Chapter 4
Using One-to-One Mobile Technology to Support Student Discourse

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Abstract Education researchers, administrators, and classroom teachers in Auburn, Maine, USA are using a design-based, iterative research approach to examine how screencasting apps can support student discourse in K–2 mathematics classrooms equipped with one-to-one mobile technology (iPads). Preliminary data analysis shows that in addition to enhancing mathematical communication, the purposeful use of screencasting apps supports more equitable opportunities for student participation in mathematics discourse, facilitates effective talk moves such as wait time, involves students in self and peer assessment, and engages students in productive struggle. Early findings also suggest that when teachers utilize this approach in their classroom, their beliefs about student capabilities may increase and their teaching practices may change.

Keywords Screencasting · Mathematical discourse · Formative assessment
Productive struggle · Research-practice partnership

4.1 Introduction

In this paper, we explain how a group of education researchers, higher education faculty, district and building administrators, math coaches, and early elementary classroom teachers worked collaboratively to identify and address persistent learning problems in mathematics within a school district in a small city in Maine. Because early elementary school classrooms (kindergarten–second-grade) in the district were equipped with one-to-one (1–1) mobile technology, specifically iPads,

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L. Ball et al. (eds.), *Uses of Technology in Primary and Secondary Mathematics Education*, ICME-13 Monographs, https://doi.org/10.1007/978-3-319-76575-4_4

using this technology to support student learning significantly shaped our approach. After a brief review of the literature that influenced the development of the theoretical framework, we identify the overarching research questions and then outline the components of the qualitative, design-based research methodology used in the study. We also describe how ongoing professional learning, tightly coupled with classroom data collection, critically influenced our work. We then share the emerging findings from the first two years of the study, with a focus on the ways in which the use of screencasting apps support students' mathematical discourse and the changing nature of teachers' beliefs as a result.

4.2 Theoretical Framework

Research suggests that interactive digital technologies have the potential to support and enhance the learning of mathematics in the early grades (e.g., Attard & Curry, 2012; Ginsburg, Jamalian, & Creighan, 2013; Goodwin & Highfield, 2013; Soto, 2015; Soto & Ambrose, 2014; Soto & Hargis, 2014). One-to-one, hand-held, mobile technology, such as iPads, provides students with unique learning opportunities. Using recording tools available through apps or the iPad camera, students can document their problem-solving approaches and share their thinking with others (Attard, 2013). Moreover, multisensory recordings allow students to review, reflect on, and critique their own as well as others' written work, representations, and oral explanations. The ease with which students can create and share recordings provides them access to different ways to solve problems and allows them the opportunity to reflect on their own and others' explanations and even discover and correct their own and others' mistakes and misconceptions (Hattie & Timperley, 2007; Soto, 2015; Soto & Hargis, 2014). Producing video recordings of their work engages students and can help them view themselves as creators of their own mathematical ideas (Yelland & Kilderry, 2010). Recordings of students' mathematical thinking can also provide students and teachers with evidence of their learning and be a source of motivation and encouragement (Blair, 2013; Sedig & Liang, 2006; Soto & Ambrose, 2014). Students who use screencastings to explain their mathematical thinking often become aware of and attentive to an audience. Therefore, they adopt a teaching identity through which they describe the process for their mathematical solution and provide a justification for that work (Soto, 2015). Moreover, audio-visual recording capabilities may be particularly beneficial for young students who often are better able to express their thoughts through speaking rather than through writing.

In their 2014 publication, *Principles to Actions: Ensuring Mathematical Success for All*, the National Council of Teachers of Mathematics (NCTM) identifies "facilitat[ing] meaningful mathematical discourse" as a research-based, high-leverage practice that improves the teaching and learning of mathematics. NCTM (2014) indicates that supporting mathematical discourse among students is central to ensuring the meaningful learning of mathematics. Teachers who encourage their students to share their work with one another provide their students with the opportunity to justify and clarify their mathematical ideas, communicate their ideas verbally or in writing using mathematics vocabulary and visual representations, and make sense of other approaches to solving problems (NCTM, 2014). Research suggests that students who have opportunities to engage in mathematical discourse may develop a deeper conceptual understanding of mathematics (Attard, 2013; Moschkovich, 2012; NCTM, 2014). The Common Core State Standards for Mathematics (CCSSI, 2010) includes "construct viable arguments and critique the reasoning of others" as one of the eight Standards for Mathematical Practice (SMP). This student practice standard closely parallels the teaching principle of facilitating meaningful mathematical discourse (NCTM, 2014) and highlights the important nature of discourse in mathematics for all members of the learning community. Supported by this research, and prompted by teachers' observations of students in early elementary grades using screencasting apps in the classroom, the study's co-investigators hypothesized that when students regularly use screencasting apps to record and review their mathematical explanations, their mathematical communication and reasoning skills improve.

4.3 Research Questions

As collaborating partners in the project, the researchers, administrators, and teachers investigated how screencasting apps support students' mathematical learning in the early grades by asking students to use a screencasting app to record their written work and oral explanations as they solve mathematical problems. The following co-developed research questions guided the investigation:

1. In what ways do teachers enact a strategy that encourages students to record and review explanations of their mathematical thinking using iPad-based recording tools?
2. What types of mathematical reasoning and discourse outcomes emerge from use of this strategy?
3. How might use of this strategy be related to teachers' instructional practices and students' mathematical outcomes?

