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Mathematical Proficiency and Perseverance in Action: The Case of Maria and Andrew*

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In response to an expanding definition of mathematical proficiency, educators must attend to what mathematically proficient students should *know* as well as what they should *do*. As students are asked to struggle and wrestle with mathematics, educators should expect that students demonstrate perseverance through engagement with difficult mathematics. This has significant implications for seeing one's self as a learner and doer of mathematics, particularly for those with historically limited access to mathematics-related opportunities. A case study analysis of a pair of students in a second grade classroom engaged in algebraic reasoning revealed a striking example of *perseverance in action that supports mathematical learning*. Analysis of classroom discourse across the classroom revealed the social and sociomathematical norms of the classroom that supported such perseverance. Developing mathematically proficient students who persevere has widespread implications as it is those who see themselves as doers of mathematics who have the most access to future educational and economic opportunities.

Keywords: Classroom Discourse, Equity, Mathematical Proficiency, Perseverance.

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The Common Core State Standards for Mathematics (CCSSM) call for the development of *mathematically pro cient[1] students, specifying not only what mathematically pro cient students are to know,* but also what it is that they are to *do*. This definition of mathematical proficiency extends beyond previous ideas of procedural skill and conceptual understanding to include such notions as having a "productive disposition" towards mathematics as well as developing key mathematical practices, including "[making] sense of problems and [persevering] in solving them" (CCSSM, 2010).

Our work targets the idea that mathematically proficient students are to do mathematics in particular ways and, more importantly, persevere in doing so. This has significant implications for seeing one's self as a learner and doer of mathematics, particularly for those with historically limited access to mathematics-related opportunities. Whereas educators might agree that perseverance is important for students, it can be an elusive term that reflects long-term goals (i.e. persevering versus dropping out of school). In this paper, on the other hand, we provide a specific example of perseverance using an in-the-moment perspective to examine interactions among students, teachers, and content that reveal *perseverance in action that supports mathematical learning*. Drawing from a close analysis of classroom interaction, our work addresses the following questions: What does perseverance in action look like within the context of a mathematics lesson? What might perseverance afford for student mathematical learning? Finally, what kind of a classroom environment would support students to persevere?

[1] The CCSSM's use of *mathematically pro cient* draws from the National Research Council's (NRC) discussion of five intertwined strands of mathematical proficiency: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (NRC, 2001).

Background

Prevailing notions of what it means to do mathematics in elementary school often yield few opportunities for students to engage in mathematical discourse and reasoning. This is particularly prominent for low-income students of color, whose experiences in mathematics classrooms are routinely characterized by repetition of procedural steps to learn "basic skills" without space for critique or connection (Anyon, 1980; Ladson-Billings, 1997; Lubienski, 2002). Not only does this procedural mathematics instruction limit students' opportunities to learn mathematics with deep, conceptual understanding, but it also prevents students from participating in mathematically-powerful practices and seeing themselves as those who do mathematics (Boaler & Greeno, 2000). Lack of access to learning and disidentification from mathematics have major ramifications for students as school mathematics, particularly algebra, is viewed as a "gatekeeper" to future educational and economic opportunities (Moses & Cobb, 2001; Stinson, 2004).

If educators are to develop students who are mathematically proficient, classrooms need to become spaces that support perseverance via "the engagement of students in struggling or wrestling with important mathematical ideas" (Hiebert & Grouws, 2007, p. 387). This study provides an example of what that looked like in a second grade classroom working on algebraic reasoning. As students grappled with their peers around difficult mathematics content, they demonstrated perseverance as they engaged in critical forms of mathematics reasoning. In this classroom, social and sociomathematical norms (Yackel & Cobb, 1996) supported students to engage in mathematical discourse as they wrestled with algebraic ideas. Close examination of the details of student-student interaction revealed the case study of Maria[2] and Andrew who demonstrated perseverance in action that supports mathematical learning.

