returned 5321 articles. As we began looking through our results, we noticed that the articles addressing categories of teacher questioning all included *questioning techniques* as a subject term. We added *questioning** (which included questioning techniques as well as questioning strategies, and others) as a subject term to our search criteria, and this reduced the number of results to 114. In parallel, we conducted a separate database search using subject term *scaffolding* in addition to *mathematics* and *NOT undergraduate or college students*. We included scaffolding as an alternative to teacher questioning, because sometimes analysis of teacher questioning falls within the broader umbrella of scaffolding moves. This search returned 269 peer-reviewed academic articles. We exported both lists to Mendeley to review for inclusion criteria.

As we read through the articles we had identified through our database search, we studied the reviews of literature and reference lists included within those articles to find other potentially relevant literature. Through this snowball sampling method, we identified approximately 20 more articles that had not been returned by our database search. Additionally, because our question was specific to mathematics teachers' questioning practices, we conducted a manual search of key mathematics education journals including *Journal for Research in Mathematics Education*, *Journal of Mathematics Teacher Education*, *Mathematical Thinking and Learning*, and *Journal of Mathematical Behavior*. Our rationale for this manual searching was that we expected these popular math education journals to be most dense with articles relevant to our interests.

The final element of our search, as we identified articles that met our inclusion criteria (described more fully below), was to use Google Scholar to locate articles that had cited the literature we had already identified. This reverse reference tracking contributed to two objectives. First, we expected it may help us catch more recently published literature that did not yet appear in the large databases. Additionally, by tracking references in both directions of the articles we identified, we overcame some of the bias inherent to our choice of databases and journals to search.

3.2. Inclusion and exclusion criteria

We included studies in the review if (a) categories of teacher questioning were made explicit (i.e., questions were sorted according to the content of the question or the responses they required from students), (b) the participants of the study were teachers or pre-service teachers (c) the study was conducted in a K-12 environment, (d) the article was published in a peer-reviewed research journal dating 2000–2020, and (e) the investigation included a mathematics classroom. The purpose of our inclusion criteria was to ensure that our selection of literature aligned with our research questions, namely to synthesize empirical evidence of the types of questions mathematics teachers pose while planning or implementing classroom discussions. We specifically focused on studies where categories of teacher questioning were made explicit—as opposed to more general documentation of the existence, frequency, or holistic quality of questions—because we wanted to understand the nuances of different types of questions teachers use. Additionally, because our interest is on the role of questions as an aspect of classroom discourse, we did not include literature where teachers wrote "questions" (i.e., mathematical problems or exercises) for students to solve. Finally, our choice to focus on the work of K-12 mathematics teachers was to support our interest in the implications for teacher preparation.

Fig. 1 includes a flow diagram of the selection process. The total number of articles included in the review is 38. After our initial database search and manual review of selected journals, we had a collection of 114 articles to screen using our inclusion criteria. As we conducted this process and reviewed the references of the screened articles, we identified an additional 20 articles that we added to our screening process. From these 134 articles, 44 met our inclusion criteria. We added three additional articles through a reverse reference search using Google Scholar. Nine articles were ultimately disregarded due to missing information in the methods or findings of the study (e.g., unclear criteria for how the researchers distinguished between different types of questions). This collection of articles represents research conducted in nine different countries across four continents.

3.3. Analysis of literature

The first and second authors catalogued the key characteristics of the articles included in the review, including the theoretical framing, the population studied, the categories of teacher questioning explored, and the findings of the study. This process led to an inductive coding scheme to organize the literature according to the categories of teacher questioning employed by the researchers. This organization was important, because researchers used a wide variety of terms and phrases to describe different types of questions. We looked for commonalities in how questioning categories were described, and in the examples provided within each category. This induction led us to identify three overarching "buckets" into which the literature could be organized—studies distinguishing teacher questioning on a continuum from "lower order" to "higher order"; studies that contrasted probing questions with other question types; and studies that categorized teacher questioning in technology-rich environments. Once we had established our inductive coding scheme—which sorted articles into three distinct categories—the first and second author each coded all of the articles. Our reliability was 89 % (i.e., our coding matched on 34 of the 38 articles), and we resolved our disagreements by consensus. We then shared the outcomes of our inductive coding with the third author for a check on the interpretive validity of our coding.

In addition to organizing our coding according to these broad themes, the first and second authors used analytic memoing to note how researchers documented relationships between categories of teacher questioning and student participation or learning, and how teacher questioning interacted with other aspects of classroom interaction. There was wide variation in the extent to which researchers took up these questions—many articles, for example, did not address aspects of student learning or participation in a direct way at all. Because of this variation, and because of the manageable number of studies included in the review, memoing was the most effective way to document the nuances of different studies, including why and how researchers sought to study teacher-student interactions

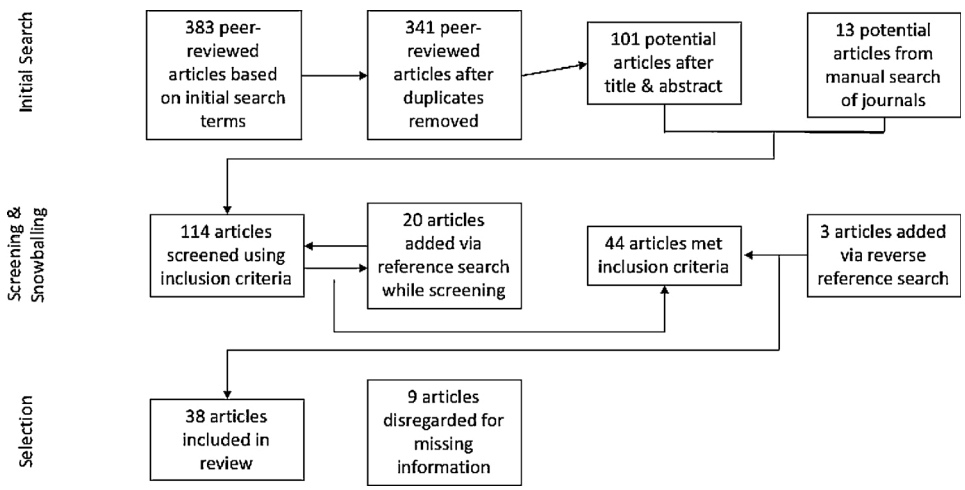

Fig. 1. A flow diagram of identified literature for the review.

within different classroom environments. The first and second authors created a shared document in which we contributed and reacted to one another's memos. This step was critical to the ability to offer some explanation for why particular categories of questions are useful to teachers at different moments of classroom instruction.

4. Results

The studies included in the review represent a range of international perspectives, including the United States, Turkey, China, Norway, and South Africa. They span K-12 math classrooms. The articles in review were organized by how the studies categorized teacher questioning: Higher-Order and Lower-Order Questions, Characterizations of Probing Questions, and Teacher Questioning in Technology Rich Environments. The results of our analysis are detailed in the following sections.

4.1. Higher-order and lower-order questions

Twenty of the articles included in this review included questioning categories that could be classified along a continuum from higher-order to lower-order. *Lower-order questioning* is defined as questions that require simple or one-word responses from students: questions requiring yes or no responses, clarification, procedural questions, or recall of facts (Drageset, 2014; Kaya & Ceviz, 2017). *Higher-order questioning* can be defined as questions that require more extended responses and place higher cognitive demand on students: analysis, evaluation, explanatory, and comparative questions (Drageset, 2014, 2015; Kaya & Ceviz, 2017; Ni, Zhou, Li, & Li, 2014). We note that the phrases "higher-order" and "lower-order" represent our way of classifying the questions documented in this body of literature. In the following paragraphs, we attend to variation in how the researchers studied and labeled teacher questioning.

