Chapter 6
Networked Technologies for Fostering Novel Forms of Student Interaction in High School Mathematics Classrooms

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This chapter focuses on the novel forms of student learning and interaction supported by classroom device networks. In particular, my focus is on classrooms in which each student has a handheld calculator or computer connected to a local network such that the teacher can communicate with and orchestrate communications between student devices through a desktop computer. Handheld computing devices have been commonplace in secondary mathematics classrooms for some time; four-function and scientific calculators have gradually evolved to include graphing capabilities, dynamic geometry tools, and computer algebra systems. More recently, at least one commercially available system, TI-Navigator™, provides a means of connecting each student's graphing calculator to a classroom wireless network. At the same time, the current rapid proliferation of Smartphones and other mobile devices with networking capabilities suggests an increasing convergence between handheld computational tools and classroom connectivity that could significantly change the nature of mathematics instruction in the near future.

Over the last decade, several innovative research projects have begun to map out a range of novel activity structures and promising instructional possibilities presented by these networked classroom devices (DiGiano et al., 2003; Hegedus & Kaput, 2004; Roschelle & Pea, 2002; Stroup, Ares, & Hurford, 2005; Tatar, Roschelle, Vahey, & Penuel, 2003; White, 2006; Wilensky & Stroup, 1999b). Classroom network tools offer new possibilities for classroom interaction; they present ways of rapidly distributing information, exchanging ideas, and constructing shared artifacts that can support a variety of engaging and mathematically rich activities that would be difficult or impossible to implement in conventional classrooms. Importantly, and in contrast to many web-based environments that likewise capitalize on the power of networked computing to create novel and meaningful

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learning experiences through virtual forms of interaction, classroom networks hybridize conventional offline classroom discourse and online transaction; they can augment rather than replace conventional learning environments and face-to-face communication. Below, I examine some novel classroom activities made possible by classroom device networks, and consider their potential for supporting the teaching and learning of mathematics.

Background

Classroom networks inherit from traditional instructional practice three basic structures for organizing learning activity, centered respectively on individual student work, small-group collaboration, and whole-class discussion (Kaput, 2000). Many early designs for classroom device networks emphasized the individual level, often aggregating contributions from each individual student to provide feedback to the instructor as in the case of classroom response systems (for reviews of relevant literature, see Fies & Marshall, 2006; Roschelle, Penuel, & Abrahamson, 2004). These uses of classroom networks can be powerful resources for formative assessment and student engagement, blending anonymity of contributions to public discussion with private accountability in student-teacher transactions (Davis, 2003).

My focus in this chapter, however, will be on technology and activity designs for classroom networks that emphasize novel forms of interaction between students as well as between students and teacher, particularly in whole-class and small-group pedagogical modes. Indeed, promoting student participation in classroom discourse has been a central theme in mathematics education research and in the reform of mathematics teaching practices over the last two decades (Ball, 1993; Lampert & Blunk, 1999; Yackel & Cobb, 1996). Often, instructional activity in this vein takes the form of teacher-facilitated whole-group conversations in which mathematical meanings, arguments, and standards of evidence are established collectively (e.g., Forman, Larreamendy-Joerns, Stein, & Brown, 1998; Staples, 2007). In other instances, students work in pairs or small groups on collaborative problem-solving tasks, and thus have opportunities to discuss ideas and strategies, negotiate and coordinate interpretations, and provide peer tutoring (e.g., Barron, 2000; Boaler & Staples, 2008; Leikin & Zaslavsky, 1997; Moschkovich, 1996).

Classroom networks may represent a powerful resource for enriching these forms of classroom interaction. Research studies focused on using classroom networks to support whole-class activity structures have found that these systems can support students' agency and participation in collective mathematical activity (Ares, Stroup, & Schademan, 2009), attention to and identification with dynamic mathematical representations (Hegedus & Penuel, 2008), and opportunities to draw on diverse cultural and linguistic resources for participating in classroom discourse (Ares, 2008). Likewise, investigations of networked handheld devices in small-group collaboration have found such designs to facilitate greater communication, coordination and negotiation among peers (Zurita & Nussbaum, 2004), and to expand and enrich avenues for active participation in joint problem-solving activity (White, 2006).