Study Context and Methods

This study draws from a larger research project that examined the interactions among teachers and students as students explained their mathematical work (Franke et al., 2009; Webb et al., 2008, 2009). Teachers across the project had participated in professional development that builds algebraic reasoning within the context of elementary mathematics (Carpenter et al., 2003). This work was conducted across schools in a large urban school district, one of the lowest performing in California, serving primarily low-income students of color (93% received free or reduced-cost lunch; 99% minority, comprised mainly of Latino/a and African American students; 52% classified as English Language Learners). The algebraic reasoning professional development was part of a broader long-term plan to better meet the needs of students across the district.

Teachers in the research project found ways to engage students in algebraic reasoning that made a difference for student learning (see Jacobs et al., 2007 for more detail). Our current study focuses on a second grade classroom whose teacher, Ms. Lee, challenged the status quo of mathematics instruction to successfully support students to engage powerfully with each other. Two consecutive mathematics lessons (approximately one hour each) were videotaped using two camcorders (one wide-angle and one close-up) and audiotaped using multiple audio sources, capturing whole-group talk of the entire class and all peer-to-peer talk of six randomly chosen pairs of students. Transcripts were created to capture all verbal dialogue as well as accompanying non-verbal communication (such as writing on the board and gesturing to written work).

During initial analyses of the data, transcripts were coded to document student answers, student explanations, and teacher moves that follow up on student thinking (see Franke et al., 2009; Webb et al., 2008, 2009; for further detail of methodology). Further analyses involved examining teacher moves beyond the scope of follow-up that communicated the social and sociomathematical norms of the classroom (Yackel & Cobb, 1996). These often included explicit verbal statements, such as "remember, I want you to talk with your partner ", as well as more implicit yet regular teacher moves such as asking probing questions of student explanations.

For this paper, we conducted a case study analysis for one pair of target students, Maria and Andrew, selected for the participation they exhibited throughout the lessons and how their participation illuminated a conceptualization of perseverance in action. We conducted more comprehensive analyses of their interactions to document such verbal and non-verbal interaction as raising hands to share, body positioning when interacting with each other, pause and intonation during talk, and so on.

We first present a detailed vignette featuring Maria and Andrew grappling with discrepant answers to an algebraic problem, illuminating the idea of perseverance in action that supports mathematical learning. We then attend to the social and sociomathematical norms of the classroom that supported students to persevere as they wrestled with algebraic ideas.

A Classroom Example of Perseverance in Action

Ms. Lee had spent the two videotaped mathematics lessons posing problems that focused on the algebraic idea of *relational thinking,* specifically helping students to: (a) understand the equal sign as a relationship between two expressions; and (b) use number relations to consider ways

[2] Student and teacher names used in this paper are pseudonyms.

of approaching problems that move beyond step-by-step computation. She posed eleven problems over two lessons (such as “20 + 10 = 10 + __” and “8 + 2 = 7 + 3 True/False?”). She then asked students to first solve with and explain to a partner, and then share ideas with the whole class. The following classroom vignette occurred during the tenth of eleven total problems.

Classroom Vignette

Ms. Lee has just written the problem they are to work on across the white board: “8 + 8 = 15 + ___”. Maria immediately begins to write down the problem on their shared paper as Andrew continues to gaze at the board. Maria begins to think out loud:

1 Maria: Eight and eight is…
2 Andrew: *(in response to Maria)* Sixteen. *(pause, then points to the location of the unknown on their paper)* Fifteen!
3 Maria: *(nudges Andrew’s hand away to try to write on the paper)*
4 Andrew: Just put fifteen!
5 Maria: It’s not fifteen.
6 Andrew: If those two are eight, then that’s supposed to be fifteen…
7 Maria: No, unh-uh!
8 Andrew: [[3] …‘cause the equal sign means “the same.”
9 Maria: [Because eight plus eight equals sixteen.

