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Cover Page Footnote

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Developing Formative Assessment Practices in Instruction: Recommendations from a Meta-Aggregation[1]

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Secondary mathematics teachers' use of formative assessments have shown promise for developing models of their students' mathematical thinking and informing their instruction. While the complexities of secondary mathematics teachers' formative assessment practices are often captured in qualitative research, there is a critical need for synthesized recommendations to connect formative assessment theory to practice. In a meta-aggregation synthesis from 11 qualitative manuscripts, we explored in-service teachers' formative assessment practices in US secondary mathematics classrooms. Our synthesis led to nine recommendations for in-service secondary mathematics teachers throughout three phases of their instruction: (a) prior to gathering evidence of student thinking; (b) while gathering, supporting, and responding to student thinking; and (c) reflecting on formative assessment practices. We close with connections to equitable teaching practices in secondary mathematics classrooms.

Keywords: Formative Assessment, Meta-aggregation, Secondary Mathematics

Introduction

Effective classroom assessment includes multiple strategies that inform learning and guide instructional decisions throughout teaching (Black & Wiliam, 2009; Collins, 2011; NCTM, 2000). Kalinec-Craig (2017) named formative assessment (FA) as one of several equity-oriented teaching processes. Namely, FA provides opportunities for teachers and students to recognize students' current mathematical understandings as well as to elicit information about and acknowledge students' linguistic and cultural resources. In our work with secondary mathematics teachers, we witness a robust working knowledge of assessment practices that serve both students and teachers, such as (a) pre-assessing students' prior knowledge, (b) making decisions during class about whether students mastered a concept, and (c) making decisions about how to move forward with instruction (Kenney et al., 2016). These are examples of teachers engaging in FA, which is a "planned, ongoing process used by all students and teachers during learning and teaching to elicit and use evidence of student learning to improve student understanding of intended disciplinary learning outcomes and support students to become self-directed learners" (The Council of Chief State School Officers, 2022).

FA involves frequent, interactive assessments of students' learning that are interpreted and used by teachers and students to "make decisions about the

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next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence" (Black & Wiliam, 2009, p. 6). FA informs action for both teachers and students toward the regulation and progression of student learning. Utilizing FA practices, such as higher-level questioning (Moyer & Milewicz, 2002; Stein et al., 2008) and formative feedback (Hattie & Timperley, 2007; Rathje, 2018), mathematics teachers can create positive classroom environments where students are motivated to learn (Moyer & Milewicz, 2002) and where students are provided opportunities to gather feedback from peers and engage in self-assessment of their own mathematical learning (Shepard, 2000). Furthermore, FA provides opportunities for teachers and students to recognize and attend to the holistic needs of learners, not only in relation to mathematical understandings (Martin et al., 2022). Helping secondary mathematics teachers see the potential of FA and implement them effectively in their daily instruction is a continuous goal of mathematics teacher education.

We find ample quantitative research-based recommendations for formal and informal data practices in instructional decision-making for teachers (e.g., Black & Wiliam, 1998; Hattie & Timperley, 2007; Kingston & Nash, 2011; Lee et al. 2020; NMAP, 2008). These quantitative studies identify types and/or features of FA that are effective for supporting students' learning when properly implemented and contextualized in learning opportunities. For example, Hattie and Timperley (2007) state that feedback is one of the most powerful assessment tools that influence students' learning and achievement. Most quantitative work, however, does not explore details of *how* different FA approaches and tools are used (Kingston & Nash, 2011). For a deeper exploration, we can turn to qualitative research, which reveals useful details of mathematics teachers' FA practices and generated evidence-based knowledge in relation to moving student learning forward (e.g., Black & Wiliam, 2009; Gotwals et al., 2015; Hodgen & Marshall, 2005). Qualitative research can provide a fine grain understanding of classroom practices, behaviors, needs, and routines with details that quantitative research cannot. It can provide support for a conceptual understanding of the assessment tools and practices that are productive for guiding and unpacking student thinking and informing teachers' instructional decisions. Findings from qualitative studies, however, are often overlooked or undervalued in policy and decision making because they do not provide measures backed by statistical power (Cai et al., 2019).

Thunder and Berry (2016) have suggested that mathematics education could benefit from qualitative synthesis, in which reported findings from relevant qualitative studies serve as "data" for analysis to derive a new theory or interpretation from original findings (e.g., Major & Savin-Baden, 2010). Thus, our goal in this paper is to use qualitative synthesis to help mathematics teachers translate and apply knowledge generated across various qualitative research studies on FA into specific classroom practices. We use a meta-aggregation method (c.f., Aromataris & Munn, 2020), a specific approach to qualitative synthesis to integrate existing qualitative empirical evidence related to secondary mathematics teachers' FA practices and to provide actionable steps that practicing secondary mathematics teachers can use that bridge findings from FA research to their instructional practices. In pursuit of this goal, we developed nine recommendations to support secondary mathematics teachers' engagement with FA based on the results of our meta-aggregation that synthesized 11 qualitative research studies.

Framework

If one searches the "assessment cycle" online, a common general picture of classroom assessment appears that resembles Figure 1. However, this and similar images tend to oversimplify the reality of teachers' daily practices, the intricacy of who and how assessments serve classroom needs, and the variety of complex considerations and decisions made within and across each part of this cycle.