4.1.1. The relationship between higher- and lower-order questioning and students' responses

Nathan and Kim (2009) examined the role of "teacher elicitations" (i.e., questions and prompts for student participation) for supporting student participation and reasoning in a middle-school mathematics classroom. They coded four different levels of elicitation: choice (students respond from a set of options), product (request for factual knowledge or recall), process (students must provide some explanation), and meta-process (students must justify or provide reasoning for a response). An important distinction between product elicitations and process elicitations was that the latter provided the teacher with new information; as such, we consider the first two categories of elicitation to be lower-level and the second two categories to be higher-level. The authors also coded for the correctness of students' responses and found that teacher's elicitations tended to move up the hierarchy following correct answers from students, while elicitations moved down the hierarchy following incorrect responses. When students gave incorrect answers, the reduction in the complexity of the teacher's elicitations seemed to be a way to maintain students' engagement and scaffold them towards higher levels of thinking.

Related to the question of how teachers modify their elicitations according to student responses is how teachers' questions—and students' responses to those questions—lead to patterns of interaction with students. Drageset (2014) identified 13 different categories of teacher discourse actions—many of which were question types—made by teachers that were filed into three final categories; redirecting, progressing and focusing actions. Teacher questions within these three categories ranged from correcting questions (redirecting), closed progress detail questions to clarify steps of a process or procedure (progressing), to open progress questions with more than one possible answer (focusing). In a follow-up study focusing on the work of just one teacher, Drageset (2015) noted that closed progress questions on the part of the teacher typically occurred iteratively with "teacher-led responses" (i.e., responses whose explanations were prompted by the teacher) on the part of students. However, when students either provided explanations or gave unexplained answers, the teacher followed with focusing actions that led to further explanation.

The studies cited above largely focus on how teachers adapted their questioning according to students' responses, but it is also necessary to consider how teachers' questions create or inhibit students' opportunities to respond. Aziza (2018) observed a teacher of primary-aged children and asked the teacher about her purposes for posing closed or open-ended questions. In one lesson, the teacher had used a majority of closed questions and noted that sometimes she used such questions to push students to think about the content of the question (e.g., to provoke students to think about the meaning of a technical term). Open-ended questions, however—while they were used much less frequently-promoted students' mathematical creativity.

In a much broader study, Ni, Zhou, Li, and Li (2014) described the impact of higher-level and lower-level questions on students' responses in reform-oriented upper-elementary classrooms in China. From a dataset including 90 classroom observations from 30 different teachers, Ni et al. found that teachers' lower-order questions were positively correlated with "simple answers" on the part of students, while higher-order questions were positively correlated with "highly participatory answers." They also noted, in the context of this research, that teachers' higher-order questions were correlated with tasks of higher cognitive demand, and lower-order questions were correlated with the pursuit of multiple solution methods. The authors suggested that lower-order questions in the context of eliciting multiple solution methods provided a form of social scaffolding (Baxter & William, 2010), encouraging students to participate but not necessarily helping them to process information.

In addition to using lower-order questions as a form of social scaffolding, research in the field of educational psychology suggests that "retrieval questions"—i.e., questions requiring students to recall known information—can support student learning. Fazio (2019) used data from several middle grades math classes to document teachers' use of retrieval questions. Fazio found that 42 % of teachers' questions were retrieval questions, with semantic and procedural questions being the most common. Contrary to her hypothesis, Fazio did not find any difference in teachers' use of retrieval questions between high-growth and low-growth classrooms. The author hypothesized this might be due to the fact that there was little requirement for all students within a class to participate in the retrieval process.

Teachers often pose questions to which they have an intended response in mind (e.g., in IRE sequences), and this impacts the opportunities that students have to participate in classroom discourse. When using such questions, teachers are likely to provide little wait time and to call only on students who volunteer to answer (Zhu & Edwards, 2019). Using linguistic methods to examine patterns in teacher-student interactions in geometry classrooms, González and DeJarnette (2012, 2015) documented a distinction between teachers posing questions to which they already had a specific answer in mind and teachers posing open-ended questions for which they did not know how students would respond. During an end-of-unit review, a teacher most often posed lower-order questions, although more authentic questions granted more agency to students in terms of directing the content of the review (González & DeJarnette, 2012). During small-group work on an open-ended task, teachers posed almost exclusively initiation questions to students as a form of scaffolding when they were stuck (González & DeJarnette, 2015). In both of these cases, similar to the work of Nathan and Kim (2009) and Ni et al. (2014), lower level questions served as a form of social scaffolding to maintain students' engagement and access to the necessary mathematics content.

While teachers often have reasons for using lower-level questions to scaffold students' learning, consistent performance of lower-level, procedural questions contribute to what Imm and Stylianou (2012) have called "low discourse settings" in which the teacher does most of the talking, the teacher's language is privileged over students', and open-ended tasks become reduced to tasks of lower cognitive demand. In contrast, high discourse settings are characterized by conceptual questions and disruptions to traditional discourse patterns. A major contribution of Imm and Stylianou's (2012) work has been to describe how patterns of individual questions on the part of a teacher contribute to defining a classroom discourse environment.

Other researchers have made connections between teacher questions and classroom norms at smaller scales, focusing on segments or episodes of classroom discussions. Kazemi and Stipek (2001) for example, compared examples of high-press and low-press exchanges across elementary mathematics classrooms that seemed similarly engaged in standards-based instruction. High-press exchanges included teacher questions that required students to "give reasons for their mathematical actions" (p. 68) in contrast with low-press exchanges that required only descriptions of a solution process. Kazemi and Stipek argued that high-press exchanges were crucial for establishing sociomathematical norms that would allow a classroom to move beyond superficial features of standards-based instruction and towards conceptual learning on the part of students.

Cengiz, Kline, and Grant (2011) similarly focused on specific episodes of classroom teaching, analyzing "extending episodes" in the classrooms of six different elementary-grades teachers using reform-oriented curricula. Extending episodes were defined as segments of whole-class discussions that involved mathematical reasoning and moved beyond solution methods. Cengiz et al. found that, once teachers initiated extending episodes, they posed few "eliciting actions", defined as lower-order questions about process and product. Instead, teachers posed more "extending actions," which were higher-order questions asking students to evaluate a claim, provide reasoning, or compare different methods. It is important to note, however, that these questions were integrated with "supporting actions" with which teachers told students information to help them make connections. Additionally, the authors noted that higher-order extending questions did not always lead to higher-order responses from students. When considering teacher questions at the level of episodes, exchanges, or the classroom setting, it is necessary to recognize that teachers' questions and students' responses are mutually informing.

4.1.2. Changes in teachers' levels of questioning over time

Less research has contributed to documenting changes in the categories of questions teachers pose over time, although there are some exceptions. One example is the work of Aydogan Yenmez et al. (2018), who adopted an existing framework for analyzing teacher questioning in the context of a professional development course for high school mathematics teachers, focused on teaching through mathematical modeling. The analysis of teachers' lesson plans and implementation identified *broadening* (higher-level) and *directive* (lower-level) questions used by the teachers, as well as specific question types: factual, procedural, conceptual, evaluative, exploratory, and invitational (Marks, 1990). In early implementations, teachers asked mostly questions that were directive and procedural, but after reviewing lesson plans and participating in the modeling activities, they embedded more broadening questions. Although the authors did not document the impact of specific questioning types on students' learning, Aydogan et al. did describe the teachers' intentions for particular questions. Invitational questions were used in order to motivate students for the solution process, and procedural questions were used in order to guide students to the solution. Broadening questions, including exploratory and evaluative questions, were intended to provoke students to expand their ideas.

In a different professional development setting, Di Teodoro, Donders, Kemp-Davidson, Robertson, and Schuyler (2012) completed action research to improve their mathematics questioning in elementary grades. The authors' goal was to shift from "surface" questions that required students to imitate, recall, or apply knowledge to answer to problem, towards "deeper" questions to provide students to opportunity to create, analyze, and or evaluate a problem. Drawing on prior research findings that mathematics teachers in 3rd–12th grades asked only 25 % deeper questions (Tienken, Goldberg, & DiRocco, 2009), the teachers had a goal to ask at least 50 % deeper questions over the course of a school year. In the first lesson the authors asked only 25 % deeper questions, and by the third lesson they asked 69 % deeper questions. Additionally, the quantity and quality of student questions improved due to explicit teaching, modeling, and practice. The authors also noted that sometimes surface questions led to deeper questions, so surface questions still had value in the classroom.

