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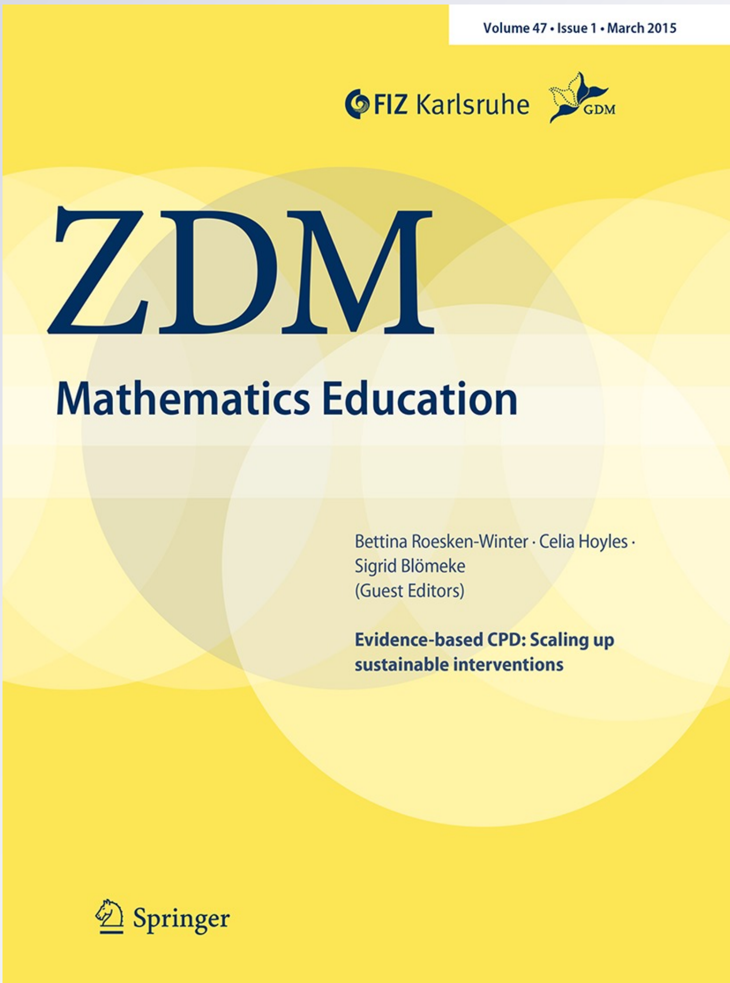

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ORIGINAL ARTICLE

Investigating the development of mathematics leaders' capacity to support teachers' learning on a large scale

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Abstract A key aspect of supporting teachers' learning on a large scale concerns mathematics leaders' practices in designing for and leading high-quality professional development. We report on a retrospective analysis of an initial design experiment aimed at supporting the learning of three math leaders who were charged with supporting the learning of middle-grades mathematics teachers across a large US school district. Initial goals for the math leaders' learning included: (a) viewing teachers' improvement of their classroom practices as a progression; (b) designing supports for teachers' learning that were informed by assessments of teachers' current practices, were oriented towards long-term goals for teachers' practices, and would enable teachers to attain short-term goals that constituted reasonable next steps; and (c) facilitating professional development by pressing on teachers' ideas differentially and building on their contributions. Findings suggest that the math leaders increasingly viewed teachers' improvement of their classroom practices as a developmental progression and began to design connected sequences of activities. However, they struggled to facilitate the activities in ways that would meet their ambitious goals for teachers' learning. Based on our findings, we indicate potential improvements to our design for supporting math leaders' learning. More generally, we provide the field with a set of potentially revisable learning goals for math leaders' learning, a set of principles to guide the design of supports for their learning, and a provisional design to support the development of their practices.

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1 Introduction

Richard Elmore (1996), a prominent scholar of educational reform in the United States, wrote that "Innovations that require large changes in the core of educational practice seldom penetrate more than a small fraction of US schools and classrooms, and seldom last for very long when they do" (pp. 1–2). Mathematics education reform in the US is no exception (Elmore, 1996; Wilson, 2003). Although a few cases of reform efforts have supported significant improvement in the quality of teaching and learning across a large number of classrooms (e.g., Franke, Carpenter, Levi, & Fennema, 2001; Silver & Stein, 1996), efforts aimed at improving the rigor of mathematics instruction across classrooms have typically had limited impact. As Elmore (1996) explains, reform that aims at more ambitious goals for students' learning often fails at scale because minimal attention is given to the school and broader system contexts in which teachers develop and revise their instructional practices (e.g., Cobb, McClain, Lamberg, & Dean, 2003; Coburn, 2003; Grossman, O'Keefe, Kantor, & Delgado, 2013). Key aspects of the school and system contexts that mediate instructional improvement efforts include curricular materials, the quality of formal and job-embedded professional development (PD), and school and educational system leaders' practices in creating conditions for instructional improvement (e.g., Bryk, Sebring, Allensworth, Luppesco, & Easton, 2010; Cobb & Jackson, 2011).

