THE IMPACT OF TEACHER QUESTIONING AND OPEN-ENDED PROBLEMS ON MATHEMATICAL COMMUNICATION

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Abstract This paper reports on an action research project that investigated the ways in which teacher practice impacted students' mathematical communication, particularly in terms of teacher questioning with the use of open-ended problems. Grade level teams in a Title I school were engaged in a professional development model that focused on integrating problem-based lessons that would elicit productive mathematical discussion among students. Results showed that the use of open-ended problems refined teachers' questioning skills and produced more productive student dialogue. Teachers and students also demonstrated more effective communication in general, and teachers specifically were more reflective in their planning and teaching.

Keywords: teacher action research, questioning, open-ended problems, math communication

Introduction

Recent reform efforts are transforming how mathematics is taught in elementary schools. Traditional models for teaching mathematics are being replaced with constructivist, community-based teaching classrooms, increased student expectations around conceptual understanding, and more rigorous standardized achievement measures (McConney & Perry, 2011). One such change includes the explicit emphasis on the role of questioning and communication in mathematics and, more specifically, engaging students to represent mathematical ideas in multiple ways (NCTM, 2014) to generate productive discussion. As such, there is a need for task-based mathematics and instructional practices that produce purposeful mathematical discussions among students in whole and small group settings. Through these practices, teachers can more readily support students' conceptual understandings of complex mathematical ideas and the connections between them (Yackel, Cobb, & Wood, 1991).

The purpose of this inquiry project was to investigate teacher questioning in the context of an open-ended problem-solving environment, and the impact of task-based lessons on student mathematical communication. The project followed the implementation of a problem-solving plan at an elementary school, in which campus mathematics specialists incorporated teacher training covering questioning, the problem-solving process, and the use of open-ended mathematics word problems. Teacher feedback, student artifacts, and personal observations were used to gain insights on the utilization of questioning strategies with pre-selected word problems and their impact on student mathematical communication.

Literature Review

The national and state mathematics standards draw predominantly from sources such as the *Professional Standards for Teaching Mathematics* (1991), *Principles and Standards for School Mathematics* (2000), and *Principles to Actions: Ensuring Mathematics Success for All* (2014). These resources emphasize the importance of mathematical communication in the classroom and the teacher's impact on student responses. For example, the teacher is seen as one who navigates dialogue through the use of questioning strategies that probe deep student thinking. Students have authority and autonomy to question, justify, and engage in productive arguments as well as provide evidence of thinking through various forms of communication such as oral, written, and symbolic text (NCTM, 1991, 2000, 2014). Thus, mathematical communication is not defined as a one-way discourse from teacher to student. Instead, the standards unearth the importance of the interrelationship between student and teacher to use a complex mathematical language that support the connection, analyzation, and expression of accurate mathematical ideas. Thus, the standards encompass a shift towards different research-based criteria for the roles of teacher and student.

Mathematical standards identify the teacher's role as one of orchestrator, facilitator, monitor, and provoker of student explanations, justifications, and arguments. This differs from a traditional model, which customarily begins with teacher modeling of problems and algorithms. Typically, the teacher then guides students through a series of application questions that require students to reproduce steps instead of generating solutions (Cazden, 1988; Barnes, 1976). This initiation-response-feedback model (I-R-F), is still a practiced method, but is no longer sufficient in meeting the current mathematics standards related to communication (Kyriacou & Issitt, 2007). Teachers "must refine their listening skills, questioning, and paraphrasing techniques, both to direct the flow of mathematical learning and to provide models for student dialogue" (NCTM, 2000, p. 197). Moreover, teachers must provide students with opportunities to share their thinking and learn from the thinking of others. For example, students need opportunities to share mathematical ideas in various ways, such as speaking, writing, listening and drawing (Gojak, 2011). Therefore, using strategies that provide opportunities for students to engage in mathematical thinking and communication are a necessity in the elementary classroom.