4.4 Design and Methodology

This study is part of the Research + Practice Collaboratory, a project that is funded by the National Science Foundation and is committed to using a partnership approach between researchers and practitioners to develop promising ways to bridge the gap between research and practice in STEM education. The project conjectures that when researchers and educational practitioners work collaboratively to exchange knowledge and to design and develop educational interventions, researchers are more likely to incorporate practitioner knowledge into their research, and educators are more likely to use evidence-based practices in their instruction. Equal positioning of researchers, administrators, and kindergarten—second grade teachers plays a key role in the study's methodological approach. Each partner is considered a co-investigator and plays a critical part in collaboratively identifying important needs to address, designing possible solutions, testing these solutions, and planning for the sustainability and scale of the reform strategies that emerge (Penuel, Fishman, Haugan Cheng, & Sabelli, 2011). The collaborative approach to this study draws from design-based research methodology. Five central principles of design-based research are: (i) the development of theories and learning environments are interconnected, (ii) research and implementation take place in ongoing iterative cycles, (iii) generated theories must be applicable to practitioners and other designers, (iv) research occurs in real environments, and (v) the data collected highlights both enacted work and outcomes (Design-Based Research Collective, 2003).

Our collaborative work means that we have remained deeply committed to providing ongoing professional learning for all participants throughout the duration of the study. Loucks-Horsley et al. (2003) indicate that professional learning for educators needs to support them in acquiring new knowledge, skills, behaviors, attitudes, and depth of content knowledge. A critical feature of effective professional learning is that it provides opportunities for collaboration with colleagues (Loucks-Horsley et al., 2003). Research shows that typical one-day professional development sessions have limited impact on teaching practice as teachers transfer less than 10% of the content into their classroom practices (Showers & Joyce, 1996). Similarly, Attard (2013) found that teachers are less likely to embed effective teaching practices with technology into their teaching without planned and sustained professional dialogue focusing on technology, pedagogy, and content knowledge. Ongoing professional development provides teachers with necessary multiple opportunities to reflect on and re-conceptualize their practice to accommodate the technology and new practices. According to Dorph and Holtz (2000), high-quality professional development meets four conditions. It should be (i) connected to content knowledge, (ii) designed with a clear and focused audience in mind, (iii) sustained over time with a coherent plan, and (iv) structured with opportunities for practitioners to reflect, analyze, and work on their practice. Professional learning communities (PLCs), defined as learning models in which collective inquiry supports changes in attitudes, beliefs and practices (Dufour & Eaker, 1998), can be one tool used to engage in the type of high quality professional learning described by Dorph and Holtz. With this in mind, education researchers, higher education faculty, administrators, math coaches, and classroom teachers participated collaboratively each month in a PLC to shape shared insights into possible research questions, examine research related to mathematics teaching and learning, share tools and strategies, and reflect on the work done in classrooms.

The partnership started in the spring of 2014 when a wide range of stakeholders, including pre-kindergraten through third-grade teachers, specialists, and principals from the six elementary schools in the district as well as the district's curriculum director, assistant superintendent, and superintendent, met to focus on problem identification. This work provided the team with a broad base of input and support, which enabled the work to move forward over two years. It also provided the team with a more clearly defined area of focus. In the summer of 2014, the collaborative work began with eight kindergarten–second-grade teachers, a math coach, and the principals of the three lowest-performing schools. The technology integration specialist, curriculum director, assistant superintendent, and superintendent were also members of the team. Three teachers, the math coach, and another specialist left the project after the first year. In the second year of the project, we scaled up our work, and kindergarten–second-grade teachers and administrators from two additional schools joined the partnership. Practitioner participants in year two included eight administrators, fourteen kindergarten–second-grade teachers (five from year one and nine new teachers) and one new coach.

In the summer of 2014, the co-investigative group met over eight days. During this time, 17 educators from cohort 1 (8 classroom teachers and 9 building administrators) worked collaboratively with a group of education researchers from a non-profit educational research organization and local state universities. We worked together to identify persistent student-learning problems and to study aspects of high quality mathematics learning and teaching. Teachers, administrators and researchers participated in a shared reading of Fosnot and Dolk (2001) book, *Young mathematicians at work: Constructing number sense, addition, and subtraction*. The teachers became particularly interested in two pedagogical ideas highlighted in the reading. The first, "learning landscapes" (Fosnot & Dolk, 2001) presented them with potential learning trajectories that students might follow as they encounter big ideas in early mathematics learning. The second, "math congress" (Fosnot & Dolk, 2001), introduced them to the importance of whole class discourse in early mathematics classes and the purposeful sharing of students' work at the end of a mathematics class. After reading and discussing this work, teachers in the study became more aware of their own students' engagement in mathematical communication and expressed concern over their students' mastery of numeracy.

During the summer months of 2014 and the beginning of the 2014–2015 academic year, we studied research related to the implementation and use of technology, particularly iPads, in early learning classrooms. We examined affordances of various mathematical apps, engaged in mathematics using the iPad apps we explored, and discussed ways in which these tools could support mathematical learning in early mathematics classrooms. In the fall of 2014, we implemented a "toe-in-the-water" induction phase when teachers explored the mathematics learning strategies and mobile technology tools we examined with their own students. Building on our work in the summer of 2014, participating teachers returned to their classrooms that fall with a goal to focus their mathematics instruction on number sense and to pay particular attention to the CCSSI (2010) SMP 3: Construct viable arguments and critique the reasoning of others, SMP 4: Model with mathematics, and SMP 5: Use appropriate tools strategically. All kindergarten–second-grade students in this district have iPads, so we focused our work on how using this mobile technology could support and improve student learning.

From experimenting in their own classes during this trial phase, participating teachers became curious about the ways in which the screencasting app Explain Everything™ (EE) might support student discourse and whole-class discussions in their classrooms. Specifically, the teachers became excited by the level of engagement and mathematical discourse that their students displayed when using screencasting apps to record, explain, and review their thinking when solving mathematics problems. Thus, after seven months of professional work together, we agreed on a group strategy that we would co-investigate. We decided that for the remainder of the school year and the following school year, the teachers would integrate this strategy into their mathematics lessons at least once a month. Employing 30-day plan-do-study-act cycles, we agreed to co-investigate how teachers implemented this strategy, how students responded to this strategy, and for whom and under what conditions this strategy might generate improved mathematics learning outcomes.