Perhaps the most compelling aspect of classroom networks involves the potential for interweaving these social and interactional aspects of participation in mathematics practices with the conceptual richness of multiple and dynamic mathematical representations available on student devices and in public displays. Hegedus and Moreno-Armella (2009) describe this intersection of the social and the conceptual in terms of integrated communication and representational infrastructures, wherein the means by which students' devices interact and exchange information via the network overlap with the computational links between algebraic symbols, graphical displays, and real-world situations to form novel modes for learners' expression of mathematical ideas. Stroup et al. (2005) likewise emphasize the ways teaching and learning in classroom networks are organized in terms of dialectical relations between social and mathematical structures. Echoing these perspectives, Roschelle, Patton, and Tatar (2007) argue that transformative classroom activities with networked handheld devices will involve linking social and cognitive aspects of learning, in particular by providing means for using symbolic tools in collaborative and collective mathematical inquiry practices. Below I illustrate approaches along these lines, presenting examples of activity designs that utilize classroom networks to organize group-level interactions around shared mathematical artifacts.

Exemplars

In this section, I describe three different interactive classroom activities supported by networked handheld devices, each drawn from research projects focused on investigating the potentials of these tools for supporting novel forms of teaching and learning mathematics. The first is illustrative of a broad class of activities oriented toward engaging all students in the classroom group in a shared focus on dynamic mathematical representations collectively constructed from contributions sent through each student's device. The second example involves linking the devices of smaller groups of students to facilitate collaborative problem solving. The third design merges these two approaches, using a classroom network to integrate and fluidly shift between small- and whole-group instructional activities.

Exemplar 1: Collective Activity in Classroom Networks

Whole-class activities in classroom networks typically revolve around the interplay between individual students' personal constructions of mathematical artifacts (e.g., an algebraic expression, a polynomial function, a segment of a motion graph, a coordinate location) on their respective devices and the aggregation of those artifacts in a public display projected to the front of the classroom from a teacher's desktop or laptop computer, which functions as a server for the classroom network. To illustrate the properties of these activities, I consider an example of what Stroup et al. (2005) label *generative* activities. They use this term in reference "to orchestrating classroom activity in ways that occasion productive and expressive engagement by participants, characterized by increased personal and collective agency" (p. 188).

One such generative activity, using a TI-Navigator™ graphing calculator network, involves inviting each student in a classroom group to invent and contribute a function equivalent to $f(x)=4x$. Students use their calculators to enter functions that match the criteria: $f(x)=2x+2x$, $f(x)=40x/10$, and so on. As they send these contributions to the server, the graph of each function appears in a single window in the public display—as overlays of a single line in cases where the functions are indeed equivalent or as multiple curves in cases where students submit non-equivalent functions. Thus, the representational link between student-inputted algebraic expression and calculator-generated graph blends with the communication infrastructure of the classroom network to build a pedagogically and mathematically rich collective construction. The visual display of individual student contributions in the public graphing window provides teachers with a ready means of assessing student responses and anonymously diagnosing errors. The appearance of the graph of $f(x)=2x*2x$, for example, occasions opportunities to discuss algebraic procedures as well as to compare families of functions. However, it also engenders rich opportunities for creative individual expression and for joint mathematical exploration. For example, as students seek novel and distinctive solutions to the task (e.g., $f(x)=-113x+117x$; $f(x)=4(\sin^2 x+\cos^2 x)(x)$), they broaden the space of equivalent functions collectively constructed by the classroom group.

An important theme in the generative design work involves using the size and diversity of the classroom group as a resource for examining variation within families and other collections of mathematical objects (Stroup, Ares, Hurford, & Lesh, 2007). In effect, generative activities use the relatively large number of students—often 30 or more in high school mathematics classrooms—as a resource for ensuring that a range of ideas will emerge, leveraging that variety to draw out a corresponding diversity of mathematical forms. The power of the classroom network is in readily transforming that array of student productions into a dynamic set of mathematical representations in a public display. The aggregation of student-contributed functions in a single shared graph emphasizes and makes salient the underlying concepts of equivalence and the varied forms of algebraic expression. Instructional approaches to teaching Algebra I that incorporate generative activities using a TI-Navigator classroom network have been shown to improve student learning outcomes on a state standardized test (Stroup, Carmona, & Davis, 2005). In the next section, I explore the ways in which a design for small groups might likewise capitalize on fewer student participants working together to emphasize different mathematical relationships among correspondingly smaller sets of elements.