In this article, we focus on one central aspect of supporting teachers' learning on a large scale—mathematics leaders' practices in designing for and leading high-quality PD. By mathematics leaders, we mean mathematics specialists charged with supporting the learning of mathematics teachers across a school system. Leaders might each be based at a particular school, or, as in the case we report on, they might be based at a central office and each serve multiple schools. As we clarify below, while research suggests that high-quality PD is essential for accomplishing instructional improvement at scale, there is minimal research on how to support math leaders in designing and leading high-quality PD. We report on a retrospective analysis of an initial design experiment aimed at supporting the learning of three math leaders who were charged with supporting the learning of middle-grades mathematics teachers across a large US school district that served 80,000 students. In doing so, we describe initial, potentially revisable learning goals for math leaders' learning, a set of principles to guide the design of supports for their learning, and a provisional design to support the development of their practices. In conducting the study, we anticipated that improvements in the math leaders' practices would be necessary but not sufficient for instructional improvement at scale because the influence of the PD they designed and enacted for teachers would be mediated by other aspects of the contexts of teachers' work (e.g., the instructional expectations that school leaders communicate to teachers). As a consequence, the findings we report do not resolve the challenge of improving the quality of mathematics teaching on a large scale. They do, however, contribute to the field's understanding of a crucial aspect of system capacity for instructional improvement—math leaders' practices in designing and leading high-quality PD.

In what follows, we first review the literature that informed our design for supporting math leaders' learning. We then describe the larger context in which our study was situated: a researcher–practitioner partnership with a large US school district (which we call District B) that was attempting to improve the quality of middle-grades mathematics instruction. Next, we provide a description of our methods before reporting our findings, which focus on the PD practices that the math leaders developed. We conclude by considering why the practices the leaders developed differed from those that we intended, thereby indicating potential improvements to our design for supporting math leaders' learning.

2 Principles for supporting math leaders' capacity to design and lead high-quality professional development

The knowledge and practices of a PD facilitator affect the learning opportunities that arise for teachers in any professional learning experience. However, within mathematics education and PD research more broadly, minimal attention has been given to how to support PD leaders in designing and facilitating high-quality PD (Elliot et al., 2009; Weissenrieder, Roesken-Winter, Scheuler, Binner, & Blömeke, 2015). As Elliot et al. (2009) wrote, "Filling in this knowledge gap … is an urgent issue if teacher learning is to be improved" (p. 364). Given the thin research base, we extrapolated from the literature on high-quality teacher PD and pre-service teacher education when designing supports for math leaders' learning. We were particularly influenced by the literature on practice-focused teacher education (e.g., Ball & Cohen, 1999; McDonald, Kazemi, & Kavanagh, 2013) because it treats the goals for teachers' learning as complex practice and attempts to support significant reorganization of current practice. As will become clear, for the math leaders with whom we worked, designing and leading high-quality PD entailed significant reorganization of their existing PD facilitation practices. In preparing for the study, we synthesized this literature in an effort to derive core principles that then informed our work with math leaders. When possible, we incorporated the minimal research available on supporting math leaders' learning.

As a first principle, there is general consensus that for teacher PD to be effective, it needs to be sustained over time and involve the same group of teachers working together (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009). We presumed that this first principle would hold for math leader learning as well—opportunities for a group of leaders to work together over an extended period of time would likely build a sense of professional community (see also Roesken-Winter, Schüler, Stahnke, & Blömeke, 2015).

Second, the in-service teacher PD and pre-service teacher education literatures suggest it is essential that the supports for teachers' learning are close to practice (Ball & Cohen, 1999)—that is, they should focus on issues central to instruction and be organized around the instructional materials that teachers use in their classroom. In our case, this implied that the supports needed to focus squarely on what the math leaders were expected to do in their professional work and, when possible, make use of tools that they would use in practice. As an example relevant to math leaders' learning, in a project aimed at supporting leaders to implement a "problem-solving cycle" with groups of teachers, Koellner, Jacobs, and Borko (2011) engaged the leaders in the same mathematics tasks that the leaders would use with teachers who, in turn, would implement with their students (see also Kuzle & Biehler, 2015).

Third, when attempting to reorganize (and not merely elaborate or refine) current practice, it is crucial that the designed supports include co-participation with accomplished others in activities that approximate the targeted practices (Forman, 2003; Lave & Wenger, 1991). This implied that the math leaders were unlikely to develop the targeted practices unless they worked closely with others who had already developed accomplished PD design and facilitation practices.

Fourth, studies of professional learning and the teacher education literature suggest that the supports should include pedagogies of investigation and of enactment (Grossman et al., 2009). Pedagogies of investigation entail analyzing and critiquing representations of practices, such as video-cases of teaching (Borko, Koellner, Jacobs, & Seago, 2011; Sherin & Han, 2004), in order to develop an image of high-quality practice and/or to reflect on current practice. Pedagogies of enactment involve planning for, rehearsing, and enacting aspects of practice in a graduated sequence of increasingly complex settings with someone who is more accomplished; such pedagogies enable professionals to actually try out intended forms of practice with targeted feedback. For example, Elliot et al. (2009) supported PD leaders in leading rich discussions of mathematics tasks by engaging them in analyzing video-cases of teacher PD to provide "vivid images of the complex work of facilitating teachers' discussions of mathematical reasoning" (p. 368). In addition, they collaboratively designed an upcoming math teacher PD session with mathematics leaders to support them in choosing and sequencing a potentially productive set of tasks for mathematics teachers.

Fifth, pressing on teachers' ideas differentially and building on their contributions is central to supporting their learning (Borko et al., 2011; Elliot et al., 2009). Productively pressing on teachers' ideas requires both identifying clear learning goals (Kazemi & Stipek, 2001) and using specific talk moves such as asking for further explanation, revoicing teachers' contributions, and orienting participants to one another's ideas (Chapin, O'Connor, & Anderson, 2003). We anticipated that supporting the math leaders to learn to press productively would be necessary but challenging because it involves highlighting some teacher contributions while dropping others, and thereby runs counter to most teacher PD in which politeness is valued over professional debate and controversy (e.g., Ball & Cohen, 1999). We conjectured that the designed supports would need to include consistent press on the math leaders' ideas if they were to learn to press on teachers' ideas.