To help teachers connect the findings and recommendations from our meta-aggregation directly to their daily practice, we organized our findings to reflect a deeper dive into this assessment cycle. As shown in Figure 2, we considered additional FA practices in three sub-domains: (a) prior to gathering information about student thinking (*planning for FA*); (b) when gathering, supporting, and responding to student thinking (*teaching, measuring, and adjusting instruction with FA*); and (c) when reflecting on and learning from student thinking (*reflecting on FA practices).* We use double-sided arrows in Figure 2 to recognize

Figure 1. Generic Cycle of Assessment

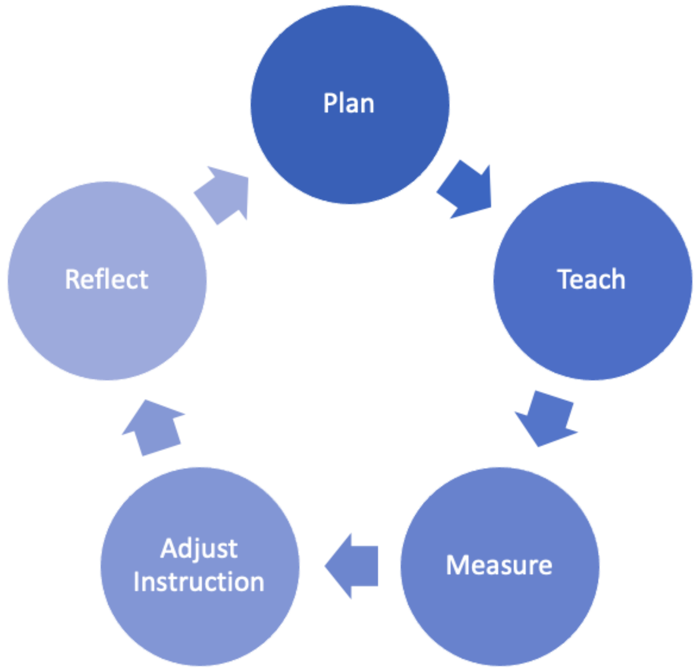

Figure 2. Teachers' FA Practices Before, During, and After Gathering Evidence of Students' Mathematical Thinking

that FA is complex. It does not necessarily follow an orderly cyclical pattern but can include practices that move from any part of this diagram to another. We used this figure to frame our analysis and synthesis of data.

Method

Research Design

We used the meta-aggregation approach for our synthesis because it was developed with the explicit aim to facilitate evidence-based practices by bridging research findings to education policies and/or classroom practices (Aromataris & Munn, 2020). In addition, our goals aligned with a key objective of meta-aggregation, which is to generate practical-level theory, or lines of action, that are directly and immediately applicable to decision-making practices (Lockwood et al., 2015).

Sampling

To be included in our meta-aggregation, we set criteria for studies to: (a) be empirical, qualitative research disseminated between 2008 and 2019; (b) target United States secondary mathematics students, teachers, and classrooms; (c) investigate in-service teachers' FA use; and (d) provide sufficient evidence to support their claims and findings as determined through a critical appraisal (i.e., Maeda et al., 2022). We focused on qualitative research developed since 2008 due to our focus on PCK and Ball et al.'s (2008) Mathematical Knowledge for Teaching framework as we considered how to support secondary mathematics teachers to develop more equitable instructional practices in our roles as mathematics teacher educators. We focused our attention on studies in the United States to examine research-based practices occurring under common curriculum standards and policy (e.g., National Council of Teachers of Mathematics, Common Core State Standards of Mathematics, Every Student Succeeds Act).

To find our pool of research, we searched multiple databases (i.e., EBSCO, ERIC, Google Scholar, JSTOR, PsychINFO) using a combination of keywords (e.g., *formative assessment (including known practices such as peer assessment, exit tickets, and others), mathematical knowledge, mathematics instruction, middle, pedagogical content knowledge, secondary, teacher practice, teaching* to identify studies that met our criteria. We also manually reviewed reference lists of the identified studies for additional resources. We identified an initial set of 47 possible studies and reviewed their abstracts to narrow our data for inclusion. Of those, we had to exclude 36 from our list as they focused, for example, on primary teachers, pre-service teachers, international contexts, or quantitative methods. We conducted a critical appraisal of each of these to make sure that they provided sufficient reporting quality to support the credibility of our synthesis results (Lockwood et al., 2015). The critical appraisal form includes 22 questions (Maeda et al., 2022; e.g., *Did authors provide descriptions of the data collection/analysis procedures? Did authors' reported results address their research questions?*) to evaluate reporting practices to understand primary study accurately. All 11 identified studies met the criteria for reporting quality and became our data sources for the meta-aggregation. These 11 studies are indicated with an asterisk (*) in the reference list.

Data Collection

Data in meta-aggregation consist of the primary author's findings, claims, themes, and metaphors (we will refer to these collectively as the *primary claims)* reported in the 11 qualitative research studies (see descriptions of these included primary studies in the Appendix). We coded studies to extract data and assign one of three credibility codes to each datum (Pearson, 2004) as follows: We considered primary claims to be *unequivocal* (i.e., no room for debate) when they were accompanied with evidence (e.g., interview excerpts, direct quotations of participants' voice, observations). When supporting evidence was present but perhaps insufficient, we coded the finding as *credible* (i.e., open to challenge). Finally, we coded claims as *unsupported* when no supporting evidence was provided to back authors' statements and excluded from our analyses. Only unsupported claims were excluded from the analysis. Through our credibility coding process, we identified 656 usable claims, and 79 as unsupported across the 11 primary studies. Following methods for meta-aggregation (Aromataris & Munn, 2020), unequivocal and credible findings are combined and weighted equally in the synthesis.