Exemplar 2: Collaborative Learning in Classroom Networks

To date, fewer classroom network designs have targeted small-group collaboration than the individual student and whole-class scales. This difference probably reflects aspects of both the hardware elements and the information architecture of commercially available classroom networking tools. Because these systems feature individual student devices and a whole-class server, but no small group-level physical platform or display, activities oriented toward individual students and the whole class are easier to orchestrate than the intermediary scale of small groups. Similarly, classroom network architectures are usually organized around exchanges of information from student devices to a teacher's server and the reverse, rather than between student devices. However, research using specialty applications designed to run on general-use mobile devices rather than graphing calculators designed for educational use has revealed some important insights and design elements for small-group collaboration that should be integrated into the next generation of classroom networking tools.

For example, a classroom application called *Code Breaker* (White, 2006; White & Pea, 2011) illustrates a means of using wirelessly networked handhelds to orchestrate small group collaborative mathematics by linking multiple representations with role assignments for each student in the group. The *Code Breaker* design is set in the context of cryptanalysis, and requires teams of four students to work together to try and decrypt a secret message. These messages are encrypted by mapping each letter in the standard alphabet to its ordinal value ($a=1$, $b=2$, …, $z=26$), and then by inputting those values into a polynomial function such that the output values form the letters of a ciphertext alphabet. When a team downloads a message that has been encrypted in this way to a handheld computer, each student in the group is assigned to examine the coded text using different representational tools included in the *Code Breaker* handheld software (Fig. 6.1) as the group works together to try to determine the unknown polynomial function used to encode the text.

Each of the different representational tools in the *Code Breaker* software are dynamically linked, so that entering a new polynomial function in the equation tool generates a new curve in a graphing tool, new sets of values in relevant table tools, and new message displays in a plaintext tool. Moreover, the classroom network server links the handhelds of all the students in each small group such that these function states match across all four computers. Thus, changes to a function displayed in one student's equation tool automatically propagate to all representational tools on all four devices. These features allow the simultaneous examination of several code and function representations, but require multiple group members to work together in order to coordinate these views and interpret them in relation to the problem-solving task. The activity design thus takes the form of a multiple representations jigsaw (Aronson, 1978; Cleaves, 2008); each group member is assigned responsibility for viewing one or two representations, and these responsibilities rotate regularly, with the intent of each student developing facility with each representational tool and a deeper understanding of its distinctive affordances for decrypting the ciphertext. Here, then, the representational infrastructure of multiple linked function displays aligns with the communication infrastructure of wireless networking between student devices. The aim of this approach is to simultaneously capitalize on the affordances of multiple linked function representations, and of multiple mutually dependent students collaborating in an engaging and