Over the 2014–2015 and 2015–2016 academic years, classroom teachers implemented project-related lessons at least once a month during which time students recorded their work using a screencasting app. For each implementation, the teachers completed and submitted a strategy planning and reflection form. Education researchers observed and video-recorded each classroom once a month and then completed an observation log. The team also collected student work done on iPads as evidence of student learning. Finally, teachers and researchers completed surveys and interviews throughout the two years of the project.

Therefore, the project adopted a three-tiered approach that coupled our professional learning and research objectives. The first was ongoing monthly professional learning experiences, facilitated by mathematics education researchers and university faculty, which were driven by the questions that emerged from the teachers' implementation of previous learning or their responses to regular surveys. The second was monthly classroom observations, video recordings, and online logs that teachers completed to record their methods of strategy implementation and observed student outcomes. The third was the sharing and discussing of student work at the monthly meetings. Through these different avenues, we collected data via:

- Reflections on and discussion about student work over one-and-a-half years
- Reflections on and sharing about strategy implementation over one-and-a-half years
- Online logs completed by teachers each month, which addressed strategy implementation in individual classrooms, and observations of potential student impact over one-and-a-half years
- Monthly surveys, conducted during our PLC meetings, in which participants reflected on their strategy implementation, outcomes, and broader themes related to our collaboration

- Student screencasts over two years
- Classroom videos over two years
- Interviews with 17 members of the collaborative team, including teachers, administrators, researchers, teacher educators, and teacher leaders at the end of the second year
- Email correspondence between researchers and educators over two years
- Final written reflections from teachers at the end of the project

Together, the data collected and topics discussed both formally and informally informed our design choices as we cycled through the iterative process.

4.5 A Focus on Ongoing Professional Learning

As previously noted, a critical piece of our work is the fact that the research and ongoing professional learning experiences have been tightly coupled. We knew that without such appropriate professional development, the potential for the iPads to enhance the teaching learning of mathematics may likely be wasted (Attard, 2013). Thus, we highlight below the foci of our ongoing professional learning over the course of the project.

When we first came together in 2014, we quickly identified that the teachers lacked opportunities to engage in learning about best practices related to both teaching and learning mathematics and the use of technology to support students' early mathematics learning in elementary school classrooms. Similarly, they had experienced few chances to reflect deeply on their own classroom practices related to teaching mathematics and using technology to support their students' mathematics learning. In order to identify whether and how the use of technology in the classroom may support students' mathematical discourse, the team realized that we needed ongoing opportunities to examine research, test out ideas, and deeply consider the outcomes of the work. Put simply, we wanted to ensure that we based our study around the use of technology in kindergarten–second-grade classrooms on research-based practices that support high-quality mathematics teaching and learning. Consequently, we needed to work together to identify, understand, and implement high-quality practices.

To achieve this, the team used the data collected to support continued professional learning opportunities. We also considered areas of interest as identified by teachers or needs as identified by both teachers and education researchers. After our initial work together engaging with technological tools and examining research around early mathematics learning trajectories (Clements & Sarama, 2004) and math congress (Fosnot & Dolk, 2001) as an avenue to foster mathematical discourse, we found that teachers needed information regarding additional topics in order to facilitate the type of learning they wished to see in their students. Therefore, in subsequent meetings we learned about and engaged in rich tasks (Stein, Smith, Henningsen, & Silver, 2000; NCTM, 2014) and open questions and parallel tasks (Small, 2012). The introduction of rich tasks into classroom practice led to discussions around productive struggle (Warshaur, 2015) and the use of wait time. Later, we began to examine the district's mathematics textbook and discussed ways to align project work with the text. We also began to explore different models and representations of mathematics problems. To facilitate this learning, we created research and practice briefs, which present short summaries of existing literature, around topics of interest or need. For example, we provided the teachers with and discussed one brief that synthesized the literature on the learning trajectories for counting and cardinality, another about technology in early grades' mathematics classrooms, and a third that detailed research on discourse in mathematics classrooms.

In addition to providing educators the opportunity to deepen their professional knowledge around best practices in mathematics instruction, the monthly PLCs gave the teachers space to share the strategies they used to implement the use of screencasting apps in their classrooms and to observe, analyze, and discuss examples of student screencasts from other teachers' classrooms. Because this time was fundamental for teachers' own learning and efficacy, and because we gained great insight about what was occurring in each classroom, we engaged in these activities monthly.

4.6 Findings

After two years of study, emerging data suggests that the strategic use of screencasting apps in K–2 classrooms can encourage students to communicate, reflect on, and revise their mathematical ideas. Because students record themselves explaining their mathematical thinking, they also listen to their own ideas and the ideas of their classmates through the screencast recording. We see evidence of increased student engagement in self-assessment and peer-assessment, which often prompts them to revise their own work. Similarly, students in our study show evidence of more persistence when working on higher-level math tasks. Participating teachers' teaching practices, meanwhile, have become more closely aligned with the high-leverage practices identified by NCTM in *Principles to Actions: Ensuring Mathematical Success for All* (2014). Specifically, we see evidence of teachers facilitating meaningful mathematical discourse, posing purposeful questions, implementing higher-level tasks that promote reasoning and problem solving, and supporting productive struggle in learning mathematics. Because students in the classrooms now explain their thinking more than before the study began, teachers have become more knowledgeable about what their students know and can do mathematically. In turn, teachers appear to be shifting their beliefs about the learning and teaching of mathematics that are possible in their classrooms.

In this section, we detail qualitative data that suggest the ways in which student discourse in mathematics classes has changed through teachers' participation in this study. We identify pedagogical practices that seem to support this increased discourse including the use of rich tasks, wait time, enabling students to engage in productive struggle, and the use of routines and teacher-created resources. We then highlight how the use of screencasting apps appears to have provided both teachers and students with increased opportunities to participate in meaningful formative assessment work. We also highlight the ways in which these changes in practices align with changes in teachers' beliefs about their students' learning. Namely, teachers are more apt to see their students as capable and competent mathematics learners. We share emerging insights into how the use of screencasting apps in early mathematics classrooms may support equity in student learning by engaging students who are often marginalized in classrooms. Finally, we identify challenges that teachers faced when implementing the research strategy.