4.1.3. Higher- and lower-order questioning of pre-service teachers

Four articles investigated the preparation of PSTs to ask higher-level questions, in a variety of contexts. Kilic (2018) matched PSTs with sixth grade students for tutoring, in order to make connections between the PSTs' noticing skills and scaffolding practices. PSTs were to reflect on their sessions with these students each week and then develop better questioning and scaffolding practices over the

14-week study. Their analysis concluded that, although PSTs improved in their noticing throughout the post-tutoring written reflections, they did not make noticeable improvements to their questioning practices. Simply having the PSTs review their interventions by watching the videos of the lesson did not increase the amount of higher-level questioning. The finding that PSTs' ability to notice student errors did not translate to high-level scaffolding implies a need for more explicit training on what to do with students' ideas.

Taking a different approach towards a similar goal, Purdum-Cassidy, Nesmith, Meyer, and Cooper (2015) examined 14 elementary PSTs' lesson plans (though not their teaching) to document the types of questions they planned for students when incorporating children's literature into mathematics lessons. Seventy three percent of the mathematics questions included in those lesson plans were classified as closed-convergent, meaning that they were "framed so that several students would arrive at the same, limited number of answers" (p. 89). PSTs' closed-convergent questions were equally distributed between procedures and concepts; when PSTs planned open-divergent questions—i.e., questions with multiple potential responses—they were almost always related to mathematics concepts rather than procedures. Purdum-Cassidy et al. noted that PSTs often made extensive use of closed-convergent questions when they borrowed directly from an existing worksheet, and that such resources could be problematic for novice teachers who do not yet have the expertise to modify such materials. They noted that future instruction should focus on how to translate closed-convergent questions—and especially yes/no questions—into open-divergent questions.

In whole-class settings, there is evidence from multiple sources that PSTs may be less prepared to use higher-order questions in math compared to other contexts. For example, Diaz, Whitacre, Esquierdo, and Ruiz-Escalante (2013) analyzed the questioning practices of eight bilingual PSTs working in a school along the US-Mexico border. Using Bloom's taxonomy to categorize PSTs' questioning practices, Diaz et al. concluded that PSTs asked mostly lower-order questions. For math, only 4 % of total questions asked by all participants were higher-order thought questions, compared to 18 % in language arts. PSTs also demonstrated challenges with questioning in a study conducted in a primary school in Turkey by Kaya and Cevic (2017). They investigated whole-class conversations led by PSTs in all main subject areas: mathematics, science, social studies, and language arts. Classifying questions as open-ended or closed-ended, they found that PSTs teaching math lessons used the lowest percentage of open-ended questions within a lesson when compared to the other subject areas.

4.1.4. Implications of higher- and lower-level questioning for equitable teaching practices

Recently, Reinholz and Shah (2018) developed and piloted an observation tool to document patterns of participation in classroom discourse. Partnering with a veteran teacher leading a summer course for upcoming fifth-grade students, Reinholz and Shah documented the frequency of "what" questions (typically, the *I* questions in an IRE sequence), "why" questions (asking students to explain their thinking), and "how" questions, as well as the types of responses that students provided. They found that "what" questions slightly outpaced the frequency of "why" questions in the class (28 % versus 22 %, compared to only 3 % "how" questions). There were discrepancies, however, in the types of questions posed by the teacher according to student demographics. Although White and Black students received proportionate questions from the teacher, White students received disproportionately more "why" questions while Black students received more "what" questions. Latinx students were underrepresented in every category, suggesting they received fewer questions overall than their peers. Reinholz and Shah noted that such findings should be useful as a resource for teachers to notice subtle differences in the discourse patterns within their classrooms.

Finally, it is important to recognize that students interpret the ways their teachers pursue student thinking. Lim, Lee, Tyson, Kim, and Kim (2020) worked for two years across 23 secondary mathematics classrooms in the U.S. to correlate teachers' questioning patterns with students' perceptions of their teachers' responsiveness. They found that students who had teachers that asked follow up questions to students' responses, and waited for their answers, perceived their teachers as being supportive and good listeners. Students with teachers who only used IRE patterns had learned that the most important thing in their class was whether or not their answer was right. This finding is particularly important in light of Reinholz and Shah's (2018) observations of patterns in the types of questions that teachers pose to students according to race and ethnicity.

4.2. Characterizations of probing questions

Many articles have developed descriptive characteristics for classifying questions beyond notions of higher-level and lower-level. Twelve of the articles in this review describe probing questions in contrast with other questioning categories. *Probing* are defined as questions that explore students' mathematics understanding and engage students in clarifying their ideas and explanations (Franke et al., 2009; McCarthy, Sithole, McCarthy, Cho, & Gyan, 2016; Sahin & Kulm, 2008). Probing questions are designed to expand students' initial responses and tend to follow a student's response to an initial prompt from a teacher.

4.2.1. Probing, guiding, and factual questions

Four of the articles that we reviewed characterized probing questioning in contrast with guiding and, respectively, factual questions. The distinction among these three question types draws from research related to questioning in tutoring settings (Graesser & Person, 1994; Graesser, Person, & Huber, 1992). Piccolo, Harbaugh, Carter, Capraro, and Capraro (2008) used constructs of probing and guiding questions, in contrast to what they called closed (factual) questions, to describe categories of questions that would lead to extended interactions with students. The authors collected classroom observations from middle school mathematics teachers following a one-week professional development program to encourage them to differentiate their questioning. Using video footage from the post-training lessons, the authors constructed a flowchart of possible teacher-student interactions. With this flowchart, the authors noted that closed questions from the teacher limited conversation and did not lead to evidence of student understanding. Sequences of probing and guiding questions were much more likely to produce interactions that led to evidence of student understanding.

Using a similar framework for categorizing questions, two articles compared novice teachers' and experienced teachers' use of probing, guiding and factual questions (Ong, Lim, & Ghazali, 2010; Sahin & Kulm, 2008). Comparing two teachers during a unit on fractions and decimal conversions in sixth-grade classrooms, Sahin and Kulm found that a novice teacher used probing questions more frequently than a veteran teacher, although both teachers used mostly factual questions overall. In contrast, Ong et al. designed a 15-month Lesson Study cycle where mathematics teachers continually refined their questioning practices. Their results diverged from Sahin and Kulm, as the experienced teachers moved away from factual questions to use more probing questions from the beginning to the end of the 15-month cycle, while only one of the novice teachers made such improvements. On one hand, it may be that novice teachers' excitement for new ways of teaching supports the use of probing questions (Sahin & Kulm, 2008). On the other hand, Ong et al. (2010) suggested that novice teachers may lack the confidence to adapt their questioning, making it more difficult to see change in their practice.

Some researchers have used slightly different language to make similar distinctions between probing, guiding, and factual questions. Moyer and Milewicz (2002) categorized questioning strategies used by preservice teachers during 1–1 diagnostic interviews with elementary-aged children. They identified checklisting, instructing, and probing and follow-up questions used by the preservice teachers. The most common questioning strategy used by preservice teachers in the setting was checklisting, although the occasional use of probing questions demonstrated the preservice teachers' greater attention to the students thinking processes. Weiland, Hudson, and Amador (2014) modified this framework to document changes in two PSTs' questioning practices as the PSTs conducted formative assessment interviews with first-grade students. Over time, the PSTs showed improvement by decreasing the frequency of non-specific probing questions and increasing their frequency of probing questions that built directly on students' thinking. These improvements coincided with the PSTs' development of noticing skills, and the authors noted the importance of structured reflection for supporting the PSTs to learn from the interview experiences.