3 Researcher–practitioner partnership

The US educational system is decentralized, with a long history of the local control of schooling. Each US state is divided into a number of independent school districts. Since 2007, we have been involved in a researcher–practitioner partnership with District B in which we seek to understand what it takes to support instructional improvement of middle-grades mathematics teaching on a large scale.

District B leaders had articulated a vision of high-quality mathematics instruction that involved teachers building on students' current reasoning to enable them to develop conceptual understanding as well as procedural fluency (Franke, Kazemi, & Battey, 2007). As part of their instructional improvement effort, district leaders adopted a new set of instructional materials, *Connected Mathematics Project 2* (CMP2; Lappan, Fey, Fitzgerald, Friel, & Phillips, 2009), in 2007. CMP2 employs a three-phase lesson structure, in which teachers first introduce or "launch" a cognitively demanding task, then students work to "explore" the task, and finally the teacher orchestrates a concluding whole-class discussion of students' solutions, referred to as the "summary". During the summary phase, teachers are expected to press students to explain and justify their solutions, evaluate their peers' solutions, and make connections between different solutions and to key disciplinary ideas (Stein, Engle, Smith, & Hughes, 2008). District B leaders supported the implementation of CMP2 by developing detailed curriculum frameworks that, for example, linked the materials to state mathematics standards, and by investing heavily in PD and other supports for teachers' learning.

When we first began working with District B, the practices of most teachers were consistent with typical US mathematics instruction and emphasized the reproduction of demonstrated procedures for solving routine problems (Stigler & Hiebert, 1999). Teachers therefore had to significantly reorganize their current practices if their students were to attain learning goals that focused on conceptual understanding as well as procedural fluency. Our analyses of video-recordings of teachers' practices (30 teachers in years 1–4 of the project, and 60 teachers in years 5–6) indicate that although some aspects of teachers' instructional practices improved during the first 6 years of our partnership, most teachers had not developed forms of practice that would support their students' development of conceptual understanding. Our analysis of video-recordings collected in year 6 (2011–2012) indicated that the majority of teachers selected cognitively demanding tasks, which was an improvement compared to the first year of the study. However, only 20 of 60 teachers maintained the level of challenge of tasks throughout the lesson. In addition, although more teachers held concluding whole-class discussions compared to the first year of the study, most discussions were of the "show and tell" variety (Ball, 2001) and were therefore unlikely to advance students' understandings of central mathematical ideas.

In summer 2012, District B hired three middle-grades district math leaders who were based in the central office. The scope of their work included designing and leading pull-out PD sessions for groups of mathematics teachers across schools, facilitating the work of collaborative teacher groups at schools, working individually with teachers in their classrooms, and supporting principals' instructional leadership in mathematics. Analyses of data collected in prior years indicated that all three math leaders were accomplished math teachers; exhibited better than average mathematical knowledge for teaching (Hill, Schilling, & Ball, 2004); and had developed sophisticated visions of high-quality mathematics instruction that were consistent with the logic of CMP2 lessons (Munter, 2014). However, senior district leaders recognized that the math leaders would need support in learning how to work effectively with groups of teachers. We therefore agreed to collaborate with district leaders during the 2012–2013 school year to support the math leaders to design and lead PD for math teachers.

Methodologically, we approached this work as an initial professional development design study (Cobb, Jackson, & Dunlap, 2014), the goal of which was to contribute to the development of a practice-specific PD theory that would consist of a substantiated learning process that culminates with math leaders' development of particular PD practices, and the demonstrated means of supporting that learning. Our decision to conduct a design study is reasonable given the thin research base on supporting instructional leaders' capacity to support teacher learning and the fact that it was unlikely that such learning would occur in situ. In the following paragraphs, we clarify the math leaders' initial practices, our goals for their learning, and our conjectures about the means of supporting their learning.

4 Math leaders' initial practices

To inform both our identification of goals for math leaders' learning and the designed supports, we video-recorded a set of PD sessions that the three math leaders led in summer 2012. One of the leaders, Alice,[1] led a two and a half hour session for seventh grade teachers on planning for an instructional unit that would last several weeks. The other two leaders, Amanda and Malcolm, co-led a two and a half hour session for grades 6–8 teachers on formative assessment. We analyzed these videos to identify the math leaders' initial PD planning and facilitating practices (we describe our methods for analyzing video of PD sessions in Sect. 7).

This assessment of the math leaders' initial practices indicated that they would need substantial support in designing and leading high-quality PD. Across both sessions, the math leaders gave the teachers little direction, and it was difficult to discern a specific set of learning goals targeted by the activities. For example, in the session focused on planning for upcoming instruction, the teachers worked in groups to co-plan an entire unit with minimal direction from the math leader. Teachers did not solve any of the mathematical tasks in the unit and were not pressed to articulate goals for student learning. In the session on formative assessments, it was not clear how the different activities that the math leaders facilitated were connected to each other.

Furthermore, although the math leaders elicited teachers' ideas in both sessions, they did not press or build on teacher contributions in meaningful ways. For example, they asked teachers to share ideas, but did not press on teachers to elaborate what they said, check to see if other teachers understood what was shared, or make connections between the teachers' contributions.