Andrew has just voiced an incorrect answer of 15. For Andrew, if there are two “8’s”, then there should also be two “15’s” because the equal sign means “the same”. Note that this imprecise explanation works for often-posed problems of the form “a + b = a + b” or “a + b = b + a”, because matching numbers are on opposite sides of the equal sign and the numbers are being added together. Andrew is likely demonstrating a developing, early attempt to think relationally, where he is beginning to attend to number relationships but still has a misunderstanding of the equal sign.

Andrew seems frustrated as he shakes his head and buries his forehead in his left hand. There is a pause in conversation as Maria writes on the paper. She makes another attempt to explain:

10 Maria: Andrew, it has to be sixteen, because eight plus eight is sixteen. So, this one has to be sixteen.

Ms. Lee approaches as she checks in on the pair sitting across from Maria and Andrew, and Maria calls her attention:

11 Maria: Ms. Lee, Andrew doesn’t understand.
12 Ms. Lee: Okay, well, have him explain to you and see where he doesn’t understand. Andrew, explain to her. *(walks away as Andrew begins to explain)*
13 Andrew: I’m saying that the equal sign means “the same” and *(inaudible)* eight plus eight… *(repeatedly gestures with his hand back and forth to different sides of the equation)*
14 Maria: No, it’s not that.

The pair seem frustrated with each other as they stop conversing for about a minute. Andrew plays with his eraser while Maria appears to be working on her paper. Then Maria re-initiates the conversation:

15 Maria: It’s not... it’s not... it’s not fifteen, because eight plus... I’ll explain it back to you so you can understand that it’s one. Because eight plus eight equals sixteen...
16 Andrew: I already tried *[to solve it]* two times.
17 Maria: Huh?
18 Andrew: I already tried two times.
19 Maria: It’s not... it’s not fifteen, because eight plus eight is sixteen. So this one has to equal sixteen—“the same.”
20 Andrew: *(pause, hesitating)* The equal sign means “the same” and there’s eight *(mumbling, trails off)*…
21 Maria: But it, the equal sign means that “the same answer”. It has to be the same answer.

Although there is no pause in conversation here, we interrupt to comment on the mathematically sophisticated move that Maria is going to demonstrate in the next line. Whereas the stated problem is “8 + 8 = 15 + __”, Maria is going to verbally “switch it” to read the right-hand side of the equation first before reading the left-hand side:

22 Maria: Like if... if I put... I could switch it: fifteen plus one is the same as eight plus eight.
23 Andrew: OH! [I know what you’re talking about.
24 Maria: [It’s just gonna be sixteen.
25 Andrew: So it’s worth sixteen right here *(con dently gestures to one side of paper)* and sixteen right here *(gestures to the other side)*.
26 Maria: That’s why. That’s what I’m telling you …
27 Andrew: [OH!
28 Maria: […that it has to be the same... the same answer.

Soon after this conversation yields a conceptual shift in Andrew’s understanding, Ms. Lee calls the class back together to have a whole-group discussion about the problem.

This excerpt of classroom dialogue is striking for the caliber of mathematical discourse that occurred. Maria and Andrew have clearly demonstrated moving beyond more superficial ways of engaging with each other, such as only voicing answers or ideas without detailed response. Not only is the pair clearly attending to each other’s ideas, but there is also a major conceptual shift in Andrew’s understanding as the pair struggles through their disagreement. Whereas

[3] Use of “[” denotes simultaneous talk.

Andrew's original language might have suggested a relational understanding of the equal sign (lines 8, 13, 20: "the equal sign means *the same*"), he was focused on the repeated "8's" in the equation rather than the placement of the numbers across the equal sign. By the end of the conversation, however, not only did Andrew move from an incorrect to a correct answer, he shared his own articulation of the equal sign relationship (line 25: "it's *worth* sixteen right here…").