Synthesis

Table 1 summarizes the steps of data analysis we carried out in our meta-aggregation. We used inductive, descriptive coding (Saldaña, 2016) in our first cycle of analysis to categorize and organize the large quantity of primary authors' claims retrieved from 11 studies. This involved each coder describing primary claims with a word or short phrase to describe the "topic" of the claim. We produced a total of 189 descriptive codes from 656 primary claims. We then grouped these by descriptive similarities (Hannes & Lockwood, 2011) for further analysis. Next, to identify conceptual commonality among the assigned codes (Hannes & Lockwood, 2011; Major & Savin-Baden, 2010), we created 24 clusters among the codes, which we refer to as our 24 synthesis *findings*. We then sorted our findings according to the framework (i.e., prior to gathering, while gathering, reflection). Finally, we synthesized findings within each framework category into broader *thematic statements* used to generate *synthesis statements* and, finally, *lines of action*. In Table 1, we share an overview of the meta-aggregation qualitative synthesis process through an example of how two primary claims were coded, themed, synthesized, and ultimately used to inform one of the lines of action shared in this manuscript.

Table 1. Overview of the Meta-Aggregation Synthesis Process for Developing Lines of Action

Meta-Aggregation Step	Example of Data
1. Retrieve primary authors' **claims** as data from primary studies	Claim 1: "The classroom environment must be an open, trusting environment where students are partners[a] in learning process." (McManus, 2008, p. 83) Claim 2: "The second overarching theme is negotiating, which represents Mr. Patrick's perspective on the importance of promoting student autonomy[b] in the classroom.... By developing and maintaining this approach to teaching and learning, Mr. Patrick made his students investors in their own development[c]." (Wallinga, 2017, pp. 93-94)
2. Assign descriptive **codes** to each claim	[a] Students as partners [b] Promoting student autonomy [c] Students investors in their own development
3. Identify common ideas in codes to thematize the data into our **synthesis findings**; categorize these according to framework	Framework section - While Gathering, Supporting and Responding to Student Thinking: • Develop relationships and recognizing needs • Encourage student involvement • Provide students with autonomy and self-efficacy • Support peer collaboration
4. Synthesize the findings to identify themes in a **thematic statement**	"Teachers develop a classroom environment that positions students as partners in formative assessment."
5. Use the themes to develop a detailed **synthesis statement**	"Effective formative assessment strategies only work if students are engaged in the learning. Knowing how to engage students is a key factor to carrying out assessment practices. Engaging students as partners in learning and assessment allows teachers and students to frame new ideas in contexts and language that make sense to the students, encouraging student buy-in to the learning process."
6. Translate synthesis statements into **lines of action**	"Position students as partners in instruction and assessment."

The 24 synthesis findings that we generated are shown in Figure 3 with a matrix illustrating which studies had claims supporting each finding. The number of studies related to each finding ranged from 3 to 11, and the primary studies contributed to a minimum of 8 of the findings and a maximum of 21. The fact that all primary studies are fairly represented in our findings lends credibility of our appraisal process to evaluate studies for inclusion as data, and as a result, the credibility of synthesis findings.

Recommendations

In each of the three sections below, we break down the components of the assessment cycle into different elements of our framework (from Figure 2), each of which are accompanied by one or more research-based recommendations for secondary mathematics teachers' practice generated from our meta-aggregation. We support these recommendations with statements from the meta-aggregation findings.

Section 1 - Prior to Gathering Evidence of Student Thinking

In this section we focus on lines of action that mathematics teachers can take when planning instruction and assessment, prior to teaching. This could include planning right before a new lesson or working on a unit or semester-long plan. The recommendations could also apply to when teachers are in engaged in professional development or professional learning communities considering FA practices.

Designing a Collaborative Learning Environment. When planning to engage in FA, a promising practice is for mathematics teachers to attend to the classroom environment and curricular aims. Collaborative, student- centered mathematics

Figure 3. Representation of Findings Across Primary Studies

Findings	References	An-Wu	Austin-Hurd	Bonham	Davis	Dyer & Sherin	Kim	McManus	Philhower	Rathje	Seashore	Wallinga	Articles
Adjusting Curriculum	46												6
Adjusting Instruction	81												8
Analysis of student work	51												7
Building on students' prior knowledge	35												9
Condidtions for FA	46												10
Content Knowledge/pck	52												6
Develop Relationships and Recognize Individual Needs	19												3
Discourse and Questioning	58												9
Drawing on prior teaching experience	51												8
Encourage Student Involvement and Provide autonomy	19												4
Feedback	51												8
Fostering a student-centered environment	16												4
Instuctional Leadership Support	65												8
Practices for monitoring understanding	103												11
Observation and Feedback to teachers	8												3
Purpose/Goal of FA	23												6
Recognizing students' affective factors	57												8
Responsive teaching	10												3
Supporting Peer Collaboration (KCS)	33												8
Teachers' disposition	9												4
Teachers as learners	29												6
Teachers' Self Efficacy	22												4
Using learning targets and objectives	46												7
Value Teachers' current practices, preferences and needs	16												3
		11	10	11	19	8	16	14	16	14	13	21	

classrooms are those that promote student engagement in learning (e.g., through problem-solving tasks) and class discussions and provide opportunities for teachers to elicit and unpack student thinking. For example, in Wallinga's (2017) study, high school mathematics teacher, Mr. Patrick, created a student-centered classroom to make learning a group process that did not rely on the teacher for answers. He shared that "knowledge should be owned by the student" and worked to make his students "investors in their own development" (pp. 93-94). This environment built student autonomy and provided opportunities for instructional assessment as Mr. Patrick interacted with the students. When teachers and students are collaborators in learning, students demonstrate greater trust in teachers and comfort amongst their peers. Learning environments that attend to student agency provide opportunities for addressing individual learning needs of students or working collaboratively on small-scale FA.