5 Goals for math leaders' learning

Based on our assessment of the math leaders' initial PD practices, as well as the relevant literature, we identified three goals for their learning. Our first goal was that the math leaders would come to view teachers' improvement of their classroom practices as a developmental trajectory or progression rather than as "filling in" or rectifying deficits in teachers' current practices. The second goal was that the math leaders would design supports for teachers' learning that were informed by ongoing assessments of teachers' current practices, were oriented towards long-term goals for teachers' improvement of their classroom practices, and would enable teachers to attain short-term goals that constitute reasonable next steps in their learning (Gibbons, 2013; Simon, 1995). We conjectured that the second goal would be related to the first in that a developmental perspective on teachers' learning would orient the math leaders to build on teachers' current practices when designing supports. The third goal was that the math leaders would facilitate PD by pressing on teachers' ideas differentially in order to build on their contributions (Borko et al., 2011; Elliot et al., 2009). We conjectured that the math leaders would need to formulate clear learning goals for teachers if they were to be strategic in deciding which ideas to build upon, which ideas to challenge, and which ideas to let go.

[1] All names of participants are pseudonyms.

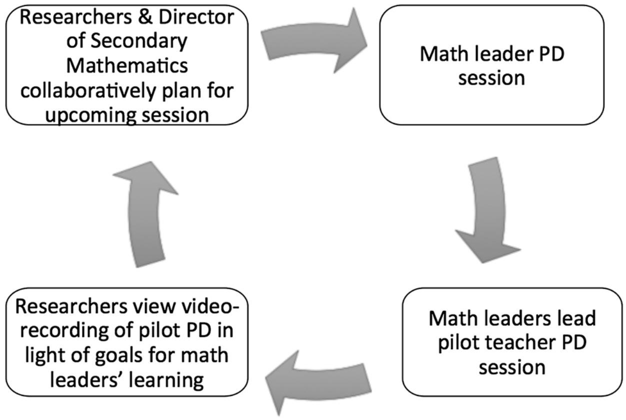

Fig. 1 Cycle for supporting the mathematics leaders' learning

6 Conjectured means of supporting the math leaders' learning

Figure 1 shows the four phases of a cycle for supporting math leaders' learning that was enacted four times between September and February.

Each cycle began with members of the research team and the district's Director of Secondary Mathematics (henceforth, the Director) co-planning for the upcoming Math Leader PD session. The nature of the co-planning deliberately changed over time. In the first cycle, members of the research team took the lead in designing the upcoming Math Leader PD session with the Director. However, we planned a gradual hand-over to the Director as her responsibilities included supporting the math leaders' learning; she increasingly took the lead in co-planning the Math Leader PD sessions as the four cycles progressed. This transition was consistent with our overarching goal of supporting the development of district leaders' capacity to support instructional improvement.

In the second phase of a cycle, members of the research team and the Director led a Math Leader PD session, which typically lasted 5 h. Members of the research team initially took the lead in facilitating these sessions, and the Director led the final session on her own. The district's two middle-grades mathematics Curriculum Specialists who developed the curriculum frameworks regularly participated in these sessions. The researchers provided expertise on designing and leading PD, and the Director and Curriculum Specialists provided expertise on the curriculum, the development of key mathematical ideas within and across grade levels, and teachers' current practices.

Each Math Leader PD session focused on planning and leading a pilot Teacher PD session with either Grade 6 or 7 math teachers that would center on an upcoming lesson that the Director and specialists identified as difficult to teach. In each Math Leader PD session aside from Session 1, we began by viewing and discussing clips of the last pilot Teacher PD session, thereby engaging the math leaders in a pedagogy of investigation. We chose 2–3 short clips (approximately 3 min each) that indicated either improvement in facilitation or areas for future improvement.

The remainder of each session focused on co-planning the upcoming pilot Teacher PD session. Based on the math leaders' and specialists' assessments of teachers' current practices, we agreed during the first Math Leader PD session that the long-term goals for teachers' learning should be: (1) understanding the logic of CMP2 lessons, and (2) leading more productive whole-class discussions. Against this background, the first step in planning the upcoming Teacher PD sessions was to identify reasonable short-term goals for the teachers' learning, given their current practices. As part of this work, we solved the tasks of the lesson, identified the key mathematical learning goals for students, and clarified how these goals fit in a sequence of lessons (Elliot et al., 2009). We also identified key student solutions that would be important to highlight in a concluding whole-class discussion and identified specific questions that teachers might ask during that discussion to support students to connect their ideas. The second step was to engage in a pedagogy of enactment, in which we co-planned specific activities that the math leaders would enact in the upcoming Teacher PD session. As time was limited, the math leaders met after the Math Leader PD to finish their planning. We did, however, press them to articulate the key ideas on which they would press teachers during the session in light of their goals for the teachers' learning.

As shown in Fig. 1, the three math leaders then co-led the pilot Teacher PD in the third phase of the cycle. This was designed to be a pedagogy of enactment in which the math leaders tried out PD facilitation practices in a setting of reduced complexity: they co-led the session, and the sessions were voluntary for teachers and had a stipend attached in an effort to attract interested participants. The Teacher PD sessions generally lasted 3 h and had an average attendance of 25 teachers.

In the fourth phase of the cycle, members of the research team viewed a video-recording of the pilot Teacher PD session to inform the planning of future Math Leader PD sessions. They first viewed the Teacher PD session in full and created a shared document in which they noted the structure of the session (e.g., activities, how long each activity took, who led each activity), the nature of teachers' participation, as well as what could be inferred about the math leaders' goals for teachers' learning from the enactment of each activity with particular attention to the quality of press. Team members then jointly created an analytic memo that summarized their observations, noted evidence of improvements in the math leaders' practice, and suggested areas for future improvement.