Perseverance in Action: Maria

Throughout the interaction, Maria persevered to support Andrew through a misunderstanding about the equal sign. Maria challenged Andrew's misunderstanding and moved him to a correct relational understanding of the equal sign using a number of different moves:

1. Disagreeing with Andrew's answer (lines 5, 7, 15; e.g., "it's not fifteen")
2. Highlighting that the quantity on the left side of the equation is 16 (lines 9, 10, 15, 19; e.g., "because eight and eight is sixteen")
3. Re-articulating Andrew's ambiguous equal sign language "the same" (line 21; "the same *answer*")

The second and third moves are particularly impressive given the focus on relational thinking. Andrew's articulation of the equal sign as "the same" would likely be accepted in many learning settings, yet this phrase could have meant "the same quantity on both sides of the equal sign" or, in Andrew's case, "the same numbers regardless of location." Maria challenged this ambiguity by repeatedly highlighting the quantity of 16 as she searched for an alternative way to verbalize "the same quantity."

Maria's mathematical elegance continued as she re-represented the equation by reversing the order of the expressions and substituting her answer for the unknown: "I could switch it: fifteen plus one is the same as eight plus eight" (line 22). This move in particular further challenged Andrew's focus on the same numbers regardless of location to solidify that the key idea here was the quantity of 16 on each side of the equation. It was at this point that Andrew not only experienced a major "a-ha" moment, but also demonstrated his understanding of Maria's idea by restating it using his word "worth" (lines 23, 25).

Maria's perseverance throughout this vignette could be specified in a number of ways. Maria persevered to challenge her partner's ideas by attending to the details of his thinking. She persevered to nurture her partner's understanding of a mathematically critical idea. She persevered to resolve a disagreement by constructing and re-constructing viable arguments and communicating them such that another could understand and make use of the idea. As she persevered to engage Andrew, her own conceptualization of the equal sign and the relationship among quantities was challenged and developed as she was pushed to re-articulate her ideas in response to those of Andrew's.

Perseverance in Action: Andrew

We now turn to a discussion of how Andrew demonstrated perseverance in action as he engaged with Maria throughout the two mathematics lessons. In the above vignette, Andrew persevered to keep his ideas on the table, even though his partner repeatedly disagreed with him. He voiced his answer (lines 2, 4, 6), repeatedly provided rationale for his answer (lines 6, 8, 13, 20), and shared that he made repeated attempts to arrive at his answer (lines 16, 18). What is particularly striking about Andrew's continued participation is that, while communicating his own ideas to his partner, he clearly attended to the details of Maria's explanation. The hesitation that Andrew demonstrated in line 20 could have been indicative of him reconsidering his own ideas, providing an opening for Maria's move of re-representing the equation to cause a conceptual shift in his understanding.

Andrew's participation here is more impressive given the social dynamics of this pair over the two videotaped lessons. Throughout the lessons, Maria took on a more dominant role in the pair: she often took the shared paper to write, even as Andrew protested and reminded her to share; she often provided explanations first in pair conversations, even if Andrew voiced his answer first; and she jumped in to explain as Andrew was struggling with an explanation in the whole-group discussion. In spite of Maria's more dominant role within the pair, Andrew found ways to participate and persevere in interaction with his partner.

Moreover, Andrew was persevering to engage in sophisticated mathematical reasoning. Given Andrew's likely prior experience with mathematics as a set of disconnected computational procedures, any attempts to use relational thinking, especially at his grade level, are notable. Though he clearly exhibited a developing understanding of relational thinking, the potential payoffs of his struggling with the mathematics are significant.

Social and Sociomathematical Norms in Ms. Lee's Classroom

If the sustained interaction between Maria and Andrew around difficult mathematical content is one that would be desirable across classrooms, then it is critical to understand the classroom context within which the interaction occurred. Maria and Andrew clearly persevered, and they persevered in a way that builds mathematical understanding. What kinds of classroom norms existed that might have supported this kind of interaction?