4.6.1 Student Discourse

Some research (e.g., Hall, 2015) suggests that using handheld mobile technology in early grades classrooms promotes isolated learning that prohibits social interaction and limits hands-on learning. However, our research indicates that careful and strategic use of screencasting apps (specifically, EE) has quite the opposite effect. When our work began in the district, students most often used iPads individually. They wore headphones and interacted with devices only by tapping their screens. Two years into the study, participating classrooms now look and sound very different. Kindergarten–second-grade students are solving richer mathematical tasks on their own and with their peers. They create their screencasts individually at times and in small groups at other times. Invariably, the students recognize that they will share their work with the teacher, a classmate, in a small group, and/or with the whole class. As students record and share their work, there is generally lively mathematical discourse occurring between students.

Participating teachers noted and are excited about this change as well. They report that students now have conversations with one another about math, sharing their mathematical strategies and improving their ability to communicate about their mathematical reasoning and their use of vocabulary. In one online strategy log entry (12/15/2015), a participating second-grade teacher, Mrs. K, wrote that "EE offered the opportunity for students to practice verbalizing how they subtracted." Mrs. K continued to reflect on her practice over the course of the project. At the end of the second year of the study, she reported in her interview,

> I guess I didn't realize how little I had students talking about math. And I'll find now just sitting on the carpet students will just be engaging in conversation while I'm writing something up on the board and it's about a math problem. And they're arguing with each other but being really reasonable and they're doing those things that we're practicing but without that scaffold of the video. Which I think is really the goal. I feel like the videos are a stepping stone towards just having math conversations with each other.

Mrs. M, another second-grade teacher, indicated in her strategy log (12/9/2015) that "when students talk through what they know and how they know it, they make connections. It also helps their classmates make connections and have 'aha's'. Connections = new learning!" Importantly, teachers identified that the use of screencasting apps in their classrooms changed their overall math instruction. An example of this change comes from Mrs. B, a third second-grade teacher, who noted that without this project "I wouldn't have been doing as much discussion and be really thinking about my instruction to foster discussions among the students" (Online Strategy Log, 10/8/2015). In her interview at the end of the second year, Mrs. B told researchers,

> In the past, my kids have said, 'Well, this is how I did it.' Or, 'I just knew it,' and they don't discuss anymore. This year, they're having discussions and talking about their thinking and responding to others.

Ultimately, survey data indicates that teachers believe that this increased communication, supported by the use of classroom technology, provided their students with more ownership over their learning and improved their mathematical language and justifications.

We see evidence of this increased mathematical discourse not only when students use the screencasting tool itself, but also without the technology. It appears that students and teachers became more comfortable and confident with communication in mathematics class. For example, a researcher in one second-grade classroom observed students sitting around an easel at the beginning of the lesson. After the teacher prompted them to solve an addition problem and share their strategy with the group in a whole class discussion, students began to talk to one another about their approaches using phrases such as, "I'm wondering why you…" or "I started the same way as you, but then I…". In a different second-grade classroom, we observed students frequently engaging in the routine of sharing work with one another before providing each other with a compliment and a question about their work.

4.6.2 Pedagogical Practices that Support Discourse

While we strongly believe that the use of the screencasting apps facilitated students increased mathematical communication both when using mobile devices and in general, we also consider the teachers' use of high-leverage practices and instructional supports, studied and shared during our monthly PLCs, to be instrumental in the improved student discourse. Other researchers, such as Attard (2013), have also noted the need for a more symbiotic connection between professional development that focuses on pedagogical content knowledge and professional development that focuses on technology integration. Attard (2013) reported on a study that highlights the need for appropriate professional development that addresses all aspects of technological and pedagogical content knowledge to ensure successful integration of innovative technologies and to ensure the new teaching practices actually enhance the teaching and learning of mathematics. We found that coupled with such professional development, the nature and affordances of the iPad and screencasting app can help promote the use of high-leverage practices and routines that support productive discourse (e.g. rich tasks, wait time, and productive struggle).

Rich Tasks. When our project first began, like many teachers in the United States, the participants in our study felt pressure to "get through" the district-adopted textbook. Through our examination of research around rich and open tasks, teachers considered how they might open up and/or increase the level of cognitive demand of some of the questions provided in their text and began to create their own rich tasks related to the mathematical content being studied. Teachers also started to identify areas in the textbook that were already ripe for richer mathematical discussion. When describing how she used the screencasting app with her students, Mrs. K reported that the best use of the tool was "definitely the more open-ended math problems." She then added,

> When we come to a more challenging kind of an open response or open-ended math problem that's when we take that time to really explain our thinking. So any opportunity, we have our math curriculum and there's a lot of opportunities within that math curriculum when they say to explain our thinking […] Instead of a few lines or a little space for them to explain how they thought which is hard for a second grader to do. They now get to talk their way around it and figure that out. (Interview, 2/2/2016)

To support their student discourse, teachers realized the importance of giving their students richer, more open tasks. For example, Mrs. B reported,

> I think having those open, rich questions and tasks and having the conversations and having the ability to use all those different apps because those apps let them see things in different ways. I think all that together has really been positive. (Interview, 1/26/2016)

School administrators also noticed that students engaged more frequently with open tasks. In her interview (2/1/2016), Principal Mrs. S said,

> If you have an open enough task, regardless of ability level, a student is going to be [able] to access that task […] How they come up with answers […] might differ, but […] it's been good to sort of facilitate more of those open-ended, multiple entry tasks versus the skill and drill.