Next, the team members debriefed the Teacher PD session with the Director, who had attended the session in person. In the course of this discussion, we jointly decided upon goals for and planned the upcoming Math Leader PD session. As part of this process, we selected two or three clips that would be useful to view with the math leaders.

It is worth clarifying that our work with math leaders was one aspect of a more comprehensive instructional improvement effort that attended to other aspects of the organizational contexts in which the math leaders were developing and enacting their PD practices. For example, the PD for math leaders was coordinated with PD for principals so that the instructional expectations that principals communicated to teachers might be consistent with the math leaders' learning goals for teachers. The Director's involvement in the work with principals as well as math leaders was deliberate as we viewed this collaboration as a context in which to support her in designing and leading high-quality PD for both math leaders and school leaders.

7 Methods

The retrospective analysis that we conducted of the data collected across the four design and analysis cycles sought to address the following research questions: what forms of PD practice (specific to the three goals for the math leaders' learning outlined above) did the math leaders develop over the course of the design study? What does the math leaders' development imply for the revision of our conjectures regarding the goals for their learning and means of supporting their learning? The data we analyzed included video-recordings of the Math Leader PD sessions and of the pilot Teacher PD sessions, and audio-recorded interviews conducted with the math leaders in January after the third Math Leader PD session. While there were, of course, differences in the practices that the math leaders were developing, we focus on the commonalities in this analysis.

7.1 Video-recordings of Math Leader and Teacher PD Sessions

For each of the four cycles, we analyzed the video-recordings of the Math Leader PD and the pilot Teacher PD session. In Cycle 4, the math leaders decided to video-record themselves co-planning a mathematics lesson in order to generate video clips that they could use in the upcoming pilot Teacher PD; we analyzed this video-recording as well. Thus, we analyzed approximately 21 h of Math Leader PD video-recordings and 24 h of pilot Teacher PD video-recordings.

We analyzed the Math Leader and Teacher PD sessions in chronological order, as we were interested in the development of the math leaders' practices. Initially, members of the research team coded the field notes taken during the first Math Leader PD session and the analytic memo written while viewing the first pilot Teacher PD session individually. Our goal in doing so was to identify what we might take as evidence relevant to each of our three goals for the math leaders' learning. We then met to compare our coding and develop a common understanding of what would count as evidence of improvements in the math leaders' practice (see Table 1).

Members of the research team then worked in pairs or trios to code the remaining video-recordings of the Math Leader PD sessions and the analytic memos associated with

Table 1 Coding scheme for assessing math leaders' development of focal practices

Abbreviated goals for math leaders' learning	Evidence of stasis	Evidence of improvement
1) Treat teacher learning as a progression	Suggestion that teachers' practices could be rectified in an isolated activity or session Design or enact activities in which the goal was to transmit information Treat teacher PD sessions, or activities within a session, as discrete	Suggestion that supporting instructional improvement would take extended, sustained support Treat sessions, or activities within a session, as connected or building on one another
2) Design supports for teachers' learning	Design supports with little attention to what is known about teachers' current practices Difficulty articulating learning goals for particular activities Design supports focused on peripheral aspects of mathematics instruction	Explicit discussion of what is known about teachers' current practices Explicit articulation of learning goal(s) for particular activities Design supports focused on core aspects of mathematics instruction
3) Press on teachers' ideas	Limited push-back on teachers' ideas Positive response to all contributions (i.e., no indication that some ideas but not others are worth pursuing) Teachers' ideas remain disconnected	Press on teachers' ideas differentially Build on teachers' contributions Push/support teachers to connect their ideas to each other's

the Teacher PD sessions. We created shared documents to organize this coding process, which included timestamps, a running list of activities, and our respective codes. We met as a whole group to discuss our respective coding for each cycle. In addition, we discussed and documented as a group why math leaders appeared to be developing, or not, the intended practices.

Next, we created an additional analytic memo for each cycle (across Math Leader PD and Teacher PD) that synthesized whether and how math leaders were taking a developmental perspective on teachers' learning, articulating goals for teachers' learning, designing supports for teachers' learning, and (in the case of Teacher PD) pressing teachers to elaborate their reasoning. We then synthesized the resulting analytic memos, which were organized chronologically in terms of the three goals for the math leaders' learning. The final step in the analysis was to account for the documented developments in the math leaders' practices by examining activities enacted in the Math Leader PD sessions.

7.2 Interviews with math leaders

The data we collect each year for the larger project includes 45–60 min semi-structured (Merriam, 2009) audio-recorded interviews conducted in January with each of the math leaders. We included a set of questions specific to the PD work that focused on what they found supportive and why, what they would like more support in and why, and their suggestions for improving the overall design. We reviewed transcripts of their responses after we had analyzed the video-recordings of the Math Leader and Teacher PD sessions and attended in particular to the extent to which their assessments of the PD fit with documented developments in their practices. This additional data source enabled us to further clarify why their practices differed, or not, from the intended PD practices.

8 Math leaders' development of the focal practices

In what follows, we present findings concerning math leaders' development specific to the three goals for their learning. The examples we discuss are representative of and consistent with evidence across the entire data corpus.

8.1 Treating teacher learning as a progression

We found that over the course of the four cycles, the math leaders began to develop a vision of teacher PD as supporting teachers' development of increasingly sophisticated forms of practice. As we illustrate below, this development was gradual. Initially, the math leaders tended to approach teacher learning as rectifying deficits in their understanding and practice. However, by the third cycle, they began to approach teacher learning as a progression.