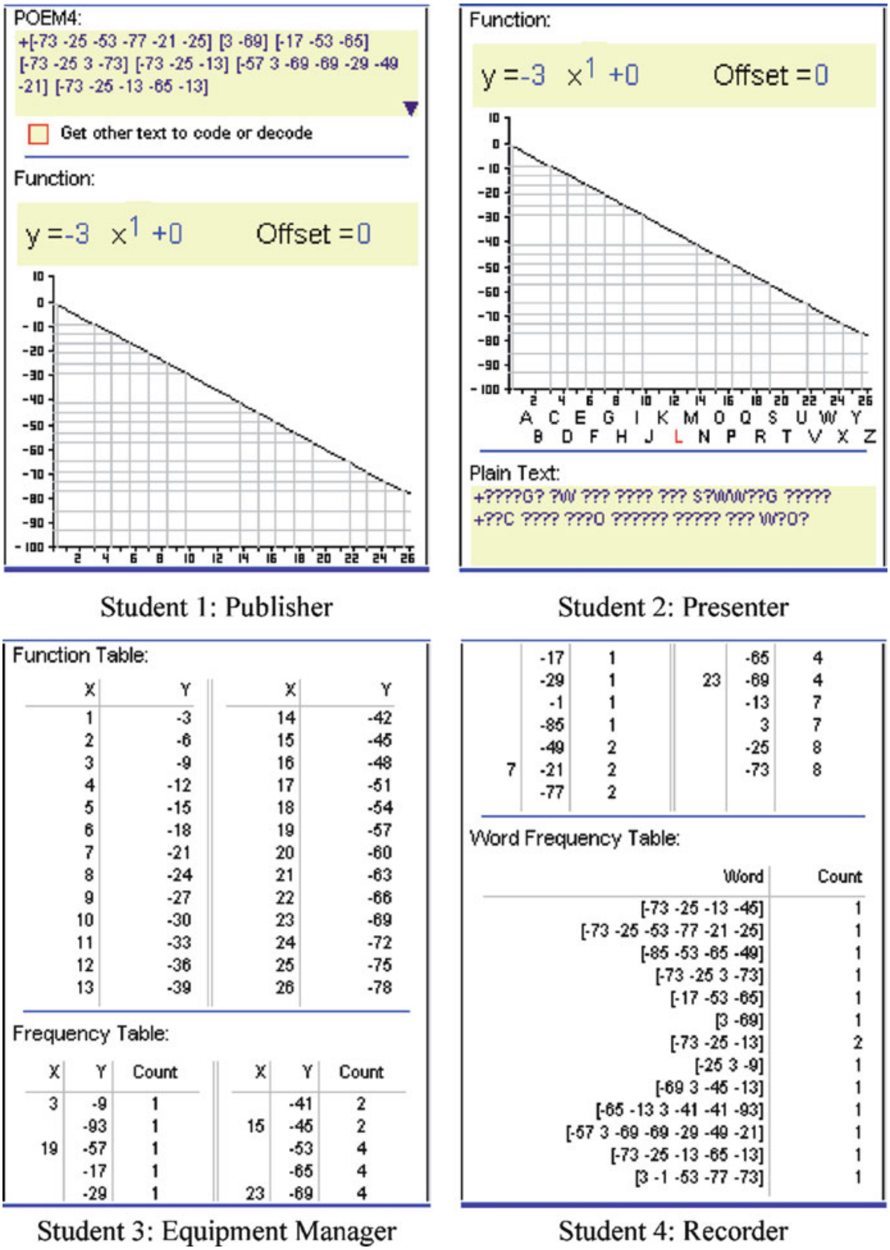

Fig. 6.1 Code breaker roles and representational tools

applied problem-solving activity. Previous research on cooperative learning has stressed the importance of positive interdependence among group members in the achievement of a shared goal (Johnson & Johnson, 1989). The *Code Breaker* example seeks to establish this interdependence by using the classroom network to distribute different representational resources to the devices of each group member so that contributions from all students are necessary to accomplish the objective.

As in generative design, the *Code Breaker* approach uses the mapping between student participants in a classroom group and mathematical objects in a shared virtual space to make important mathematical relationships and properties of these objects salient. In the case of small groups, however, the design focus shifts from expansive and potentially infinite mathematical spaces, like a class of equivalent functions, to a small number of components of a single shared mathematical object—in this case, multiple linked representations of a common function—that can be matched with two to four students working together in a small group. This design for small-group collaboration with networked devices has been found to support student reasoning about function representations, especially when groups develop successively more sophisticated strategies for using the connections among their devices to solve increasingly challenging tasks (White, 2006, 2009; White & Pea, 2011). In both the whole and small-group activity structures, these network-based relationships among students are intended to serve as resources to support learners' efforts to jointly navigate the conceptual territory delineated by their corresponding mathematical relationships in the space of the network. In the next section, I present a final example of an approach to using classroom networks to blend the affordances of these small and whole group designs.

Exemplar 3: Linking Multiple Levels of Classroom Activity

Ultimately, the viability of classroom networks as effectively and widely used tools for teaching and learning school mathematics probably hinges on their potential to effectively span and enrich the full range of conventional pedagogical modes and activity structures. Indeed, another potentially powerful use of classroom networks involves integrating classroom activity structures across the different scales of individual, small group, and whole group. Mapping student participants to mathematical objects in the network creates a flexible set of collective artifacts that can be readily shifted across instructional modes. To that end, I briefly present a design for Algebra One classes that links an activity for small groups, along the lines of the *Code Breaker* approach, with a whole-class design that shares some properties of generative design.