When teachers first began to use rich tasks in their classrooms, they primarily drew upon examples provided by researchers at PLC meetings. Later, however, they started to identify areas in their text with richer tasks than they might have first assumed, as is evidenced by Mrs. K's previous statement. Teachers also began to create their own open tasks for students, grounded in contexts related to their own classrooms. For example, we observed this in spring 2015, when the Mrs. S, a second-grade teacher, used the following prompt: "I bought a package of cardstock yesterday. The package contained four colors (red, yellow, blue, and green) and 50 sheets of cardstock. How many of each color might have been in the package?" As the project has progressed, teachers have more deliberately chosen open questions and rich mathematical tasks for their students. These types of problems allow students to identify a variety of possible solutions and use multiple strategies, and they help to promote more prolific mathematical explanations that students can capture on their screencasting apps.

Wait Time and Productive Struggle. Participating teachers indicated that using the screencasting tool promoted their use of wait time. Because students pre-record their solutions and play them from beginning to end, the teachers would not interrupt a student's presentation to prompt his or her thinking as they traditionally would do when the student would orally present the work off of technology. Furthermore, because teachers cannot get to all students as they record their videos, students often talk or think through a problem themselves. The teachers discovered that students often self-correct in the middle of the video when the teacher doesn't interrupt the students' thinking.

One math coach shared that the examination of research around productive struggle was valuable for the primary-level teachers and indicated in her interview at the end of the second year,

> [T]hat's the piece we want to make sure, for some teachers, it's not just regurgitating what you told them to do. It's really letting children think and explore their own thinking and then being able to listen to what the children have said, and identify where they're at, to find out where to move them next. This would be probably a challenge for some teachers, because, especially in the primary level, we're still coddling and motherly types. We don't like to teach in struggle. So needing to really have a clear understanding that productive struggle is where kids learn might be new learning for some.

A school administrator, Mrs. D, echoed this sentiment in her interview (3/11/2016) and told researchers that she sees evidence of this in the classrooms that participate in the study: "[W]hat I've seen is that students are willing to take risks and engage in productive struggle […] And for kids the end result is a better understanding of the learning process itself."

Providing students with wait time and opportunities to experience productive struggle in tandem with the rich, open tasks described above appears to have resulted in students persevering through challenging problems for longer periods of time. When the teacher does not immediately provide the student with the correct answer or an appropriate strategy, and when the student is tasked with creating a video explaining his or her thinking, students invest in sorting through their misconceptions and incorrect answers. Students are also now more comfortable sharing their partial solutions and sharing what they have found challenging with one another. They solicit feedback and ideas from one another when they struggle with a problem. They then use this information to help them record and re-record their work multiple times until they are satisfied with their final product. For example, when second-grade students worked on solving the cardstock problem above, the teacher had the students come together after about 15 min of work time in order to share their ideas. Three students shared their videos even though no one had the correct answer. Before one video played, the student told the class, "I don't have an answer, I only know how many sheets there are." His first attempt showed only the number 50 on his screencast. The students talked about the problem together and, in a conversation facilitated by the teacher, came up with new ideas for approaching the work. The students then continued working on the problem for another 30 min before coming together again to observe three finished videos, all with correct solutions to the problem.

Instructional Routines and Resources. In addition to implementing research-based practices in their classrooms, teachers further adjusted their practice to enable students to use their iPads to communicate their ideas. Teachers adapted, refined, and shared with one another pedagogical practices that support the use of screencasts to improve communication. Kindergarten teacher, Mrs. G, for example, started to incorporate math tools, such as the rekenrek and number frames, into her every day classroom activities. Guided by information in one of the project's research and practice briefs about developmentally appropriate use of technology, Mrs. G provided her students with opportunities to explore both hands-on and technology-based versions of the same tool. One researcher observed a morning routine change in a second-grade classroom so that the teacher now provides students the opportunity to critique their own reasoning and that of their peers. In this routine, each child solves a math problem and records his or her solution on the iPad. The class then observes, discusses, and reflects on some of the videos. Children return to their iPads to continue working on their solutions by re-recording their work if their thinking changed, or to add to their original work if it did not. In another second-grade classroom, the teacher, Mrs. H, introduced the notion of a "Math Guest Teacher of the Day." For this activity, the teacher chooses one student's video to be shared at the beginning of math class. After they share the video, the students in the class discuss what made the video strong and what might make it even stronger. Additionally, they ask one another questions about and discuss the mathematics shared. The teacher tries to incorporate this instructional routine into her lessons at least three times a week.

In their surveys, teachers reported the use of other pedagogical moves such as modeling teacher-created videos of various quality for class discussion and analysis, pausing during a lesson to share "quality" videos in order to keep students on track, ensuring time for students to share their work with partners before coming together as a whole class, and a series of moves that includes student think time, time for partners to record and watch videos together, and sharing and critiquing videos in small groups.

Teachers also identified and researchers observed a variety of tools being created and used by teachers to support their students' communication. These include the use of sentence starters (e.g. I know my work is correct because…), sentence frames (e.g. I started at __ and counted up to 10. That was __ jumps. Then I counted to __. That was __ jumps. Then I added my jumps to get __. So, __- __ = ___), co-constructed checklists of indicators that contribute to a strong video (e.g. I can hear my explanation; I can see a picture that helps to explain my thinking; My picture and writing are clear and easy to read; I say what problem I am solving; My explanation is easy to understand; I explained the math words when needed; My math is correct), discussion guidelines (e.g. It's OK to change your mind, It's OK to feel confused), and anchor charts about quality explanations. Notably, after teachers created these tools, they often shared information about the tools during the monthly PLCs. They shared templates with one another, information about how they use the tools in class, and their reflections on how the tools promote student learning. Some of these teacher-created, shared tools have been adopted by other teachers across the district.