8.1.1 Approaching teacher learning as rectifying deficits in understanding

We found evidence in the first two Teacher PD sessions that the math leaders designed and enacted some activities that reflected the perspective that teachers' practices could be "fixed" in an isolated activity. To illustrate, we provide an example of an activity they designed and enacted in the first two Teacher PD sessions, which we refer to as the Sorting Activity.[2] In this activity, the math leaders attempted to address what they referred to as "teachers' misconceptions" about the logic of a CMP2 lesson. The design and enactment of the activity presumed that the misconceptions could be addressed quickly, by telling teachers how they should understand the logic of CMP2 lessons.

In designing the activity, the math leaders prepared statements about the purpose of each phase of a lesson. Teachers worked in pairs to decide which of the statements matched with which phase of a lesson. The math leaders then led a SmartBoard activity in which they called on individual teachers to come to the front of the room and place each statement in turn in its appropriate box—launch, explore, or summary. The SmartBoard was set up to allow for a statement to drop in only one box, indicating there was only one right answer. Teachers usually did not agree about where each statement belonged, and they frequently indicated that they thought a statement matched with more than one phase of a lesson. However, the math leaders pushed back, telling the teachers explicitly that each statement matched only one phase. For example, in the second session, Amanda asked a teacher to match the statement "Students gain new tools to solve problems" with its appropriate phase of the lesson. The teacher responded, "[W]e talked about the fact that if it's a physical tool they would … learn about that in the launch, but if it's a strategy it may be in either … the explore or the summary. So we had a really tough time with that one and I think everybody else did too". Amanda then asked other teachers to share their ideas. It appeared Amanda's purpose in doing so was to elicit what the math leaders considered to be the right answer—the summary. Once a teacher suggested that it should match with the summary phase because students are gaining "new tools" from others during the concluding discussion. Amanda revoiced this: "So do we want to

[2] Although the math leaders made a few changes to the activity for the second session, the overall design was quite similar.

put it under, uh, she said summary? Let's try summary" (B_PDV_121205, part 1, ~37:00).

This activity surfaced teachers' understandings of the phases of lessons. However, in enacting the activity, the math leaders indicated directly that teachers' ideas about the various phases of the lesson were either right or wrong. Moreover, they treated the phases as discrete and did not focus on how they were connected. For example, with regard to the statement about "gaining new tools", while it is true that students should learn new skills and strategies for solving problems during the summary phase, it is also the case that students should be learning new skills and strategies during the other two phases of the lesson. Moreover, there was minimal press on the part of the math leaders in this activity, as illustrated in the example described above. At best, the math leaders revoiced particular answers to reinforce the intended answer.

One might wonder if the math leaders approached the Sorting Activity as rectifying deficits in teachers' understanding of the logic of a CMP2 lesson because their own understanding was limited. This was not the case; when the math leaders discussed the logic of a CMP2 lesson in interviews in prior years as well as in the first Math Leader PD session, they viewed the phases as connected and described the purposes in sophisticated ways.

8.1.2 Approaching teacher learning as a progression

It was not until the third Math Leader PD session that the math leaders began to delineate a progression of goals for teachers' long-term learning. There were also indications that they were beginning to conceptualize the PD sessions in terms of a sequence of linked activities.

The first two Teacher PD sessions included both the Sorting Activity and an activity in which the math leaders modeled a high-quality lesson, with an explicit focus on the value of the summary phase of the lesson. During the third Math Leader PD session, Amanda observed that thus far they had modeled a high-quality lesson and highlighted the value of a high-quality summary, but were yet to engage the teachers in an activity that focused on what co-planning for high-quality instruction should entail. She said to the group, "So here we're trying to get them to [see] value [in] the summary… but we're also wanting them to be able to take it and actually [plan lessons] with other teachers…. [W]e're just modeling the lesson and what happens in the classroom, not the [actual planning]". Alice suggested that in the spring they could focus on how teachers should co-plan with one another to improve the quality of the summary. Malcolm then questioned whether the last group of teachers they had worked with would have been able to co-plan effectively if they had they introduced co-planning during that session. He wondered, "I was thinking [about]…the group of teachers we did it with last time, would they have been ready at that point to plan a lesson [together]?" Amanda responded, "No, they were overwhelmed at that point", and Malcolm suggested that co-planning was not something to focus on quite yet (B_PDV_121221, part2, 41:36–43:41).

As illustrated above, in the course of the conversation, all three math leaders articulated that they should continue to support teachers to develop a shared image of a high-quality summary in the third Teacher PD session, and then support teachers to learn how to co-plan a high-quality summary in the fourth Teacher PD session. We took this as evidence that the math leaders were developing a vision of high-quality PD as supporting teachers' development of a progression of increasingly sophisticated forms of practice.

8.2 Designing supports for teachers' learning

In conjunction with beginning to approach teachers' learning as a progression, we found that over time, the math leaders' designs for Teacher PD reflected a more substantial focus on improving the core of instruction. In the earlier Teacher PD sessions, the math leaders tended to focus at least some of the PD on peripheral aspects of instruction. For example, throughout the Sorting Activity, the math leaders modeled a method for engaging and praising students for their participation. Each teacher was asked to write her name on an index card and a compliment she would like to receive (e.g., "Ms. Williams, you're great at roller-skating"). The math leaders then drew from those index cards to choose teachers to participate. After each teacher's response, a math leader read the teacher's chosen compliment aloud. Importantly, this manner of praising teachers ran counter to pressing on teachers' ideas, in that the math leader automatically responded to a teacher's idea by reading a compliment that was disconnected from the learning goals for the specific activity.