Also drawing upon Moyer and Milewicz's (2002) characterizations of probing, instructing, and checklisting questions, Van den Kieboom, Magiera, and Moyer (2014) explored the relationship between PSTs' algebra content knowledge and the types of question they posed during tutoring. The authors defined instructing questions as segments in which "the prospective teacher predominantly asked questions with a goal of guiding the student toward the answer" (Van den Kieboom et al., 2014, p. 440), similarly to how other authors have described guiding questions. McCarthy, Sithole, McCarthy, Cho, and Gyan (2016) used the language of "leading questions" to refer to a similar practice of guiding students towards a correct answer. McCarthy et al. noted that leading questions seemed to serve an important purpose towards scaffolding students' thinking, which is consistent with earlier findings on the role of lower-order questions. Beyond the definitions of questioning categories they used, Van den Kieboom et al. (2014) also made an important connection between PSTs' content knowledge and their questioning practices. The authors measured PSTs' "algebraic thinking proficiency" with respect to describing functions through rules and divided the PSTs according to those who had lower and higher algebraic thinking proficiency. Although only 18 % of tutoring segments overall included probing questions, PSTs with higher algebraic thinking proficiency posed more probing questions and fewer checklisting questions than those with lower algebraic thinking proficiency. Notably, the algebra content of the interviews that the PSTs conducted was aligned to the content of the assessments given to the PSTs, suggesting that questioning practices are closely linked to specific content knowledge.

4.2.2. Sequences of probing questions

Five articles included in this review focused more specifically on teachers' use of sequences of probing questions to uncover the details of student thinking. Franke et al. (2009) identified elementary school teachers' follow up questions that would uncover details of a student's mathematical problem-solving strategy. Probing sequences of specific questions promoted students to elaborate their initial responses as well as helped students provide correct answers after their initial answers were incorrect or incomplete. Regardless of the level of specificity, the authors found that single questions were rarely enough to uncover the details of students' thinking or facilitate a correct explanation.

In addition to supporting students' correct and complete explanations, sequences of specific probing questions are important for helping students engage with one another's ideas and clarify their own ideas. Webb et al. (2009) investigated how teachers interacted with students during small-group work in elementary mathematics. Probing students to uncover details of their problem solving had a strong relationship with students' correct explanations. Engaging without probing, such as acknowledging their ideas or making a brief suggestion, was rarely linked to correct and complete responses between the students. Similarly, Webb et al. (2014) found that, when sharing solutions after small-group or individual work, students engaged with one another's ideas the most when teachers posed specific questions to help a student elaborate upon their solution in relation to another student's. This also led to higher student achievement. These studies support Franke et al.'s (2009) suggestion that probing sequences of specific questions are the most effective for students to develop complete and correct responses.

Similarly to how others (e.g., Imm & Stylianou, 2012; Kazemi & Stipek, 2001) have described how questioning sequences contribute to a broader classroom learning community, Huffered-Ackles et al. (2004) documented how sequences of probing questions contributed to a "math-talk learning community" in an elementary school math class. Within the focal classroom, the teacher and students moved through a trajectory of math talk together throughout the school year from mostly factual or recall questions, towards more probing questions and even students posing questions to one another. Importantly, shifting between the levels of math talk required the teacher not only to change her questioning practices, but also to model for students the appropriate responses to the new types of questions she posed.

Weston, Kosko, Amador, and Estapa (2018) adapted Huffered-Ackles et al.'s (2004) questioning rubric to analyze PSTs' cartoon depictions of hypothetical classroom interactions. Weston et al. applied the four levels of math talk to approximately one minute of classroom interaction that the PSTs wrote. Among the 99 PSTs that participated in the study, the most frequent questioning sequences

were level 1 (asking for explanations), followed by level 0 (short, focused questions) then level 2 (sequences of probing questions). Weston et al.'s findings suggest that PSTs struggle to use sequences of probing questions, even in fictional settings where they control both the content of the questions and the content of students' responses. Novice teachers may be prepared to ask students to explain their thinking but be unprepared to follow up on the responses students provide.

4.3. Teacher questioning in technology-rich environments

The use of modern technology environments enables new types of interactions among teachers and students (Hollebrands & Lee, 2016). Five articles included in this review discuss teacher questioning practices when integrating technology. Four of these studies address teachers' use of dynamic software such as computer algebra systems or dynamic geometry environments. One article takes a novel approach towards teachers' use of technology by examining text interactions between teachers and students using smartphone capabilities.

When integrating technology in the classroom, teachers differ in how they use a particular technology. Cayton, Hollebrands, Okumus, and Boehm (2017) investigated the questions teachers posed during "pivotal teaching moments" (PTMs, Stockero & Van Zoest, 2013) using dynamic geometry, and how the relationship between the teacher and the tool influenced questioning. The authors' used Boaler and Brodie's (2004) characterizations of teacher questions: procedural/factual, probing, exploring meaning or relationships, and generating discussion. There were some consistent patterns related to the teacher-tool relationships. Namely, the teacher who used GSP as a "partner" asked probing questions more than any other type, in contrast to the other two teachers who used primarily procedural/factual questions. The teacher who used GSP as a "master" posed almost exclusively procedural/factual questions. The teacher-tool relationship aligned with the individual teachers' preferences for responding to PTMs and their questioning practices.

Other studies of teachers' use of software environments attend more directly to how teachers balance questions about mathematics with questions about technology. Akkoç (2015) implemented a formative assessment workshop to help PSTs improve their mathematics-related and technology-related questions using two computer learning environments. Analyzing the PSTs' lesson plans and teaching notes, the authors noted that PSTs increased the number of mathematics questions asked and changed the purpose of the questions after the workshop. There was an increase in mathematics questions that would require reasoning, making connections, and assessing prior knowledge. Additionally, PSTs posed more technical questions focusing on reasoning and linking representations. There was also an increase of technology usage to enhance teaching among the PSTs after the workshop.

Hollebrands and Lee (2016) similarly sought to document the mathematics-related and technology-related statements that PSTs would make when implementing short interventions using GSP with geometry students. The PSTs posed questions that focused students' attention to mathematics using the technology, but they tended to be broad questions such as "how did you get that?" PSTs generally did not pose mathematical questions to push students to explain relationships they might have observed. In most cases the PSTs began with technology-focused questions, possibly because they were still becoming familiar with the technology as well. In a study building on the work of Hollebrands and Lee, Hähkiöniemi (2017) compared the questioning practices of two groups of PSTs—one group who taught a problem-based lesson without using dynamic geometry, and one group who taught a problem-based lesson with the use of dynamic geometry.[1] Although the PSTs posed more conceptual questions than procedural questions overall in the problem-based context, the use of dynamic geometry did not correlate with greater frequency of conceptual questions. The presence of mathematics software, alone, is not sufficient to substantially change PSTs' questioning practices.

Departing from the use of traditional mathematics software towards novel uses of modern technology for teaching, Chao, Murray, and Star (2016) investigated how teachers used text messaging via smartphones to conduct diagnostic interviews with students. The authors hypothesized that the use of smartphone technology might remove the physical constraints and biases that inform teacher questioning, improving teachers' opportunities to listen and respond to students. Teachers posed four different types of questions: clarification, verification, extension or redirection. Clarifying and verifying questions were ways the teachers could probe student thinking. Two of the three teachers used the redirecting approach—which were mutually exclusive with extension questions—which indicated the teachers did not believe the student's explanation was sufficient. The authors concluded that the teachers may have not had well-developed noticing skills because their communication with the students did not focus on the details of their strategy.

5. Discussion

This body of literature represents a range of perspectives on mathematics teacher questioning, in terms of how questions are categorized, the purposes of categorizing teachers' questions, and the contexts in which researchers have chosen to study teacher questioning. In the following sections, we first discuss some of the connections between the literature that we have reviewed and existing questioning frameworks, and then we consider how the findings of this review contribute to a broader theory of teacher questioning. Finally, we share some opportunities for future research.

[1] Hähkiöniemi (2017) categorized nine types of "probing" questions, but their use of probing was slightly different from how other researchers have characterized probing questions and spans a ranger of lower and higher-order questions.