In an activity called *Graphing in Groups* (White & Brady, 2010), which uses a TI-Navigator™ system in combination with the NetLogo modeling environment (Wilensky, 1999) (http://ccl.northwestern.edu/netlogo/) and the HubNet network tools (Wilensky & Stroup, 1999a) (http://ccl.northwestern.edu/netlogo/hubnet.html), each calculator displays a graphing window and allows the student to adjust the coordinates of a point graphed within that window using directional arrow keys in the calculator. The coordinate points inputted through the calculators of each student in a small group are displayed together in a single graphing window on the

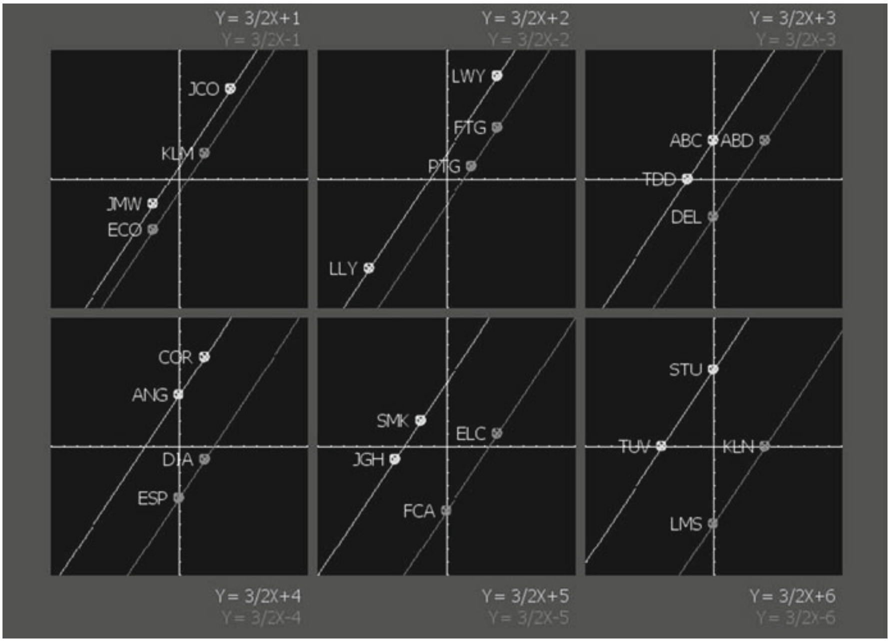

Fig. 6.2 Graphing in groups whole-class display of parallel lines activity

classroom server, creating a shared mathematical space for the members of a group. An array of these coordinate graphs, each of which is assigned to one or two student pairs, are all displayed in a grid on the server computer and projected to the front of the classroom (Fig. 6.2).

Like the *Code Breaker* design, *Graphing in Groups* uses the premise of assigning each student in a small group different elements of a shared mathematical object—in this case, two distinct coordinate points that jointly determine a linear graph—in order to foster collaborative investigation between partners. In the example of Fig. 6.2, 12 student pairs sitting together in the classroom were asked to position their points so as to construct lines with a common slope of 3/2. These pairs were also clustered into teams of four students, numbered groups 1 through 6, corresponding with the different windows in the shared display of Fig. 6.2 in which groups' respective graphs appeared (groups 1–3 formed the top row and groups 4–6 the bottom row). In addition to the assigned slope common to all pairs, one pair in each team was asked to make the *y*-intercept of their line equal to their group number, while the other pair had to make it equal to negative one times their group number. Tasks like these can layer two different kinds of collaborative activity in the interactive graphical environment: (a) between students in a pair as they negotiate ways of moving their respective points to form the desired line and (b) between pairs in a group as they discover or seek to maintain the parallel relationship between their respective lines.