In contrast, in the fourth cycle, the math leaders designed a coordinated sequence of activities that focused on an issue central to instructional improvement—effective co-planning. The math leaders' decision to focus on effective co-planning was prompted in part by the conversation detailed above that occurred in the third Math Leader PD session as well as by video clips from the third Teacher PD that they viewed at the beginning of the fourth Math Leader PD session. One of the clips showed the math leaders modeling a high-quality summary and the Director questioned whether the teachers were able to understand the decisions that the math leader leading the activity was making in the summary. This led to a conversation in which the math leaders decided it was important that, in their words, they "unveil" the co-planning process for teachers. To this end, they decided to video-record themselves co-planning for the upcoming lesson that was the focus of the fourth Teacher PD session.

The design of the fourth Teacher PD session was ambitious. The first activity entailed several groups of teachers co-planning for an upcoming lesson; one teacher was asked to observe the process in each group and then share her/his observations. In the next activity, the math leaders showed the teachers a 27-min video-recording of themselves co-planning the upcoming lesson. The math leaders then led a discussion regarding what the teachers noticed in the video.

Even though the design of the session indicated a marked improvement in terms of a sustained focus on the core of instructional improvement, there was certainly room for improvement in both design and enactment. For example, the math leaders did not provide the teachers with any guidance about how to co-plan or the aspects of co-planning on which the observing teachers might focus. As a consequence, the subsequent discussion of what teachers observed was quite fragmented and generally abstract. In addition, rather then selecting short clips to focus the discussion, the math leaders showed the entire 27-min clip and provided the teachers with minimal direction on what to focus. As a consequence, the discussion that followed again comprised a series of unconnected teacher observations. There was virtually no press evident in any of the activities. It appeared that the math leaders' implicit theory of learning was that by seeing good practice, teachers would automatically know what to do.

Despite these limitations, the fourth Teacher PD session represented an advance in their design practices given that the math leaders targeted a core aspect of instruction with little time devoted to peripheral issues. Additionally, in contrast to the first and second Teacher PD sessions, the main activities of the session were clearly linked together.

8.3 Pressing on teachers' ideas

We found that the quality of the math leaders' press varied across activities and across the cycles. In other words, we did not identify a linear progression in terms of the math leaders' capacity to press on teachers' ideas in PD sessions. Rather, it appeared that the quality of their press depended on the nature of the activity they designed, their goals for teachers' learning for the specific activity, and whether they had been provided with a clear image of what press might sound like in the context of the specific activity.

For example, as described above, in the first two sessions, the math leaders enacted minimal press in the Sorting Activity. However, we found evidence of high-quality press in other activities in the same sessions. As briefly mentioned above, in the first two Teacher PD sessions, the math leaders engaged teachers in a sequence of activities that focused on developing an image of a high-quality summary. One of the math leaders took on the role of teacher, while the teachers took on the role of students. The math leader then modeled a high-quality launch and explore before facilitating two versions of a concluding whole-class discussion. The first took the form of a "show-and-tell", whereas in the second (which we will refer to as a genuine discussion) the math leader pressed the teachers to explain their reasoning and to make connections among solutions. A different math leader then facilitated a conversation in which teachers compared the two types of whole-class discussions.

In contrast to the Sorting Activity, the math leaders consistently pressed the teachers to identify differences between the two types of discussion and clarify the advantages of the genuine discussion for students' learning. The following exchange from the first Teacher PD session is representative in this regard. Amanda assumed the role of the teacher and Malcolm then led a 13-min conversation about the relative merits of the two types of discussion. The teachers noted that the genuine discussion included "higher-order questions", and that students had to "defend their answers" and "validate" their solutions. Malcolm then pressed teachers to identify more specific differences. He asked, "What's lacking from the show and tell summary, the first one?" A teacher responded with, "Questioning", and Malcolm pressed teachers to move beyond whether the teacher questioned students. He asked, "What else? Is it just the questions that's missing?" Another teacher then suggested that students did not provide evidence of their reasoning in the show-and-tell discussion. Malcolm revoiced and expanded on this contribution to elaborate what providing evidence involves: "The students describing and having those mathematical discussions talking about 'this is what I did and this is why I did it'." A minute or so later, Malcolm pressed teachers to clarify the consequences of a show-and-tell discussion for students' learning. He asked, "What would have happened if … [two students] shared answers then we stopped right there? What … would be the result?" Malcolm continued to orchestrate the discussion, focused on the differences between the two types of discussions and specific mathematical ideas that were important to highlight (B_PDV_121025, part 2, ~41:00–54:00).

The contrast between the quality of press in the Sorting Activity and in the Summary Activity, both of which occurred in the first two Teacher PD sessions, is something that needs to be explained. We address this issue in Sect. 9, as it has implications for modifications we would make to the goals as well as the means of support for the math leaders' learning.

9 Discussion and conclusion

The goal of this work was to investigate how to support the development of math leaders' capacity to design and lead high-quality PD for teachers as a necessary (but not sufficient) means for supporting teacher learning at a large scale. As illustrated above, we found that over the course of the four cycles, the math leaders began to develop a vision of teacher PD as supporting teachers' development of a progression of increasingly sophisticated forms of practice. The math leaders' development of this perspective on PD appeared to go hand-in-hand with a shift from designing PD that focused on more peripheral aspects of instruction to more central aspects of instruction. However, although they increasingly designed activities that targeted the core of instruction, they frequently evidenced a "show-and-tell" approach when they facilitated those activities. We therefore doubt that the activities supported the teachers' learning in the way that the math leaders intended. Relatedly, we found that the quality of the math leaders' press varied across activities and across the cycles.