We begin with the brief teacher interaction in the above vignette where Maria requested help as the teacher walked by (line 11: "Ms. Lee, Andrew doesn't understand."). As the teacher who is circulating the classroom as students work together, Ms. Lee might have responded to Maria in a number of ways: by asking Maria to explain to Andrew, by asking Andrew probing questions to help him herself, or by asking the pair to wait until the problem was addressed in the whole-group discussion (these were all moves exhibited by teachers across the larger study). Ms. Lee, however, prompted Andrew to explain again, asked Maria to listen specifically for his misunderstanding, and walked away. Though we do not have access to the rationale behind the move, we can hypothesize the expectations that are conveyed by the teacher to students: that there is more work to be done, that the responsibility of the work lies within the pair, and that the pair is fully capable of engaging in this type of mathematical talk.

Beyond this interaction, analysis of teacher statements made across the two lessons revealed broader expectations for student participation in mathematics that resonate with the interactions exhibited by Maria and Andrew. These teacher statements are presented in Table 1, along with corresponding expectations for student participation in mathematics that could be considered the social and sociomathematical norms[4] of the classroom.

Table 1. Teacher Statements and Communicated Expectations for Student Participation

Examples of Teacher Statements	Expectations for Student Participation
• Okay, come explain. • Do you want to come up here and show us? • And instead of just saying true or false, tell [your partner] why you think it's true or why you think it's false.	Students should regularly give explanations, not just answers.
• Okay, why did you do eight plus two? Where did you get that from? • And what are you trying to show us with three groups of ten? • What are you trying to express with the lines going across?	Students should provide specific details of their thinking.
• Who has a different way? • Is there another way that someone else can explain this? • I want you to watch what he's doing cause this will give you another strategy of how to figure out this problem.	Students should consider more than one strategy for the same problem.
• Would you guys agree with that? • Do you see what he is saying? • I want you to see if you did the same thing as [student], or if you did something differently.	Students should attend to each others' strategies.
• Talk to your partner about how you solved the problems. • I want you to work with him, please. • Let her explain to you, okay?	Students should work with their partner.

As social and sociomathematical norms are not created only by teacher statements, but rather dynamically co-constructed in interaction, it is important to consider student participation to reveal which expectations for participation could be considered normative. The following list characterizes patterns of interaction across both lessons for all target pairs (11 total problems, 11 whole-group discussions, 66 student-student conversations):

- Students discussed explanations (and not just answers) for all 11 problems in the whole-group setting.
- During 72% of total explanations given during whole-group discussions, students voiced more thinking beyond the initial explanation, prompted by teacher follow-up questioning.
- At least one explanation was shared during 85% of student-student conversations.
- At least two explanations were shared during whole-group discussions for 10 of the 11 problems.
- During 27% of student-student conversations, students either voiced two different strategies or explicitly verbalized attempts to find "another way" or a "different way."

While this is not an exhaustive list of the social and sociomathematical norms that guided student participation with the mathematics, it is clear that learning mathematics in Ms. Lee's classroom is guided by norms that support mathematical discourse: formulating explanations of one's work, communicating those ideas to others (who might agree or disagree), and considering one's own ideas in relation to those of others. We can see the influence of norms like these on the extended interaction between Maria and Andrew.

[4] Whereas social norms are not content specific, sociomathematical norms refer to mathematics-specific ideas that govern mathematical engagement within the classroom, such as what counts as a valid argument, a different solution, a more sophisticated strategy, and so on (Yackel & Cobb, 1996).

Discussion

Attending to both the detailed vignette of Maria and Andrew as well as participation across Ms. Lee's classroom illuminates a rich classroom environment that supports students to engage in powerful ways. "Constructing viable arguments and critiquing the reasoning of others" (CCSSM, 2010), for example, are critical forms of mathematical reasoning that, as Cobb and Hodge (2002) would argue, "have clout" and are far-reaching beyond classroom walls (p. 271). Though this analysis provides only limited evidence of who Maria and Andrew are as mathematics learners, we might begin to speculate from their interactions their mathematical strengths and potential for future wrestling with the mathematics.