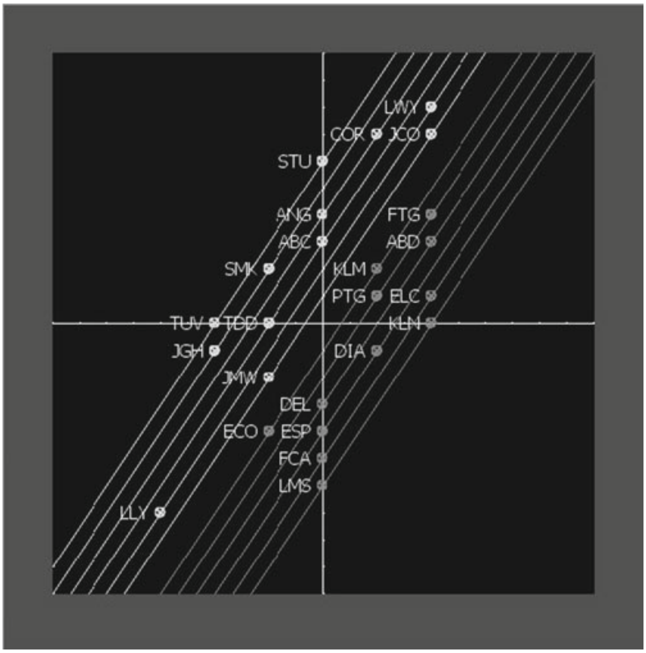

Fig. 6.3 Graphing in groups whole-class display of family of linear functions

But the artifacts the students produce as they work together in pairs and small groups also readily yield exploration of a broader set of mathematical relationships among these lines that can be readily made visible in the public display. The *Graphing in Groups* design includes a feature that allows the teacher to switch from a small- to a whole-group display, so that the student points and lines shown in each separate graphing window in Fig. 6.2 can be instantly redrawn in a single larger graphing window (Fig. 6.3). Switching from small- to whole-group scale in the display can mark a corresponding shift from pair and small group collaboration to whole-class discussion of the common and distinct properties of all their lines highlighted in this aggregate display. In this way, the activity seeks to capitalize on both small- and whole-group structures in order to illustrate corresponding mathematical relationships at each scale. Importantly, the activity sequence described here lacks the open-ended and creative qualities of a generative activity in Stroup et al. (2005) terms. I have chosen to present an activity in which the parameters of each student construction were well defined for clarity of illustration, and for which a particular result was anticipated in the whole-class construction. But the whole-group display in Fig. 6.3 remains dynamic; students can be invited to further explore the space of this family of functions, generating other lines with the same slope, or forming lines with the same intercept but different slope, or forming the same line using different points, or constructing perpendicular relations between the lines of two pairs, and so on. Designing learning activities in mathematics inevitably involves navigating some tensions between open-ended exploration and narrowly defined construction. My point here is not to emphasize either side of this balance, but rather to illustrate the flexible array of tools that classroom network tools provide for engaging students in each kind of task across multiple mathematically rich activity structures.

Conclusion and Next Steps

For technological innovations to support meaningful transformations in teaching and learning, they should be compatible with and seek to build bridges between both the daily instructional practices of teachers and the informal digital experiences of learners. Classroom networking systems offer a potential means of achieving that balance. For a generation of learners increasingly accustomed to personal and mobile computing devices, networking systems represent an engaging and mathematically rich means of connecting those informal digital experiences to classroom learning activities. Additionally, for teachers skilled in multiple instructional modes, they offer a means of tailoring technological resources to these varied pedagogical strategies.

The examples presented in this chapter primarily feature handheld devices that are widely used in high school mathematics classrooms and classroom-specific networking systems that are already commercially available. A next generation of Smartphones and other handheld multimedia devices with powerful and flexible computational and networking tools, already increasingly commonplace at the time of this writing, will likely make new classroom network platforms available and a much wider array of learning activities possible in the near future (see Chap. 11 for applications of wireless network devices in content areas beyond mathematics). Though these technologies are likely to evolve rapidly, the small- and whole-group activity structures presented here should continue to serve as important exemplars for teachers and designers seeking to capitalize on classroom networks as resources for supporting students' interactions with one another and with important ideas in mathematics. Each of these instances highlights the importance and the potential value of technology features that facilitate exchanges among students as well as between students and teacher. In the case of generative activity design, peer interaction and class discussion are achieved through the use of a collective mathematical space (a graphing window featuring function contributions from all students) and a public screen display. In the *Code Breaker* example, grouping student devices within the classroom network likewise provides a means of establishing interdependence among peers and orchestrating students' engagement in joint work. Finally, the *Graphing in Groups* example illustrates an approach to leveraging both a collective classroom display and communication between student devices in order to integrate interactive classroom activities across multiple instructional modes. One or both of these features are and will likely remain critical resources to include in new classroom networking tools if they are to support a full range of teaching activities and approaches necessary for creating rich and varied mathematics learning opportunities for all students.

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