Plan to use Multiple FA Strategies for Multiple Purposes. Teachers in the 11 studies incorporated frequent FA throughout each lesson to provide multiple access points to student thinking, opportunities for written and oral feedback, active engagement with students during class, and other useful information. Teachers learned to both recognize the purpose of and know how to enact various FA strategies. For instance, while planning to engage students in mathematical tasks, teachers considered what type of information they could gain from different FA strategies as well as how to gather the necessary information from their students to inform instructional decisions. Furthermore, teachers recognized that "formative assessment cuts two ways: it reveals student difficulties but also shows unanticipated student strengths" (Seashore, 2015, p. 40).

Include assessment of student affect. To effectively gather information about students' mathematical thinking, teachers in the meta-aggregation studies developed trust and rapport, both between themselves and their students, as well as across peer groups. To support students' mathematical thinking, teachers went beyond gathering technical information, such as how students are thinking about mathematical problems, and planned frequent check-ins about students' experiences, beliefs, confidence, and attitudes in and outside of the mathematics classroom. Using FA for this purpose in mathematics classrooms encourages teachers to frequently adjust their instruction and demonstrates to students that the teacher cares about them as learners. This can help to promote student "buy-in" and better motivation and engagement in learning. For example, in Bonham's (2018) study, teachers used exit tickets or thumbs-up/down questions to intentionally gather information about their students' disposition toward mathematics and the tasks at hand. The teachers often planned these affective aspects of FA for early in a lesson when new material was being presented to connect with the students and to help them make decisions about how to proceed.

Anticipate Multiple Ways Students Can Approach Mathematical Tasks. As teachers plan assessment tasks for the secondary classroom, they need to anticipate different ways that students may understand or approach the tasks and consider possible student errors on specific standards and learning objectives. Wallinga (2017), for example, found that teachers developed their ability to anticipate student thinking by planning multiple FA methods to collect a diversity of student thinking on a common topic. Teachers can also develop this understanding in small steps by unpacking multiple student approaches to one mathematical learning target at a time. In An & Wu (2012), for example, the researcher used grading and analyzing student work on homework as a way to help teachers understand and anticipate diverse ways students make sense of the material. Teachers can also consider ahead of time how they will use questioning, discourse, group work, and other oral FA practices to capture and give feedback to students' in-the-moment thinking during learning. Such planning activities related to FA can support mathematics teachers' pedagogical content knowledge through developing deeper understandings of students' diverse ways of thinking.

Understand mathematical learning progressions. Key to being able to assess and draw out students' prior knowledge is awareness of the mathematics that students have been exposed to before and where new knowledge will be used in the future. Thus, teachers need opportunities to understand learning progressions or trajectories. In Wallinga (2018), for example, "Mr. Patrick's knowledge of learning trajectories has led him to interpret certain curriculum standards based on his appraisal of what students can handle, and what will ultimately serve them best in the long run." Knowing details about the mathematics curriculum from year to year and from unit to unit is important in the development and use of FA. Philhower (2018) underscored this point, sharing that prior teaching experience was seen as a support for FA practices like writing learning goals, determining questions, and adjusting instruction. Schools can help novice teachers in this effort by giving them opportunities to teach or observe multiple classes and grade levels and to discuss common threads across content areas with other mathematics teachers. Collaborating across a span of courses that students will take in middle or high school allows teachers to understand the learning progressions that students will experience and incorporate that knowledge into FA planning.

Practice analyzing written work. In An and Wu (2012), the researchers analyzed student work on homework to help teachers understand and anticipate diverse ways students make sense of the material. They shared:

> Teachers are learners who catch students' errors, inquire about students' thinking, analyze patterns of errors, take action to correct, use errors to reinforce understanding, and learn from error analysis on a daily basis in a progressive process as the content level increased from fall semester to spring semester. Their engagement in the inquiry process of error analysis provided the evidence of their progress and growth in knowledge of students' thinking. (p. 734)

When secondary mathematics teachers practice anticipating student thinking by engaging in error analysis of students' written work, they can consider how this translates into in-the-moment analysis of student thinking and instructional decisions.

Section 2 - While Gathering, Supporting and Responding to Student Thinking

In this section, we focus on lines of action that teachers can take during instruction to effectively implement and use FA to guide student engagement and learning.

Connect FA Strategies to Learning Targets and Objectives. It is critical to keep learning targets front and center for both the teacher and the student during learning and assessment. As teachers in the studies engaged their students in FA, many drew upon and reflected on their prior knowledge, knowledge of learning progressions, and experiences teaching mathematics to connect students' experiences to current and future learning targets. Connecting FA explicitly to specific mathematical learning targets and objectives can support students to make connections to larger mathematical concepts. Seashore (2015) stressed the importance of supporting teachers in their use of learning goals for effective FA and the need for teachers (a) to establish learning goals for themselves and their students, (b) to consider how their learning goals relate to the instructional choices they make during lessons, and (c) to know a lesson is moving toward meeting all learning goals, and refine the learning goals and/or lessons as needed.