5.1. Connections to existing questioning frameworks

In our review of literature, we identified many instances of questioning categories that aligned with NCTM's (2014) definition of gathering information (i.e., recall of facts or rote knowledge) and probing thinking (i.e., engaging students in making their thinking more clear and complete). In fact, probing questions seem to be one of the most consistently defined categories of teacher questioning, as well as the best supported in terms of facilitating students' construction of correct explanations and conceptual learning (Franke et al., 2009; Kazemi & Stipek, 2001; McCarthy et al., 2016; Piccolo, Harbaugh, Carter, Capraro, & Capraro, 2008; Webb et al., 2009, 2014). It is clear that probing questions targeting specific aspects of students' work can support students to develop correct and complete explanations and engage with one another's thinking, which may ultimately lead to higher achievement.

In contrast to probing questions, questioning related to making mathematics visible (i.e., making specific connections or relationships explicit) is less documented. One exception to this is the work of Cayton, Hollebrands, Okumus, and Boehm (2017), who used Boaler and Brodie's (2004) framework and included a category of questions related to exploring mathematical meanings or relationships. In other cases, there were implicit examples of how making mathematics visible might overlap with other categories of questioning, such as when a teacher poses conceptual questions (e.g., Kazemi & Stipek, 2001) or uses technology to focus on mathematics (e.g., Akkoç, 2015). Similarly, questions related to encouraging justification and reflection (i.e., questions pushing students to argue for the validity of their work) are treated less explicitly in much of the empirical research on teacher questioning, though there are some exceptions (Cengiz, Kline, & Grant, 2011; Drageset, 2014, 2015; Webb et al., 2014). From the examples that do exist, it is clear that these two categories of questioning—making mathematics visible and encouraging justification—are often more difficult for teachers to enact and place substantial demand on students in classroom discussions.

5.2. Explaining teacher questioning via demands and contributions of questions

We began this review by noting that studies of classroom discourse are well aligned with a sociocultural theory of learning, suggesting that learning is a process of increasing participation in the practices of a discipline. The way such practices are taken up depends largely on the social, mathematical, and sociomathematical norms of a classroom community (Cobb & Yackel, 1996; Cobb, Wood, & Yackel, 1993; Yackel & Cobb, 1996). Any explanation of teachers' questioning practices, therefore, should take into account how such questions contribute along one or more of those dimensions.

Research that characterizes mathematics teachers' questions does so largely according to the types of responses that different questions elicit. For example, "closed" questions are defined as those that require short responses of known information from students, while probing questions are those that require explanations for why a particular mathematical idea or procedure was valid. Put differently, teacher questioning categories are generally determined according to the mathematical demands they put on student responses—i.e., what would a reasonable response to a question include. However, these mathematical demands are not enough to fully characterize the role of a question within classroom mathematical activity.

Instead, teacher questions should be considered not only in terms of the mathematical demands they place, but also in terms of what they contribute to mathematical activity. Knowledge of how different question types contribute to discussion can help give reason to teachers' implicit, in-the-moment decision making around question posing. In some cases, the contributions of different types of questions are more obvious. Higher-order and probing questions, when they elicit more extended explanations from students, provide a teacher with new information about student thinking, help students develop their mathematical ideas, and promote conceptual learning (Cengiz et al., 2011; Franke et al., 2009; Kazemi & Stipek, 2001; Nathan & Kim, 2009). Additionally, higher-order questions that elicit open-ended or extended responses from students grant more agency to students over their own learning (González & DeJarnette, 2012; Huffered-Ackles et al., 2004; Imm & Stylianou, 2012; Kazemi & Stipek, 2001).

In other cases, the contributions of particular questions may be less evident. Questions that are often deemed undesirable in classrooms—closed, procedural, or factual questions—can serve important purposes for social scaffolding (González & DeJarnette, 2015; Nathan & Kim, 2009; Ni et al., 2014). There are times when teachers need to support students to stay engaged in a task so that they can build towards more sophisticated levels of reasoning, and lower-level questions can be a useful strategy to accomplish that goal. Higher order questions, such as asking a student to provide reasoning for a claim, sometimes stall a classroom conversation (Cengiz et al., 2011). Lower-order questions make an important contribution in these situations in maintaining the momentum of mathematical activity. Notably, that there is no clear evidence that PSTs use lower-level questions as a form of social scaffolding. Findings to this point have come from studies with more experienced teachers.

It is also necessary to give careful consideration to what, in particular, makes particular questions unproductive. Research from educational psychology has indicated that, although retrieval questions ought to support conceptual learning, this does not always happen in practice (Fazio, 2019). However Fazio suggested that this apparent failure may be due to the fact that, in classroom settings, it is difficult to ensure that all students participate in answering such questions. No question is likely to contribute much to classroom activity if there is little expectation on students' part to respond. In other contexts, lower-order questions might serve as supporting actions that can help students expand their thinking when integrated with more sophisticated questions (Cengiz et al., 2011). Teachers might use lower-order questions in an effort to model for students the cognitive or meta-cognitive processes necessary for completing a task (Herbel-Eisenmann & Breyfogle, 2005); but again, more explicit instruction is likely necessary in order for students to eventually adopt such a process independently.

With respect to questions that set high expectations for student responses, aligned with standards-based instruction (e.g., probing questions, elaboration questions, open-ended questions), it is not enough for teachers to develop the skills to ask these questions. Additionally, teachers must also teach and model for students how to respond (Di Teodoro, Donders, Kemp-Davidson, Robertson, &

Schuyler, 2012; Huffered-Ackles et al., 2004). Even if teachers learn to pose questions that should elicit meaningful explanation, justification, and mathematical relationships, these questions will not make productive contributions if students do not recognize or respond to the demands.

Opportunities for teachers to pose questions that contribute productively to a classroom's mathematical activity are constrained by factors like inexperience, content knowledge, and noticing skills. A consistent finding across research is that PSTs are generally not equipped to pose questions that move beyond closed-ended, prompting, or checklisting with students (Akkoç, 2015; Diaz, Whitacre, Esquierdo, & Ruiz-Escalante, 2013; Hollebrands & Lee, 2016; Kaya & Ceviz, 2017; Kilic, 2018; Purdum-Cassidy et al., 2015; Van den Kieboom et al., 2014; Weston et al., 2018). This seems to be the case whether researchers observe PSTs in classrooms, in tutoring or interview settings, or through the questions that they prepare in lesson plans. Sophisticated question posing may be more challenging in mathematics compared to other subjects (Diaz et al., 2013; Kaya & Ceviz, 2017). Moreover, it is unclear from existing research whether PSTs have the same reasons for posing lower-level questions as more experienced teachers.

Evidence on whether shorter-term interventions lead to improvements in questioning—either for PSTs or for more experienced teachers—is mixed, suggesting an important need for sustained attention to questioning practices throughout teacher preparation and field experiences. The most promising outcomes in terms of teachers modifying their questioning practices has come from explicit and sustained attention to questioning over time (e.g., Aydogan Yenmez et al., 2018; Di Teodoro et al., 2012; Ong et al., 2010). Additionally, teacher questioning practices are related to other aspects of professional practice, such as content knowledge and noticing skills. In general, teachers with stronger content knowledge seem better equipped to pose questions (Cengiz et al., 2011; Kilic, 2018; Van den Kieboom et al., 2014). In cases of technology use, a teacher's level of experience using the technology also seems closely related to their level of questioning (Cayton et al., 2017; Hollebrands & Lee, 2016). These findings suggest that training on questioning practices should be explicit, ongoing, and connected to the content teachers need to teach and the context in which they will be doing so.

5.3. Opportunities for future research

From this review, we have identified three particular areas of opportunity for future research. The first of these is a need for continued attention to the interaction between the questions that teachers pose and the ways that students respond, as well as how these interactions contribute to students' learning. In many cases, analyses of teachers' questions suggest implications for student learning, but the most compelling study findings come from instances when teacher questioning is tied directly to students' responses. There is room for more work in this area, to better understand how questioning can be responsive to students' needs. For example, given the suggestion that lower-level questioning serves an important purpose for scaffolding, there is opportunity to explore when such questions are necessary and productive and how they might be built upon to gradually increase the demand placed on students.