4.6.3 Formative Assessment and Student Discourse

One, unanticipated, promising result of using the EE screencasting app in the early elementary school setting has been a noticeable increase in the use of formative assessment, done by both teachers and students. Research emerged over the last two decades that shows the critical nature of formative assessment, including peer and self-assessment, in fostering growth in student learning and engagement (Black & Wiliam, 1998; Fontana & Fernandes, 1994; Hwang, Hung, & Chen, 2014). Likewise, Wiliam (2000) suggests that "effective learning involves having most of the students thinking most of the time" (pp. 21–22) and that when formative assessment becomes an everyday routine, students think more deeply and reflect on their own academic progress.

Teacher Formative-Assessment. The teachers in our study reported that the recordings provide a valuable source of assessment data. For example, Mrs. M indicated,

> The opportunity to observe students self-correct their thinking as they talk out a problem with a peer gives us lots of information. It gives us a window into their thinking and helps us plan next steps for instruction and explorations for students. (Email message to author, April 11, 2015)

Similarly, Mrs. K reported,

> [W]hereas before it was one teacher and 20 students, so I didn't always get to listen to how every student was listening and sharing their thinking. [Now,] I can look at those students who I know are struggling and take time to review their recording later, and then I can meet with them again. So, it's a nice snapshot of how students are doing with a particular problem at that moment. (Interview, 2/2/2016)

Multiple teachers share that observing their students' screencasts helps them to plan instruction to meet their students where they are in their learning trajectory. We theorize that the fact that teachers now have the opportunity to hear each of their students explain their mathematical ideas allows the teachers to better understand the abilities and misconceptions held by their students. Additionally, because the teachers now have the ability to watch a student work through a problem and listen to their students' explanations via the screencasts, teachers have a better sense of what the children understand than they did when looking at static work, which is typically handed in on paper. In his interview, school Principal Mr. D called the screencasting app a "fantastic" tool for formative assessment and praised its potential to provide teachers with powerful information for their instructional decision making. Teachers also appreciate that the EE videos serve as a "container" that holds student thinking over time and helps show students' learning progress. Some even shared their students' videos with parents during conferences.

Student Peer and Self-Assessment. Teachers not only found more frequent and meaningful ways to assess their students' thinking, but the use of the screencasting app also appears to support students' own ability to engage in self and peer assessment. Black and Wiliam (1998) suggest that this type of formative assessment is "essential to good learning" (p. 6). After students record their solutions on the iPad, they often review their own recording either on their own or with prompting from their teachers. As they hear themselves explain their thinking, they can identify areas in which their explanations are unclear or where they misrepresent their thinking. The students often delete their work and start this process again in order to create a stronger explanation. Soto (2015) identified similar evidence of students engaging in self-assessment when using EE to describe their mathematical work. However, Soto's study examined students' screencasts in a 1–1 environment, in which a researcher and student sat together, while the student recorded his or her video. Our research indicates that Soto's (2015) findings around improved student self-assessment hold true in a classroom environment even when the student and teacher do not interact 1–1.

We found multiple examples of students correcting their work in their screencasting samples. For example, when one second-grade student, Brendan, recorded his solution to the problem "You bought something at the store that costs 72 cents. You paid one dollar. How much change did you receive?," he began by making jumps on an open number line. He started at 72 and jumped to 80. As he did this, he said, "I'm going to skip to 80 and I'll put ten" and then wrote a 10 underneath the jump from 72 to 80. Brendan then made a second jump to 90 and said, "then I'm going to skip to 90, and I'll put ten right there" as he recorded a second 10 under the second jump. He then said, "oh, this isn't ten, I accidentally messed up" at which point the screencast shows him erasing the first ten he recorded while saying, "so, this is actually eight."

Another student in the same class, Brian, recorded a screencasting video for a similar problem. This time, though, the amount of money spent was 63 cents. In his first video, we see the student making 7 jumps of one from 63 to 70 and then a "really big hop" of 30 to 100. When he recorded his final answer, he miscounted the jumps of one and recorded 38 cents as his solution to the problem. Students in this class then shared their work with a peer and used the class' co-constructed "Is My EE Video Complete?" checklist to guide their conversations. The teacher did not expect students to fix their videos during their peer discussions. However, she found that most of her students decided to make new videos. Brian was one of those students. His second video shows a more efficient strategy as he takes a jump of seven and a jump of 30 to reach 100. In his second video, Brian also records the correct answer, 37 cents.

Teachers and researchers also observed students self-correct their work. While the timing, method, and rationale behind the students' self-corrections vary widely, the EE app enables students to decide independently to fix their work in order to make it stronger. In her strategy log (11/18/2015), Mrs. K reported that a math congress, in which a small number of students shared their videos, helped deepen students' understanding of the math content and that "through this conversation, many students were able to revise their thinking and went back to change their work." Mrs. M, also spoke to this during her interview (3/11/2016) when she stated, "I think a really big 'aha' is that kids will self-correct. They self-correct when they make a mistake."

The teachers also indicated that students often report that they "change their minds" about their mathematical work or solution after seeing a partner's video. The teachers suggested that this is because students now observe their peers' work, reflect, and learn from their own errors. Mrs. C, a math coach, told researchers in her end of year interview,

> When they're doing their work and recording, and then they go back and listen, they can either deepen their understanding, or be reflective in the sense of self-correcting. Like, 'Oh, wait a minute. I meant this.' And within that piece, [they] may also clarify a misunderstanding they may have had.

Administrators also noted this change in student learning. In his interview (2/9/2016), Mr. D indicated,

> With the use of that technology as a tool, they're able to go back, and reflect on their work, and revise as needed […] Our biggest learning comes in reflection, and when students can hear their tablets, […] It's so powerful when you can see students self-correct on the spot or, even after the fact, when they're reviewing it […] So, I think students' understanding of math is enhanced by this.