Teachers across the studies connected students' thinking during class to specific learning targets by posting them in the front of a room for each lesson. Teachers in Philhower's (2018) study adjusted this practice for their student-centered, multi-day lessons by posting focus questions from their curriculum every day and discussing and reflecting on them with students continually throughout the learning activities. Such questions linked to the learning objectives also help guide how teachers assess progress and make meaningful instructional decisions.

Use FA to Adjust Instruction and Move Student Thinking Forward. Across the 11 primary studies, teachers adjusted their instruction based on FA evidence specific to their prior experiences, the classroom and school environment, as well as their knowledge of their students. Common adjustments in response to student information included altering the (a) lesson pacing, (b) mathematics tasks and exercises, and (c) modes of student engagement (e.g., transitioning from whole group to independent or group work).

The use of formative feedback, particularly useful when students are engaged in small groups, was highlighted by Austin-Hurd (2015) as a tool that aides greatly in moving student thinking forward. The teachers in this study saw importance in providing written feedback to students, but more importantly, to discuss the feedback in a timely manner with students individually or in small groups so they could ask questions and make use of the feedback for learning. One teacher, for example, created stations in the classroom that provided an opportunity for students to conference one-on-one with the teacher for feedback and discussion on their ideas. Teachers found that the feedback process generated more student engagement and allowed the teachers to build relationships with students and better understand the ways students thought about the mathematics.

Remaining flexible in which FA strategies teachers use allows them to better meet individual students' needs, while also attending to diverse learners. Through employing multiple FA strategies, teachers can support students' mathematical thinking by: (a) making connections between students' ideas to task structures, (b) connecting interpretations of student thinking across time, and (c) linking students' ideas with prior class discussions and mathematical engagements. Dyer and Sherin (2016) referred to this as teachers engaging in connecting specific moments reasoning, sharing that "teachers can find the similarities and differences in how students are thinking and plan whole-class discussions or even new tasks that directly address and build on multiple students' thinking" (p. 80).

Position Students as Partners in Instruction and Assessment. Secondary mathematics teachers' understandings of their students and curriculum determine which FA strategies are effective for moving student learning forward. Teachers can use multiple FA strategies that will actively engage their students as partners in the learning process. As McManus (2008) shared,

> students became more engaged in the [learning] process by justifying answers, and analyzing solutions. They also participated in more peer and self-assessment. The students enjoyed being involved in developing rubrics and appreciated having more transparency in the grading process. Teachers reported that students had more positive attitudes in their classes. (p. 78)

Students in the study reported that creating the rubric helped them understand expectations and made evaluating their work transparent. We would also suggest that engaging students in designing rubrics encourages both teachers and students to value mathematical problem-solving and tasks that do not have a single approach or solution, where the focus is not just on an answer being right or wrong. Positioning students as partners in assessment can support teachers' use of tasks that attend to students' conceptual understanding and problem-solving practices.

Teachers in several studies also used self-assessment and peer-assessment to successfully build students' confidence and autonomy in learning mathematics. For example, in Davis' (2017) study, the teachers "modeled self-reflection strategies for students to use throughout the lesson, and as observed later, students were using these strategies to build confidence in their own abilities to master the content" (p. 158). These strategies are critical because if students do not have the confidence to engage in the mathematical tasks, FA will show very little about what they know and can do.

Discuss Mathematical Concepts with Students. Our analysis of the studies emphasized the importance of discussing mathematical concepts with (rather than telling mathematical concepts to) students. Engaging in classroom discourse allows for teachers to assume the role of facilitator and invite students to take on most of the academic thinking (Davis, 2017). Seashore (2015), for example, used frequency counts of how many different students were able to share a solution strategy to represent students' agency in mathematics classrooms. Teachers in Seashore's study used questions like "Did anyone use a different method" (Mr. Davidson, p. 84) to engage multiple students in conversations about mathematical solutions. Teachers across the studies structured mathematical tasks and classroom activities to promote classroom discourse and peer collaboration. For instance, teachers in Davis' study relied on turn and talks, think-pair-shares. Prioritizing discourse and group work encouraged students to take on more of the responsibility for their own mathematical learning. Using purposeful questioning and ample wait time in secondary mathematics classrooms supports students to grapple with multiple solution strategies. Teachers in McManus' (2008) study, for example, asked "why" to facilitate dialogic discourse, or questions that were used for the purpose making sense of new ideas. Dialogic discourse between teachers and students, as well as in small groups, aides greatly in assessment by allowing teachers to learn from in-the-moment evidence of students' thinking and support students work and ideas.

Section 3 - Reflecting on FA practices

In this final section, we address how teachers can reflect on their FA practices and the usefulness of these practices for generating productive understandings of students' ways of thinking. This level of reflection engages teachers as life-long learners and researchers of their own practice.

Identify Current FA Strategies and Areas for Future Growth. After engaging students in FA, secondary mathematics teachers in the primary studies, like many teachers, engaged in purposeful reflection about their practice and what they learned about their students' mathematical thinking. As teachers reflect on the effectiveness of their applied FA strategies, they can identify additional adjustments (e.g., changing pace, student pairings, mathematical tasks) to make in response to student information gathered in the moment.