In addition to attending to the interaction of teachers' questions with students' responses, there is an opportunity for future research projects to give teachers more explicit opportunities to improve their questioning practices. These opportunities should attend to categories of questions according to the mathematical demand they place on students as well as according to how different questions contribute to the classroom mathematics activity. Comparisons of different classroom environments (e.g., Kazemi & Stipek, 2001) might be useful for supporting teachers to think beyond surface-level features of questions to consider how the use of different questions contributes to the overarching mathematical expectations within a class.

Finally, there is opportunity to get more input from practicing teachers on why they pose the questions they do at a given time. There were a small number of intriguing findings in the research we reviewed related to teachers' rationales for posing particular questions in particular moments of instruction. These findings lend support to the assumption that teachers have reasons for using the questioning patterns they employ, and they are often able to articulate these reasons long beyond the conclusion of a lesson. Research and professional development that combine classroom observations with teachers' reflections on their own questioning practices can inform decision making about which types of questions serve particular purposes in the best way. This knowledge can then be used to more fully understand how questioning can be responsive to students in ways that support productive mathematics learning communities.

6. Concluding remarks

Reviewing literature on mathematics teacher questioning presents challenge of how to delineate teacher questioning as a phenomenon that is part of, but distinct from, other aspects of teachers' classroom discourse and scaffolding. There are cases of existing research in which categories of teacher questions are a central focus of the study and cases in which categories of teacher questions are embedded within broader research questions. Insights that we gained from this work include the ambiguity of locating a question as part of classroom discussion. Discussions include multiple participants, statements which may not be intended as questions but elicit responses regardless, and prompts that may be intended as questions but go unanswered. The work of posing good questions is difficult at least in part because questions are so intertwined with other discursive moves that mathematics teachers use.

Even with these challenges, there is value in giving specific focus to the different types of questions that teachers pose and the contributions they make to mathematics teaching and learning. For mathematics instruction to align with the ideals of the reform movement, students must be engaged in authentic interactions about mathematics on a regular basis. While teachers tend to dominate classroom discourse, questioning is the most direct and explicit way to involve students in conversation. This review highlights the strides that have been made, by teachers and teacher educators, towards using questions as a way to engage students at all grade levels in doing mathematics. It also illuminates opportunities for future work to build upon teachers' experience to improve how questioning

is learned and practiced.

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Appendix A. Summary of Articles Included in Review

Citation	# Teacher Participants	Grade level	Setting	Questioning Categories	Findings
Higher and Lower-Level Questions					
Aydogan Yenmez, Erbas, Cakiroglu, Cetinkaya, and Alacaci (2018)	4	9–10 (ages 15–17)	Teachers in Turkey, during a 5-month PD related to teaching through mathematical modeling.	• Broadening or directive; • Factual, invitational, procedural, conceptual, evaluative, or exploratory	In early modeling cycles, teacher questioning was mostly directive, especially invitational and factual broadening questions. By the third modeling cycle, teachers began using broadening questions, especially of the evaluative and exploratory types.
Aziza (2018)	2	year 3 (ages 7–8)	An elementary school teacher in the UK, teaching a lesson on angles and triangles.	• Closed or open-ended	In an observation of one lesson, the teacher posed 26 closed questions and 12 open-ended question. The teacher shared her purpose for using closed questions—to elicit quick answers and to provoke students to think about a mathematical term or idea. However, students' reasoning skills were developed by "where?", "how?" and "why?" questions, and open-ended questions promoted students' creativity.
Cengiz, Kline, and Grant (2011)	6	1–4	Teachers in U.S. using reform curriculum after PD in how to use the curriculum effectively.	Inviting students to • Evaluate a claim • Provide reasoning • Compare different methods • Use same method for new problems • Provide counterspeculation	Teachers performed extending actions in combination with supporting actions (e.g., suggesting ideas, reminding students of the goal) during extending episodes. Inviting students to evaluate a claim, provide reasoning, or compare methods were the most common question types. Teachers' performance of instructional actions was linked to their mathematical knowledge for teaching.
Di Teodoro, Donders, Kemp-Davidson, Robertson, and Schuyler (2012)	4	2–3	Teachers in Canada, each teaching three different problem-solving tasks as part of an action research project related to asking more meaningful questions.	• Surface • Deeper	The goal of this action research project was to improve teacher questioning, as well as to improve the questions that students posed to one another. The teachers had a goal to ask at least 50 % deeper questions. In the first lesson the authors asked only 25 % deeper questions, and by the third lesson they asked 69 % deeper questions. Additionally, the quantity and quality of student questions improved due to explicit teaching, modeling, and practice.
Diaz, Whitacre, Esquierdo, and Ruiz-Escalante (2013)	8*	K-6	Bilingual mathematics and language arts PSTs on US-Mexico border, during 12-week student teaching.	• Bloom's taxonomy: knowledge, comprehension, application, analysis, synthesis, and evaluation	PSTs most often asked lower-order thinking questions (i.e., knowledge, comprehension, application) in both math and

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Citation	# Teacher Participants	Grade level	Setting	Questioning Categories	Findings
					language arts, and they asked a higher percentage of lower-order questions in math (96 %) compared to language arts (82 %).
Drageset (2014)	5	5–7	Teachers in Norway filmed for 1 week during the start of a fractions unit.	• Correcting • Closed progress details • Open progress details • Enlighten details • Justification • Apply to similar problems • Request assessment from others	The purposed of this article was to identify types of teacher comments and responses. The categories of questions listed were a subset of the 13 teacher actions identified by the author, and these 13 actions were organized into three subsets—redirecting, progressing, and focusing.
Drageset (2015)	1	5–7	Teacher in Norway filmed for 1 week during the start of a fractions unit.	• Correcting • Closed progress details • Open progress details • Enlighten details • Justification • Apply to similar problems • Request assessment from others	Teacher actions and student responses were closely related. Closed progress detail questions were typically followed by teacher led responses from students (i.e., funneling interactions) or by focusing actions. Unexplained answers were followed up by requests for justification or closed progress details. When student explanations were followed by questions, they were usually closed progress details.
Fazio (2019)	40	6–8	Forty videos of classroom instruction selected from a broader data set—20 classrooms that had shown high growth on a test of math achievement, and 20 that had shown low growth.	• Semantic retrieval • Arithmetic retrieval • Procedural retrieval • Episodic retrieval	The purpose of this study was to compare teachers' use of retrieval questions in high-growth and low-growth middle grades math classrooms. Overall, 33 % of retrieval questions were semantic, 16 % were arithmetic, 27 % were procedural, and 24 % were episodic. There were no significant differences among teachers of high-growth classrooms and teachers of low-growth classrooms in terms of the extent to which the teachers used retrieval questions.
González and DeJarnette (2012)	1	9–12	Teacher in U.S., filmed for 2 days leading a review session at the end of a geometry unit.	• dK1 – questions for which the teacher has a correct answer in mind • K2 – questions that can have multiple answers, for which the teacher does not know how students will answer	The teacher led the class discussion using almost exclusively dK1 questions, which were equivalent to "I" questions in the IRE sequence, leading to funneling patterns of interaction. When the teacher posed K2 questions, students had more agency in directing the content of the review.
González and DeJarnette (2015)	2	9–12	Teachers in U.S., filmed for 2 days during a problem-based lesson in geometry.	• dK1 – questions for which the teacher has a correct answer in mind • K2 – questions that can have multiple answers, for which the teacher does not know how students will answer.	Both teachers used primarily dK1 questions, which served purposes related to analytic and social scaffolding. dK1 questions allowed the teachers to assess whether students had the necessary information to solve the problem and to guide the problem-solving process.
Imm and Stylianou (2012)	5	6–8	Teachers in U.S., filmed 1–3 times per month following a week of professional development.	• Procedural (e.g., inserting terminology, clarifying or correcting, gathering information) • Conceptual	The purpose of this study was to document how talk was structured across low, high, and hybrid discourse settings. Low discourse settings were characterized by procedural questions and IRE patterns, which