Notably, Mrs. B connected student self-assessment to increased engagement, interest, and confidence in their math work:

> The videos were extremely helpful because we could follow students' thinking as it unfolded. Often students would self-correct as they were making their videos and revise their thinking. Students were engaged and eager to share their thinking. I saw my students gain confidence in solving problems not just to have the correct answer but to be a part of the process of solving the problem and deepen their understanding. (Final Project Reflection, 6/29/16)

Teacher survey data further indicated that students not only correct their own work, but they offer suggestions to help their peers improve their work as well. In one interview (1/26/16) Mrs. M underscored the fact that teachers across the district were noticing and commenting upon improved student assessment:

> I see a difference between my students and what they're learning and how they're talking about their learning and their thinking […] In our groups at our meetings, the other teachers are mentioning that they're seeing the same thing… They're seeing that their students are looking at their work and they're making the corrections and they're pointing out each other's mistakes and they're doing it in a respectful way. And the other teachers, […] they're seeing this growth in their students with math.

Overall, participants reported that students have a greater awareness of their own work, more recognition of multiple strategies for solving problems, and a deeper level of engagement with and reflection about their mathematics due to using the screencasting app.

4.6.4 Changing Teacher Beliefs

Over the course of the study, education researchers observed that participating classroom teachers changed their beliefs about what it means for children to know and do mathematics. Our evidence also suggests that the teachers came to believe that their students are more mathematically capable than they had originally assumed. Teachers' participation in our collaborative study appears to have supported a change in teacher beliefs in two ways.

The first is the way in which they understand what it means for students to be engaged in doing mathematics. For example, during one second-grade class, students struggled to find a correct solution to the problem presented. Students' recorded explanations on their iPads helped to prompt a lively conversation about the problem, and by the end of the day's lesson, the students identified their misconception and how they might fix it. After the observation, the teacher, Mrs. S, indicated to the researcher that in the past she would have considered the lesson a failure because none of the students got the right answer. She reported that she now considers this to be a very successful lesson because her students were able to think deeply, reason mathematically, and determine what their new approach would be. Additionally, Mrs. S noted that the students all remained engaged and excited by the work. A kindergarten teacher, Mrs. G admitted, "In the past, I'd never really thought about how important it is to have [students] explain what they're doing, what they're thinking. So it has been huge for me; it's really been an eye-opener, and a changer, in how I teach my kids" (Interview, 02/25/2016). In her end of project reflection (6/29/2016), Mrs. G added, "My practice has become more thoughtful and reflective in what and how I teach math to my Kindergarten children. I no longer am the teacher in charge, but put that role in the hands of my children." Similarly, Mrs. K reported in an interview (2/2/2016), "I'm finding myself trying to step away and talk less to allow the students to talk more […] Students can really learn a lot from each other and that's valuable." Other teachers echoed this belief in their surveys. They indicated that they now find it important to allow students to struggle and that teachers shouldn't be afraid of this. One teacher stated that she and her students discovered that mistakes help with learning. These findings align with other research in mathematics education, which highlights the importance of productive struggle for learning (NCTM, 2014; Warshaur, 2015).

A second way that teachers' beliefs changed relates to their estimation of their own students' mathematical abilities. Many students in this project come from low-income households, and participating schools have experienced chronic underachievement in mathematics. Kindergarten teacher, Mrs. T, explained in her interview (2/3/2016),

> I have [a student] that just [makes] video after video [...] His are just right on and he's picking up and using tools that I haven't even taught yet. And he's using them correctly and it's just a lot of really neat stuff from that kid that I did not expect.

After just one year of work on the project, these changing beliefs were evident. Mrs. S reported,

> "I watched children from other schools explain their thinking and assumed they were just 'smarter' than the kids I work with. Now my students are those 'smart' kids because they can explain and show their thinking" (Email message to author, 05/20/2015).

4.6.5 Equity

Perhaps the most important finding from our work is the way that the use of screencasting apps in mathematics classrooms provided more equitable learning experiences for the children involved in the study. Our findings suggest that using the screencasting tool in mathematics classrooms has the potential to support equitable learning for *all* students in the mathematics class. Only a few students may have the opportunity to present their ideas each day in a typical math class. In classrooms using screencasting apps, every student records and explains his or her work. In essence, each student creates, and often revises, a presentation of his or her mathematical ideas each time the screencasting tool is used, even if that presentation is not shared with another student or with the entire class. In an interview, Mrs. K stated that the screencasting tool "forces everyone to engage in that problem and everyone to talk" (Interview, 02/2/2016). Mrs. K further commented in her log about this fact stating, "creating the videos requires ALL students to think" (01/23/2016) and that during their whole class discussions, students begin to make connections and "light bulbs" go on. Principal Mr. D also shared ways in which using the screencasting app supported equitable learning in the classroom in his interview (2/9/2016),

> We may come up with the same answer, we may all have taken a different route to get there, and I think that being able to capture these things honors that process of we all think differently, and so what students are sharing out in the classroom [is] OK.

Mrs. B an English language learner teacher reported in an interview (01/26/2016),

> Sometimes they don't have the language and the ability to write down what they're thinking. But if they can use this recording tool and an app, they can show it and can talk about what they've done a little bit more easily than if it was pencil/paper.

Moreover, we observed children who receive intervention supports, children with autism, and a student who is selectively mute record their voices using the screencasting tool and share their video-recordings with their classmates. In this manner, students who may commonly be marginalized in a classroom or who may not have opportunities to share their ideas publically participated more fully in mathematics lessons. School administrator, Mrs. D reported in her interview (3/11/2016), "In a classroom where this is happening all of the students are equal participants. And all of the students' ideas are equally valued." This emerging evidence suggests that screencasting tools, such as EE, may provide a platform for a wider range of learners to communicate their ideas and have their voices heard in math class.