Frequent reflections can provide opportunities for teachers to build confidence in their instructional practices and transition into their next lesson or unit. For instance, in Dyer and Sherin's (2016) study, teachers recorded their lessons and used a remote to timestamp moments in their instruction they wanted to engage in further reflection on. This provided the teachers with an open prompt to engage in responsive teaching specific to FA. Davis (2017) used guiding questions, such as "What forms does feedback take in your classroom?" and "What do you expect students to do with feedback information" to guide teachers' reflections on the purpose and implementation of FA in their mathematics classrooms (pp. 48-49). Furthermore, reflections do not need to be completed alone and can incorporate collaborative debriefs and conversations with peers and instructional coaches (Murray, 2015). Teachers may also need support in identifying these next steps, or how to implement new ideas in their instructional practice, leading to our final recommendation.

Engage In FA Development Opportunities. Teachers can benefit from developing shared definitions and understanding of the multiple purposes of FA with their peers. The teachers in the studies who developed strong FA practices relied on a high level of self-efficacy in their mathematical and pedagogical content knowledge. Similarly, a lack of confidence in themselves as mathematics teachers and a fear of not understanding students' mathematical thinking can hinder the effective use of FA for instruction. Thus, in addition to critical self-reflection, teachers should seek out and engage in collaborative discussions about FA practices with peer teachers. Asking a colleague to observe the classroom and to share their feedback in a post-observation discussion was an effective tool in Davis' (2017) study for building teachers' self-efficacy with FA strategies, for teachers found they learned "to self-evaluate and self-regulate their own learning for how to impact students' self-evaluation and self-regulation" (p. 157). Similarly, Kim (2019) showed that teachers in her study could be "supported to set goals by encouraging them to analyze curriculum materials, for example in collaborative teacher meetings, lesson study groups, or professional development sessions (p. 360). Teachers benefit from establishing shared instructional FA practices and norms through ongoing professional learning communities, as well as from individualized instructional coaching, and differentiated professional development catered toward their needs. Finally, practice with the FA process can support teachers to develop greater confidence in understanding students' mathematical thinking.

Limitations and Next Steps: Connections to Equitable Teaching in Secondary Mathematics

Reflecting on our analysis, we recognize areas in which our research could have gone further. For instance, in our explorations of the primary sources, as well as those of the primary authors, we focused on formative assessment in isolation from other instructional practices. Namely, little attention was given to the interrelations between formative assessment and efforts toward developing equitable mathematics learning spaces. However, we see ways in which our recommendations of effective implementation of FA in secondary mathematics classrooms are aligned with other teaching documents including the mathematics teaching practices from *Principles to Action* (NCTM, 2014) and the equitable mathematics teacher practices from *Catalyzing Change in High School Mathematics* (NCTM, 2018). For example, we have identified from this study that teachers are better able to collect productive FA evidence when they design a collaborative learning environment and facilitate mathematical discussions surrounding course concepts. These recommendations align with the goal of posing purposeful questions found in both NCTM documents (2014; 2018). Similarly, our recommendations for planning to use FA for multiple purposes and using FA to adjust instruction in response to students' needs can help support the goal of eliciting and using student thinking to build their mathematical identities (NCTM, 2018).

NCTM (2018) shares that equitable teaching practices must acknowledge students' community-based knowledge. Thus, teachers should draw upon their knowledge of students both within and beyond the mathematics classroom when developing and implementing FA practices (i.e., elicit and use evidence of student thinking). The FA process is also well-informed when students are central to the design and implementation. These practices highlight the need for teachers to transition from teacher-centered to student-centered mathematics classrooms, enhancing students' agency by positioning them as knowers and doers of mathematics (NCTM, 2018). Thus, while our research did not explicitly explore or foreground the role of the FA process in developing equitable teaching practices, teachers can and should consider the recommendations we outline in this manuscript in relation to their everyday efforts to teach mathematics with attention toward equity.

Concluding Thoughts

While the recommendations described above are provided independent of one another, it is important to recognize the interrelations between each. How teachers gather information about student thinking is informed by teachers' understandings of their students, themselves, and the contexts in which they are situated. Furthermore, how teachers reflect on their individual practices relative to the students, curriculum, instructional adjustments, and the purpose and application of FA strategies informs their use of future FA. Our recommendations serve to highlight the complexities that influence effective use of FA and contribute to quantitative findings that underscore the promise of FA on supporting students' learning. Namely, our recommendations help unpack teachers' prerequisite preparation and knowledge for FA and can be used to guide specific actions in teacher development environments.

We invite mathematics teachers to reflect on their current FA practices as they consider how best to move their students' thinking forward. Because advancing current classroom assessment practices along with these recommendations will require considerable time and effort from teachers, continuing vital supports and collaboration by districts, instructional leaders and colleagues are critical for implementing successful FA practices. These investments in time and resources will support teachers, schools, and districts to better meet students' holistic needs, promote sustained learning, and improve students' mathematical learning outcomes. Teachers and instructional leaders can utilize these recommendations from 11 primary studies about FA practices as they work to further refine their pedagogy and promote equitable, student-centered mathematics instruction. Students vary in their learning approaches and educational goals, and our nine recommendations are centered on preparing teachers to be ready to attend to the uniqueness of individuals' learning with FA and to provide equitable learning opportunities.

References

References marked with an asterisk indicate studies included in the meta-aggregation.

*An, S., & Wu, Z. (2012). Enhancing mathematics teachers' knowledge of students' thinking from assessing and analyzing misconceptions in homework. *International Journal of Science and Mathematics Education, 10*(3), 717-753.