More importantly, we are compelled to consider how this interaction reveals how Maria and Andrew may see themselves as learners and doers of mathematics. Boaler and Greeno (2000) discuss the implications of classrooms that convey mathematics as a set of ritualized procedures where it is not important to think about how or why. Their interviews with students revealed a disidentification from mathematics because they rejected being positioned as passive receivers of knowledge. This is in contrast to a mathematics learning environment where students are asked to collaborate together as they make connections and generate questions and ideas, where they are, "quite simply, given more agency" (p. 189). It would not be a stretch to conclude that Maria, Andrew, and others in Ms. Lee's class are positioned to see themselves as agents of their own mathematical learning, a learning that is characterized by formulating arguments, responding to the ideas of others, and persevering through mathematical struggles. This positioning is critical in response to current ways of doing mathematics that provide inequitable access to future opportunities.

We are struck by the caliber of mathematical participation exhibited by the students in Ms. Lee's second grade classroom. Few would argue the difficulty of cultivating this kind of a classroom environment, especially given prevailing discourses in low-performing urban schools that have historically limited access to powerful engagement with mathematics. This example, while not the only example of perseverance in action that can be found in classrooms such as Ms. Lee's, provides for educators a more detailed and specified way to conceptualize perseverance. Continued attempts to create learning spaces that develop mathematically proficient students would be incomplete without direct attention to students' demonstrations of perseverance as they develop the skills and identities of doers of mathematics. The case of Maria and Andrew in Ms. Lee's second grade classroom pushes us to consider what mathematically proficient students are to *know,* what it is that they are to *do*, and possibly most importantly, who they are to *be.*

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"*I've come too far, I've worked too hard*": Reinforcement of Support Structures Among Black Male Mathematics Students

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Along with the growth and refinement of our shared discourses on equity, the community of education researchers focused on Black males has developed lenses with which to examine the risk and protective factors related to Black males' participation in and experiences with mathematics. In this paper, the authors focus on the importance of the "supports" associated with mathematically high-achieving Black high school students in urban high schools. Using Critical Race Theory (CRT) and narrative analysis, the authors report findings from semi-structured interviews of mathematically successful Black male students (n = 12) from four urban high schools. Analysis of key themes suggests that high-achieving Black male mathematics students make use of powerful family & peer networks, as well as various features of the school and classroom community as support structures in the course of maintaining consistent mathematics achievement. Recommendations for strengthening support for all Black male mathematics students in urban contexts are discussed.

Keywords: Black males, mathematics achievement, supports

Introduction

> *…and as we were coming back in the house, I didn't know that a guy was trying to run up behind us with a gun… (H)e looked up and told me,"You call the police because we're killing everybody in that house tonight." And I'm like, I've come too far and worked too hard to have everything taken away from me because of the mistake of one person and we moved on from that.*
>
> —Hasani, 12th grade high-achieving Black male

Success in school mathematics seems fairly easy to predict when considering individual factors like race, class, and gender—as well as other contextual factors such as, for example, school and teacher quality. The mathematics education community has, along with our evolving discourse on equity, developed powerful lenses to examine and refine the current pedagogical practices that negatively impact "high need" and "at-risk" students. The National Council of Teachers of Mathematics [NCTM] *Standards* document describes a vision for high-quality mathematics instruction and calls for instructional practice that aids in the healthy development of students' robust understanding of mathematical literacy (Jackson & Cobb, 2010; National Council of Teachers of Mathematics Research Committee, 2006, 2007). However, when it comes to the mathematics education of Black students, some scholars contend that students' civil rights have been infringed upon, in part, due to the constant and systematic assaults on their opportunities to learn (Moses & Cobb, 2001; Esmonde, 2009; Martin, 2009; Oakes, 2005). As a result of well-known disparities in classrooms with low-income Black mathematics students (i.e., lack of qualified teachers; under-resourced classrooms, schools, and communities; low expectations and negative racial stereotypes, etc.), most Black children in these contexts are expected to fail. Mathematics education researchers' attention to the plight of these low-performing students is the unmistakable yield of our equity ethics and the focus of the national attention on achievement gaps. There is, however, a fraction of mathematics students—students like Hasani above—who, because of their unpredictably high achievement in mathematics, may be overlooked or simply