4.6.6 Challenges

Unsurprisingly, some challenges occurred with implementing the screencasting tool in classrooms. As expected, both teachers and students experienced a learning curve related to the use of new technology, and this held true with the EE app and its features. In surveys, interviews, and monthly debriefing sessions, teachers and administrators cited overcoming discomfort with the technology itself as a hurdle. Furthermore, the teachers confronted the challenges of poor recording quality, particularly with sound, storing the videos for later reference, and ease of accessing the videos once stored. Teachers also identified difficulties with internet strength, particularly during the state-mandated testing period when students in the upper grades used much of the bandwidth to complete their assessments. Additionally, teachers struggled with finding time to learn the technology themselves, to teach the students how to use it, and to integrate the project strategy into their already busy schedules. With time and practice, many of these challenges dissipated and teachers reported them less frequently. We suggest, however, that these are akin to challenges that might be faced when introducing any new tool in a mathematics classroom, tangible or technological. We know that students and teachers need time to become comfortable and familiar with a new tool and its use.

Beyond the use of technology in the classroom, but closely connected with the work done on the project, teachers and administrators indicated that classroom management (specifically keeping students focused on their task), allowing time for productive struggle, supporting student explanations and critique, and understanding the development of numeracy skills proved to be difficult. We addressed many of these topics during our professional learning time; however, we believe that the teachers might have confronted a disequilibrium between the newly introduced high-leverage, research-based practices and those they currently implemented, which teachers commonly experience when introducing new pedagogical approaches into their teaching, whether or not technology is a part of the work. While we recognize that these challenges were indeed real, we also suggest that they were an important component of improving practice.

4.7 Discussion

After two years of study, our findings suggest that there is not just one way to implement the use of screencasting apps, such as EE, in kindergarten–second-grade mathematics classrooms. Instead, we found that the participating teachers used this tool in a variety of ways, depending on their context and on what was most comfortable for them and their students. Some teachers used screencasting tools more frequently than others. Some teachers had students create videos with a partner, while others had them share their videos with a peer. Some classes used screencasts to respond to problems that came from the district-wide curriculum, and in other classes teachers created problems for students to respond to when using screencasts. In some instances, students shared their work with the whole class, and in other instances, they shared it with small groups. Sometimes, students solved a problem directly on the screencast. Other times, students solved a problem, took a picture of their completed work, and then described it. Regardless of the approach, however, we observed commonalities across classrooms.

In all classrooms, students and teachers began to attend to one another's mathematical ideas. Students first began to explain and later justify their mathematical thinking. Because students in every class shared their screencasts with at least one other person, and because students in every class viewed at least one other video each time the tool was used, the children in this study began to consider how they might present their ideas to someone else in the best way. Our findings suggest that the opportunities to see and hear others' work allow students to assess, edit, and re-do their own work. Additionally, because students viewed one another's work and heard one another's mathematical thinking process, they became more comfortable with the idea that in mathematics there is often more than one appropriate approach and sometimes more than one correct solution to a problem. This allowed students to engage in problem solving and persevere through challenging moments.

We observed that teachers in this study began to change their teaching practices as a result of the increased student discourse. As students began explaining their thinking in more detail, teachers began to recognize the need for richer mathematical tasks. Additionally, because of the pre-recorded nature of the screencasts, teachers were essentially forced to engage in wait time. This allowed students to self-correct as they worked through a problem. As students began to solve more cognitively demanding problems and were provided with sufficient time to think through them, teachers realized that their students were capable of more sophisticated mathematical thinking than they previously thought.

Teachers in this study recognized the need to support their students not only with the task of solving mathematics problems, but also with the task of creating a high-quality explanation. Teachers, therefore began creating tools such as sentence starters, checklists, discussion guidelines, and sentence frames. They also began to take time during math class to discuss not just the mathematics, but also the components of a strong mathematical justification.

The fact that the research (observation, survey, interviews, logs) was tightly coupled with ongoing professional learning was critical to our work on this project. Not only did our summer meetings and monthly PLCs provide teachers with a shared, research-informed, vision of high quality mathematics instruction, it also provided them the opportunity to share tools and implementation strategies with one another. This chance to both reflect on and take ownership over their professional learning and teaching practice is, we believe, strongly linked to the outcomes of the study.

4.8 Limitations

One notable limitation of this study is its sample size. Moreover, school-based partners, particularly participating teachers, self-selected to participate. Participation in this study required an intensive time commitment. In addition to allowing researchers into their classrooms, and to completing monthly strategy logs, participants committed to summer professional development sessions, monthly meetings of the PLC during the school year, and pre- and post-observation meeting times. The time required to participate in this study prohibited some teachers from joining the project and others from returning during the second year. Students in this study each had access to 1–1 iPads in their classrooms, which is atypical in many early elementary school classrooms. The work done on this project would be strengthened with additional research including, but not limited to, studies done in different community settings, with larger numbers of participants, in grades beyond kindergarten–second-grade, and in schools with and without 1–1 mobile technology. While we recognize the significant time challenge for all participants in the study, we also strongly believe and other research supports (Attard, 2013; Attard & Curry, 2012) that the professional learning was a critical feature in the design of the study, and that the outcomes would not be possible if this were removed.

4.9 Conclusion

The project's collaborative team of researchers and practitioners believe that the use of screencasting apps in early elementary mathematics classrooms holds significant potential for supporting mathematical discourse among students. Participating teachers reported and researchers observed improved student communication in mathematics, which in turn allowed for changing teaching practices and beliefs, increased use of formative assessment by both teachers and students, more evidence of student self-correction and perseverance, and a more equitable learning environment for all. As one second-grade teacher, Mrs. M, indicated in her strategy log (10/9/2015), "the EE app is great tool for students to share their thinking. If we start students at an early age talking about problem solving in all curriculum areas, it will be natural for them to share their thinking. We will be able to see learning in action as students use their prior knowledge to make connections to new learning. WOW! This is what learning and school is all about!!"

Acknowledgements Supported by the National Science Foundation (grant DRL-1238253). Opinions expressed in this manuscript are those of the contributors and not necessarily those of the Foundation.

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