Aromataris, E., & Munn, Z. (Eds.). (2020). *Joanna Briggs Institute Reviewer's Manual.* The Joanna Briggs Institute. https://reviewersmanual.joannabriggs.org/

*Austin-Hurd, B. G. (2016). *How educators conduct formative assessment with middle school student in order to improve student achievement.* (Publication No. 3745101) [Doctoral dissertation, Capella University). ProQuest Dissertations & Theses Global. (1757740794). https://search.proquest.com/docview/1757740794?accountid=13360

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability, 21*(1), 5-31. https://doi.org/10.1007/s11092-008-9068-5

*Bonham, J. L. (2018). *A study of middle school mathematics teachers' implementation of formative assessment.* (Publication No. 10745351) [Doctoral dissertation, University of Delaware]. ProQuest Dissertations & Theses Global. (2025939881). https://search.proquest.com/docview/2025939881?accountid=13360

Collins, A. (2011). *Using classroom assessment to improve student learning: Math problems aligned with NCTM and Common Core State Standards*. Reston, VA: National Council of Teachers of Mathematics.

*Davis, A. A. (2017). *A case study of mathematics teachers' use of short-cycle formative assessment strategies.* (Publication No. 10753754) [Doctoral dissertation, University of North Texas]. ProQuest Dissertations & Theses Global. (2009458498). https://search.proquest.com/docview/2009458498?accountid=1336

*Dyer, E. B., & Sherin M. G. (2016). Instructional reasoning about interpretations of student thinking that supports responsive teaching in secondary mathematics. *ZDM Mathematics Education, 48*(1-2), 69-82. https://doi.org/10.1007/s11858-015-0740-1

Gotwals, A. W., Philhower, J., Cisterna, D., & Bennett, S. (2015). Using video to examine formative assessment practices as measures of expertise for mathematics and science teachers. *International Journal of Science and Mathematics Education, 13*(2), 405-423. https://doi.org/10.1007/s10763-015-9623-8

Hannes, K., & Lockwood, C. (Eds.) (2011). *Synthesizing qualitative research: Choosing the right approach*. Wiley.

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research, 77*(1), 81-112. https://www.jstor.org/stable/4624888

Hodgen, J., & Marshall, B. (2005). Assessment for learning in English and mathematics: A comparison. *Curriculum Journal, 16*(2), 153-176.

https://doi.org/10.1080/09585170500135954

Kalinec-Craig, C. A. (2017). The rights of the learner: A framework for promoting equity through formative assessment in mathematics education. *Democracy and Education, 25*(2), 1-11. https://democracyeducationjournal.org/cgi/viewcontent.cgi?article=1298&context=home

Kenney, R. H., Bloome, L. & Maeda, Y. (2016). Unpacking teachers' perspectives on the purpose of assessment: beyond summative and formative. In Marcy B. Wood, Erin E. Turner, Marta Civil, & Jennifer A. Eli (Eds.), *Proceedings of the 38th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp.1228-1235). Tucson, AZ: The University of Arizona. http://www.pmena.org/pmenaproceedings/PMENA%2038%202016%20Proceedings.pdf#page=1242

*Kim, H. (2019). Teacher learning opportunities provided by implementing formative assessment lessons: Becoming responsive to student mathematical thinking." *International Journal of Science and Mathematics Education, 17*(2), 341-363. https://doi.org/10.1007/s10763-017-9866-7

Kingston, N., & Nash, B. (2011). Formative assessment: A meta-analysis and a call for research. *Educational measurement: Issues and Practice*, *30*(4), 28-37.

Lee, H., Chung, H. Q., Zhang, Y., Abedi, J., & Warschauer, M. (2020). The effectiveness and features of formative assessment in US K-12 education: A systematic review. *Applied Measurement in Education*, *33*(2), 124-140.

Lockwood, C., Munn, Z., & Porritt, K. (2015). Qualitative research synthesis: Methodological guidance for systematic reviewers utilizing meta-aggregation. *International Journal of Evidence-Based Healthcare,* *13*(3), 179–187. https://doi.org/10.1097/XEB.0000000000000062

Maeda, Y., Caskurlu, S., Kozan, K., & Kenney, R. H. (2022). Development of a critical appraisal tool for assessing the reporting quality of qualitative studies: a worked example. *Quality & Quantity.* Advance online publication. https://doi.org/10.1007/s11135-022-01403-y

Major, C. H., & Savin-Baden, M. (2010). *An introduction to qualitative research synthesis: Managing the information explosion in social science research*. Routledge.

Martin, C., Mraz, M., & Polly, D. (2022). Examining elementary school teachers' perceptions of and use of formative assessment in mathematics. *International Electronic Journal of Elementary Education, 14*(3), 417-425. https://doi.org/10.26822/iejee.2022.253

*McManus, S. M. (2008). *A study of formative assessment and high stakes testing: Issues of student efficacy and teacher views in the mathematics classroom.* (Publication No. 3306610) [Doctoral dissertation, North Carolina State University]. ProQuest Dissertations & Theses Global. (304546258).

https://search.proquest.com/docview/304546258?accountid=13360

Moyer, P. S., & Milewicz, E. (2002). Learning to question: Categories of questioning used by preservice teachers during diagnostic mathematics interviews. *Journal of Mathematics Teacher Education, 5*(4), 293-315.

Murray, E. (2015). Improving teaching through collaborative reflective cycles. *Investigations in Mathematics Learning, 7*(3), 23-29. https://doi.org/10.1080/24727466.2015.11790343

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Author.

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematical success for all.* Author.