In areas where the research base is thin and there is little prior work on which to build, the development of a solid design typically takes a series of design studies that incorporate insights gained in prior studies, rather than a single initial study. We view our specification of the goals for math leaders' learning, of principles for designing supports for their learning, and of a provisional design contributing to the admittedly thin research base on how to support the development of PD facilitators. However, our findings indicate specific improvements that should be made to our design prior to engaging in similar work. Therefore, we conclude by discussing key modifications to this particular design that can inform others engaged in similar work.

9.1 Modifications to learning goals for math leaders

One modification concerns the learning goals for math leaders that guided the overall design. In addition to the stated three goals, we would add a fourth that targets leaders' assumptions about how teachers develop new practices. Although we noted that the math leaders began to think about teacher learning as a progression and targeted increasingly central aspects of instruction, it appeared that the implicit view of teacher learning that guided their design and enactment of activities was that if they "unveiled", or showed, a practice in its entirety, teachers would identify the significant aspects of the practice and then be able to enact it. Interestingly, this is analogous to the show-and-tell form of discussion that the majority of teachers were enacting in classrooms. These observations indicate that the math leaders needed more support in explicating how teachers might develop specific practices, and therefore, what they would need to do to support the development of those practices. Therefore, we would formulate as a fourth goal for math leaders' learning that they come to view teachers' development of new practices as a process of reorganizing their current practices that requires explicit guidance. This additional learning goal highlights the math leaders' role in scaffolding these developments.

9.2 Modifications to means of supporting the math leaders

Our designed means of support, as described in Sect. 6, entailed engaging math leaders in cycles of pedagogies of investigation and enactment in which they planned for and enacted PD sessions for teachers. Our analysis indicates that this overall structure was a strength of our initial design. The opportunity to investigate prior Teacher PD sessions (via analysis of video clips) and to jointly plan for upcoming Teacher PD sessions with accomplished others appeared to support the math leaders' development of increasingly sophisticated PD design and facilitation practices.

The modifications we would make to the means of support focus on the substance of the work we engaged in together during the Math Leader PD sessions. A first modification is related to our finding that the quality of the math leaders' press varied over the course of the four cycles. For example, they enacted both high-quality press (e.g., Summary Activity) and minimal press (e.g., Sorting Activity) in the first Teacher PD session. In the first Math Leader PD session, we had enacted the Summary Activity with the math leaders and although we had discussed teachers' current understandings of the phase of a CMP2 lesson, we did not model how they might push on teachers' understandings of the logic of a CMP2 lesson. In the absence of an explicit image of how to press on teachers' understandings of the logic of a CMP2 lesson, the math leaders designed the Sorting Activity that, understandably, reflected their prior practices in designing and leading PD. Thus, in future work with math leaders, it appears important to support them in learning how to press on particular teacher understandings and specific aspects of their practice. These supports might include explicit conversation about why the intended activity might lead to particular developments in teachers' understandings and practice, and about specific aspects of the leader's role in scaffolding these developments.

A second modification concerns the use of video clips as a pedagogical tool in PD. This modification is informed by our finding from the fourth Teacher PD session, when the math leaders decided to show the teachers a video of themselves co-planning. Although the math leaders were not yet proficient in using video to support teachers' learning, they recognized its potential because they had developed important insights through participating in pedagogies of investigation organized around video clips. In interviews conducted in January (after the third cycle), two of the three math leaders mentioned that they valued viewing video clips of the previous Teacher PD session because it supported them in becoming more aware of what they were doing. For example, Alice said, "I think what [viewing video clips] helped us do is fine tune things and help us know where we need to push back [on teachers' ideas]" (Interview, 130116). Similarly, Amanda noted: "[Viewing the video clips] was just an eye opener and so the whole time I did this last [Teacher PD session] I was like I need to make sure I expand on [teachers' ideas], and I stayed quiet on one of the [teacher's] responses … and I was like man, I did it again. So I think I'm just more aware of it. Instead of just saying 'good job' I should have pushed back some more… If I hadn't seen that clip I would have never known" (Interview, 130116). Although we engaged the three math leaders in this pedagogy of investigation on a regular basis, we did not anticipate that they would draw on it when planning Teacher PD sessions and therefore had not discussed with them how to select and use video to support others' learning (e.g., the optimal length of clips, setting up clips, orchestrating a discussion after viewing a clip).

More generally, a modification we would make to the designed means of support is to explicitly target a few potentially productive types of PD activities (e.g., modeling a lesson with follow-up discussion, viewing video-recordings with follow-up discussion) that would be useful to enact in Teacher PD, given the identified goals for teachers' learning. In light of our findings, we would engage leaders in pedagogies of investigation and enactment regarding each type of PD activity, and would give explicit attention both to why the activity might be appropriate for particular goals for teachers' learning, and to the rationale for facilitators' decisions specific to the activity.

We conjecture that the modifications we have discussed will result in more robust supports for math leaders' development of high-quality PD design and facilitation practices. However, we also acknowledge that the development of supports for complex forms of practice is unlikely to be completely smooth. It is therefore important to take stock of the "bumps and bruises" that arise as people engage in developing new forms of practice (cf. Sleep, 2012), and to capitalize on them to further improve the design. For example, had there been a fifth cycle of this work, the fourth Teacher PD session would have served as an excellent "bump" to build on, as it explicated an important aspect of the math leaders' practice, namely their assumptions about how teachers move beyond their current practices, that could have then oriented adjustments to our design.

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