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Citation	# Teacher Participants	Grade level	Setting	Questioning Categories	Findings
					did not allow students to wrestle with concepts, and often reduced the cognitive demand of the task. High discourse settings used more conceptual questions and widened students' participation.
Kaya and Ceviz (2017)	39*	3–4	PSTs in Western Turkey, teaching in 4 local primary schools, all subjects.	• Closed-ended • Open-ended • Task-oriented	In math, the lowest percentage of open-ended questions (18 %) were recorded, compared to other subjects.
Kazemi and Stipek (2001)	4	4–5	Teachers videotaped the same lesson on fractions in an urban California elementary school with a ethnically diverse student population.	• High press • Low press	This study examined how classroom practices create opportunities for pressing students conceptual understanding of mathematics. They classified high and low press prompts and determined that high press opportunities allows for clear communicate between teacher and student on the student's problem-solving process.
Kilic (2018)	6*	6	PSTs in Turkey, each tutoring a pair of students on a weekly basis for 10 weeks.	• Prompting • Probing	Questioning categories were described as elements of PSTs' scaffolding practices. There was a negligible number of probing questions. Although PSTs improved their noticing skills, this did not translate to high-level questioning or scaffolding.
Lim, Lee, Tyson, H.-J. Kim, and J. Kim (2020)	23	9–12	Teachers in the southern U. S., and their students, observed across 2 years.	Follow-up questions included • Seeking clarification and probing • Asking to restate • Prompting further discussion • Asking for alternative answers • Applying to another's reasoning	This study documented the relationship between teachers' pursuit of follow-up questions and students' perceptions of their teachers' responsiveness and listening. Follow up questions were questions that the teachers posed following students' responses to an initial question (i. e., after the "R" in an "IR" sequence). The authors found that students who favorably perceived their teachers' listening had teachers that often posed follow-up questions to probe student thinking and prompt further discussion.
Nathan and Kim (2009)	1	7–8	Teacher in U.S., filmed for 4 days during a middle school algebra lesson.	Elicitations included • Choice • Product • Process • Metaprocess	The authors documented how teachers modified their elicitations according to students' responses to their initial questions. When students gave incorrect answers, the teacher reduced the level of their elicitations, which kept students engaged and filled gaps. This allowed the teacher to scaffold towards higher levels of thinking and speaking
Ni, Zhou, Li, and Li (2014)	30	5	Teachers in China, each observed for 3 consecutive days using reform curriculum.	• Low-order (memory recall/ confirmation, procedural/ descriptive) • Higher-order (explanatory, analytic/comparative)	The study documented relationships between instructional tasks, teacher questioning, and students' responses. Lower order questions from the teacher were positively correlated with students' simple answers; higher order questions were correlated with students' highly participatory answers.

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Citation	# Teacher Participants	Grade level	Setting	Questioning Categories	Findings
					When teachers pursued multiple solution methods via lower-ordered questioning they encouraged student participation but did not help them process information.
Purdum-Cassidy, Nesmith, Meyer, and Cooper (2015)	14*	3–4	PSTs in U.S., planning literature-based mathematics lessons throughout a 14-week practicum.	• Text-dependent versus text-independent • Closed-convergent versus open-divergent • Procedural versus conceptual	This study analyzed the questions that PSTs included in lesson plans. Overall, 73 % of PSTs' planned questions were closed-convergent; these were almost equally distributed between procedural and conceptual. Open-divergent questions (27 %) were almost all conceptual.
Reinholz and Shah (2018)	1	5	Teacher in U.S., leading a 10-week summer program for struggling students.	• Why (asking students to explain) • What (typically, the "I" in IRE) • How	The purpose of this study was to pilot a metric for measuring aspects of equity in classroom discourse. Overall, solicitations from the teacher did vary by demographic. Black students received proportionate opportunities to participate; but White students received disproportionately more "why" questions; Latinx students were under-represented in every category.
Zhu and Edwards (2019)	1	3	Teacher in a Chinese primary classroom, one-day observation	Closed questions about • Objective facts • Personal opinion • Non-academic	With this study, the authors documented the types of questions a teacher posed, who the teacher called on, and the teacher's demeanor while posing questions during one day in a Chinese grade-3 classroom. The authors only noted different types of closed questions. They found that the teacher posed questions about objective facts most often, almost always called on students that volunteered to answer, and almost always used a dry tone.
Contrasts with Probing Questions					
Abdulhamid and Venkat (2018)	4	1–6	Teachers in South Africa, following a 20-day "mathematics knowledge for teaching" PD course.	• Breakdown episodes – questioning the student's correctness, probing the student's response, probing the task • Sophistication episodes – asking another student, probing the student's response • Individuation/collectivization – confirming or probing with individuals or with the class	The purpose of this study was to elaborate upon ways teachers might respond to students' ideas. The authors identified three different types of episodes: breakdown episodes (a student offered an incorrect response), sophistication episodes (a student offered a correct response with inadequate reasoning), and individuation/collectivization episodes (a student or chorus provided a correct response with adequate reasoning). In each of these episode types, the authors mapped the possibilities for how the teacher further pursued student thinking.
Franke, Webb, Chan, Ing, Freund, and Battey (2009)	n/a	2–3	Teachers in U.S., filmed during a 1-week period, using reform-oriented materials following PD about relational thinking.	• General • Specific • Probing sequences • Leading	This study examined how students' responses related to teacher questioning with respect to the explanations students provided. General questions, specific questions, and probing sequences of specific questions all led students to expand upon

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Citation	# Teacher Participants	Grade level	Setting	Questioning Categories	Findings
					initial explanations, but only probing sequences consistently led to students providing correct and complete explanations. Uncovering details of students' strategies often required multiple specific questions.
Huffered-Ackles, Fuson, and Sherin (2004)	1	3	One novice teacher in an urban elementary school, with primarily bi-lingual Latino students.	Questioning sequences: • Level 0: questions are short and frequent • Level 1: questions require explanations of strategies • Level 2: probing questions follow requests for explanation • Level 3: teacher facilitates students asking questions	This study aimed at describing the development of a math-talk learning community in an elementary school setting. The teacher and students together moved through the levels of math talk (of which, questioning was one component among others) throughout the school year. As teacher evolved in the types of questions she posed her her role in classroom discourse, she also modeled for students what she expected in their talk.
McCarthy, Sithole, McCarthy, Cho, and Gyan (2016)	2	8	Teachers in U.S., each teaching a lesson on quadratic modeling.	• Probing and follow up • Leading • Check-listing • Student-specific	The purpose of this study as to describe the patterns of questioning the teachers used, which led to the list of four categories. Teachers probed incorrect responses more often than correct responses. Leading and checklisting questions helped guide students towards an answer, and they differed in the opportunities for students to explain their thinking. Student-specific questioning was used to invite students to participate.
Moyer and Milewicz (2002)	48	K-6	PST conducted mathematics interviews with students with an intervention on questioning in between interviews.	• Probing and follow up • Check-listing • Instructing rather than assessing	The goal of this study was to develop appropriate questioning strategies by preservice teachers. Each participant audiotaped their interviews with students, which followed by an analysis and reflection of the interview. The reflections allowed preservice teachers to recognize and reflect on how effective their question was.
Ong, Lim, and Ghazali (2010)	7	K-12	Primary and secondary teachers in Malaysia, participating in a 15-month lesson study process.	• Probing • Guiding • Factual	This study compared changes in the questioning practices of novice teachers and experienced teachers through a lesson-study process. Experienced teachers moved away from factual questions to more frequent use of probing questions. Novice teachers used primarily factual questions, and only one novice teacher (of three) showed any progress towards the use of probing and guiding questions.
Piccolo Harbaugh, Carter, Capraro, and Capraro (2008)	48	7–8	Teachers in U.S., each videotaped 3–4 times throughout one school year, following a 1-week summer PD about discourse strategies.	• Closed/rhetorical • How prompts followed by a series of closed questions • How prompts followed by probing or guiding questions	The purpose of this study was to look beyond individual utterances to see how sequences of interaction unfolded. Closed/rhetorical questions, and how prompts followed by closed questions, always led to a teacher moving on with little evidence of student understanding. Sequences of probing and guiding questions