National Council of Teachers of Mathematics. (2018). *Catalyzing change in high school mathematics: Initiating critical conversations.* Author.

National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel.* Washington, DC: U.S. Department of Education.

Pearson, A. (2004). Balancing the evidence: Incorporating the synthesis of qualitative data into systematic reviews. *JBI Reports, 2*(2), 45-64.

*Philhower, J. (2018). *Investigating high school mathematics teachers' formative assessment practices.* (Publication No. 10815272) [Doctoral dissertation, Michigan State University]. ProQuest Dissertations & Theses Global. https://search.proquest.com/docview/2042344819?accountid=13360

*Rathje, R. J. (2018). *A qualitative case study of mathematics teachers' formative assessment feedback.* (Publication No. 10974599) [Doctoral dissertation, Walden University]. ProQuest Dissertations & Theses Global. https://search.proquest.com/docview/2129736126?accountid=13360

Saldaña, J. (2016). *The coding manual for qualitative researchers.* SAGE.

*Seashore, K. H. (2015). *Learning through the use of instructional materials: Secondary mathematics teachers' enactment of formative assessment lessons.* (Publication No. 3733419) [Doctoral dissertation, University of California, Berkeley]. ProQuest Dissertations & Theses Global. https://search.proquest.com/docview/1730386296?accountid=13360

Shepard, L. A. (2000). *The role of classroom assessment in teaching and learning* (CSE Technical Report 517). Center for the Study of Evaluation National Center for Research on Evaluation, Standards, and Student Testing Graduate School of Education & Information Studies and Center for Research on Education, Diversity and Excellence https://nepc.colorado.edu/sites/default/files/publications/TECH517.pdf

Stein, M. K., Engle, R. A., Smith, M. S., & Hughes, E. K. (2008). Orchestrating productive mathematical discussions: Five practices for helping teachers move beyond show and tell. *Mathematical Thinking and Learning, 10*(4), 313-340. https://doi.org/10.1080/10986060802229675

The Council of Chief State School Officers. (2022, March 27). *Revising the definition of formative assessment.* Authors. https://ccsso.org/sites/default/files/2018-06/Revising%20the%20Definition%20of%20Formative%20Assessment.pdf

*Wallinga, W. (2017). *Examining the benefits of instructional assessment as experienced by secondary mathematics teachers.* (Publication No. 10685701) [Doctoral dissertation, University of New Hampshire]. ProQuest Dissertations & Theses Global. https://search.proquest.com/docview/2013336163?accountid=13360

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Appendix.

Table A-1. *Characteristics of Included Studies for the Qualitative Meta-Aggregation Synthesis*

Manuscript	Methodology	Method	Phenomenon of Interest	Setting	Geographic Region	Participants	Data Analysis
An & Wu (2012)	Qualitative (not specified)	Pre- & post-questionnaires and tests; observations; interviews; daily student-work analysis logs	Teacher learning of student thinking through evaluating homework	Three middle schools	Los Angeles County, CA	Ten middle school math teachers	Constant comparison
Austin-Hurd (2015)	Case study	Interviews; observations; participant logs	Formative assessment process in middle school classrooms	One middle school	Suburban Michigan	Six middle school math teachers	Coding
Bonham (2018)	Qualitative (not specified)	Document analysis; observations; interviews	Formative assessment practices in middle school mathematics classrooms	Three middle schools	Delaware	Five eighth grade teachers	Thematic framework, indexed, charted, mapped, and interpreted
Davis (2017)	Case study	Interviews; PD sessions; observations; post-observation conferences	Teacher knowledge and short cycle formative assessment strategies	One middle school	Urban; North Texas	Two sixth grade mathematics teachers	Time-series analysis
Dyer & Sherin (2016)	Case study	17 point-of-view observations	Cognitive dimensions of responsive teaching	One secondary school	Urban; Midwestern United States	Two high school math teachers	Open coding
Kim (2019)	Systematic comparison	Observations; semi-structured interviews; PD workshops	Relationships between formative assessment curriculum and teachers' responses to	Two middle schools	Urban; Northern California	Two seventh grade teachers	Categorizing, applying, and modifying themes

Manuscript	Methodology	Method	Phenomenon of Interest	Setting	Geographic Region	Participants	Data Analysis
			students' mathematical thinking				
McManus (2008)	Grounded theory with a restricted timeframe	Observations; interviews; artifact reviews	Formative assessment training and use as a means for improving student learning	Three high schools	North Carolina	Four Algebra I teachers	Constant comparison
Philhower (2018)	Qualitative (not specified)	Interviews; Observations of pair/small group activity	Formative assessment practices in high school mathematics classrooms	Four high schools	Rural, Urban, and Suburban; Central Michigan	Six high school mathematics teachers	Open coding
Rathje (2018)	Case study	Archival documents; observations; semi-structured interviews	Assessment and feedback practices of mathematics teachers in a private high school	One high school	Suburban; Midwestern United States	Three mathematics teachers	Multi-cycle descriptive coding; theme development
Seashore (2015)	Two case studies	Teacher surveys; classroom observations; classroom artifacts	What and how teachers learn from use of instructional materials	One middle school; one high school	Urban; San Francisco Bay area	Eight secondary mathematics teachers	Categorical coding and counting
Wallinga (2017)	Two instrumental case studies	Interviews; classroom observations	Teachers' instructional assessment practices and relation with their self-efficacy and knowledge of math content and students	One secondary school	Urban; Massachusetts	Two secondary mathematics co-teachers	Coding and thematic analysis