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Citation	# Teacher Participants	Grade level	Setting	Questioning Categories	Findings
					could eventually lead to evidence of student understanding, but this was not guaranteed.
Sahin and Kulm (2008)	2	6	Teachers in U.S., one novice and one veteran, both using reform texts, five focal lessons related to equivalent fractions and fraction-decimal conversions.	• Probing • Guiding • Factual	The purpose of this study was to clarify the difference between probing, guiding, and factual questions, and to understand teachers' purposes for asking each type. Both teachers asked mostly factual questions, and the novice teacher asked more probing questions overall than the veteran teacher. Neither teacher used many guiding questions. Both teachers explained that they used factual questions to assess whether students knew requisite facts, concepts, or procedures. They used probing questions to allow students to explain their thinking, which they said could also help other students in the class.
van den Kieboom, Magiera, and Moyer (2014)	18*	middle school	PSTs in the U.S., each of whom conducted two 1−1 diagnostic interviews as part of a 14-week field experience.	Questioning segments included • Checklisting (asking a list of questions with no attempt to instruct) • Instructing (asking questions to guide towards the answer) • Probing (investigating the thinking that led to a response)	The purpose of this study was to document the relationship between PSTs' knowledge of functions and their questioning skills related to this topic. Overall, 49 % of segments were checklisting; 33 % were instructing; and 18 % were probing. PSTs who showed higher levels of algebraic thinking used more probing segments and fewer checklisting segments.
Webb, Franke, De, Chan, Freund, Shein, and Melkonian (2009)	4	2−3	Teachers in U.S., videotaped twice within a week, using reform materials 12 months after a PD about relational thinking.	• Probing students' explanations compared to non-probing responses	Teachers probed students' explanations in 26 % of interventions during small group work. In 63 % of instances in which students' explanations were not correct/complete prior to the teacher's intervention, the group did provide correct/complete explanations when the teacher probed students' explanations. By contrast, when the teacher engaged with students around their work but did not probe, only 20 % of those interventions led to correct/complete explanation. At the classroom level, classrooms with teachers who did more probing showed higher rates of correct explanations in small groups and higher achievement.
Webb, Franke, Ing, Wong, Fernandez, Shin, and Turrou (2014)	6	3−4	Teachers in the U.S., videotaped for 2−3 days following 6 months of informal observations.	• Asking a student to compare solutions, with no follow up • Asking a student to explain another's solution • Asking a student to compare, followed by specific questions to elaborate the relationship between two solutions.	When a teacher only requested a comparison, with no follow up, students showed low levels of engagement with one another's ideas. When a teacher asked a student to explain another's solution, they showed medium levels of engagement. When a teacher posed questions to help a student elaborate upon their solution in relation to another student's, students showed high levels of engagement. Moreover,

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Citation	# Teacher Participants	Grade level	Setting	Questioning Categories	Findings
					higher levels of engagement between students was positively correlated with student achievement.
Weiland, Hudson, and Amador (2014)	2*	1	PSTs in the U.S., each of whom conducted weekly 1−1 formative assessment interviews for 10 weeks.	• Problem posing (checklisting) – protocol, framing, or new • Instructing – teaching or leading • Follow up (probing) – nonspecific, competent, or incorrect	This study documented changes in two PSTs' questioning throughout a 10-week field experience in which they each conducted weekly 1−1 assessment interviews with students. The PSTs increased their frequency of competent follow-up (i.e., specific probing) questions, and decreased the frequency of non-specific questions. These changes roughly corresponded to improvements in the PSTs' noticing skills.
Weston, Kosko, Amador, and Estapa (2018)	99*	elementary	PSTs in U.S. elementary math methods courses, creating comic-based depictions of teaching using one of two media platforms.	Questioning sequences: • Level 0: questions are short and frequent • Level 1: questions require explanations of strategies • Level 2: probing questions follow requests for explanation • Level 3: teacher facilitates students asking questions	In this study, PSTs displayed questioning practices by creating illustrations of teacher questioning in a cartoon-based lesson. The most frequent questioning sequences were level 1, followed by level 0, then level 2. No level 3 sequences were identified. PSTs performed similar levels of questioning regardless of whether they used a platform to create still depictions, or a platform to create animations.
Questioning with Technology					
Akkoç (2015)	35*	9−12	PSTs in Turkey, taking a course to develop TPCK, developing technology-based lessons for peer teaching.	• Mathematical – Promoting reasoning, assessing prior knowledge, generating examples, relating concepts, linking representations, asking for real-world examples • Technical – Promoting reasoning, relating concepts, linking representations	The purpose of this study was to document how PSTs used questioning as part of formative assessment in technology-integrated lesson plans. PSTs increased the frequency of mathematical questions in their lesson plans and teaching notes, and the purposes of mathematical questions changed, following a formative assessment workshop. Namely, participants posed fewer low-level questions and more questions related to reasoning, making connections, and assessing prior knowledge. Additionally, the PSTs posed more technical questions focusing on reasoning and linking representations.
Cayton, Hollebrands, Okumus, and Boehm (2014)	3	9–12 (geometry)	Teachers in U.S., using a dynamic geometry program over 2 years, following a 2-week summer PD and 2 years of online PD, each observed ~2 times per semester.	• Probing • Exploring mathematical meanings and relationships • Generating discussion • Procedural/factual • Other mathematical • Non-mathematical	The purpose of this study was to document how teachers responded to pivotal teaching moments in technology intensive classrooms, and how those responses may have been connected to teacher-tool relationships. One teacher used the technology as a "servant"; her use of higher-level questions (probing, exploring, generating) outweighed her use of factual questions. The teacher who used the technology as a "partner" consistently asked higher-level questions. One teacher used the technology as a "master"; her

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Citation	# Teacher Participants	Grade level	Setting	Questioning Categories	Findings
					classroom was most often characterized by mathematical and technical confusion, and her questions were primarily procedural/factual.
Chao et al. (2016)	3	1–2 7–8 11–12	Teachers in U.S., using smartphone technology for 1–1 diagnostic interviews; the authors prepared a 2-minute fictional video of a student solving a problem, and each teacher held a 30−60 min interview session.	• Clarification • Verification • Extension • Redirection	This study documented how three different teachers interacted with students through the use of smartphone technology. Clarifying and verifying questions were ways the teachers could probe student thinking; the teachers noted that the technology helped them clarify and verify students' thinking, because they could review the video and interaction. Only one teacher pursued extension questions, which were mutually exclusive with redirection. The types of questions the teachers posed seemed related to how they viewed the purpose of the interview (i.e., diagnostic versus instructional).
Hähkiöniemi (2017)	29*	7−12	Finnish secondary math PSTs, introduced in the teacher preparation course to inquiry-based teaching and the use of GeoGebra; each PST implemented one inquiry-based lesson, half using and half not using Geobra.	• Probing method • Probing reasoning • Probing cause • Probing meaning • Probing argument • Probing extension • Unfocused probing	Overall, the PSTs posed 70 % conceptual probing questions (reasoning, cause, meaning, argument, extension) and only 30 % procedural probing (method) during their problem-based lessons. There was no significant difference among PSTs who used GeoGebra versus those that did not, although PSTs who used GeoGebra asked slightly more conceptual questions during the "explore" phase of the lesson compared to those who did not use GeoGebra.
Hollebrands and Lee (2016)	6*	middle school	PSTs in U.S., implementing a 30-minute dynamic geometry exploration with middle school honors geometry student as part of a methods course.	• Focus on technology • Focus on technology to notice mathematics • Focus on mathematics with the use of technology • Focus on mathematics	The purpose of this study was to describe the types of questions that PSTs would pose to focus students' attention to the relevant mathematics and technology when working on dynamic geometry tasks. The authors identified 13 questioning purposes across the four categories. In all but one case, the PSTs began with questions focused on the technology. Although they used questions focused on mathematics and technology, they rarely asked students to explain relationships.

Note: An asterisk (*) indicates the teacher participants were pre-service teachers.

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