Studies have shown that purposeful, high-level, problem-based questions help teachers extend students' mathematical language (Di Teodoro et al., 2011; McConney & Perry, 2011; Strom, 2001; Webb, 2009; Webb, 2014). These studies collectively imply that using open questioning, where more than one correct response is possible, as well as asking questions that connect student ideas and probe for further explanation (e.g. "why did you…?" "how could you both…?" and "what if…?"), have been found to increase mathematical communication. In this regard, new areas of curriculum development and training support teachers' questioning strategies by providing research based tools and techniques that support students' metacognitive and communicative skills (Walsh & Sattes, 2011). This includes using open-ended questions, connecting student ideas, and probing student thinking.

Additionally, using open-ended mathematics problems is effective in the promotion of mathematical communication. Often heuristic in nature, open-ended problems provide students the choice to select various strategies, arrive at multiple answers, and perform multi-step operations in different combinations (Clarke, Sullivan, & Spandel, 1992). These diverse options allow students to express their mathematical thinking in numerous forms and engage in valuable dialogue with their teachers and peers. Students who solve open-ended problems are prone to actively participate, express their ideas more frequently, and discuss their solutions with other students. More so, utilizing open-ended problems provides an approach to evaluate higher-order-thinking skills and improve teaching and learning (Becker & Shimada, 1997). Using a combination of effective questions with thoughtfully constructed, multifaceted mathematics word problems may provide an effective way for teachers to increase mathematical communication in their classrooms.

Thus, this action research inquiry project aimed to explore the following questions:

1. How does the use of questioning strategies with open-ended word problems impact students' mathematical communication at an elementary school campus?

2. What classroom instructional practices on this campus need to be modified, based on the study's findings, to improve mathematical communication among students?

Methodology

School Description and Sample. This project was conducted at a Title I elementary school in a large, urban district in the Southern U.S. At the time of the study, the school housed a total of 542 students with the following demographic breakdown: 81% Hispanic, 7% White, 6% Black, 4% Asian, and 2% other. Of the population, 85% of students qualified for free and reduced lunch and 75% were considered to be of low socio-economic status. The school had four kindergarten, four first-grade, three second-grade, four third-grade, four fourth-grade, and three fifth-grade teachers. Of the 22 teachers, 10 were new staff members at the campus. All 22 teachers and their students participated in the problem-solving program that was implemented through this project. Typical case sampling was used to select one first-grade, one second-grade, two third-grade, and two fourth-grade teachers and their students as participants of the project for data collection purposes (Creswell, 2012). We will provide an overview of the program, followed by an overview of the data collection and analysis process.

Campus Goals and Training. In collaboration with administration and teachers, the two campus mathematics specialists implemented a series of initiatives to improve mathematical instruction. One particular area of focus was classroom mathematical communication. This included, but was not limited to the following goals:

- Use effective questioning strategies that support the use of the Texas Essential Knowledge and Skills (TEKS) Process Standards
- Support students' use of the district's problem-solving model
- Provide students and teachers with mathematically-rich word problems
- Support student mathematical communication, defined as the use of discussions, drawings, text, and manipulatives to demonstrate development in mathematical knowledge

The staff development program, *Problem-Solving with a Purpose*, was assembled and presented to teachers at the beginning of the school year to address these objectives and provide teachers with training in three areas: the district's problem-solving model, questioning strategies embedded with the state's process standards, and the use of open-ended word problems. An important objective of the training was to emphasize the need for teachers to support students in becoming problem-solvers that communicate, connect, prove, and reason mathematical ideas (Gojak, 2011). Specifically, through the use of quality questions and open-ended problems, teachers were trained to guide students through the problem-solving process and engage learners in these various forms of mathematical communication. Resources created by the school district as well as other supplemental materials were used to develop the training.

First, information about the districts' problem solving model, Facts-Action-Solve-Think (FAST), was presented to the entire staff. Although the school had used this model for several years, foundational training was necessary due to a high number of new teachers at the campus as well as end-of-year feedback from senior staff. The components of *Facts* (gathering necessary facts), *Action* (selecting an appropriate strategy), *Solve (*finding a solution), and *Think* (explain your thinking in words), were modeled and explained. Secondly, concepts of teacher questioning were presented using Walsh and Sattes' (2011) *Thinking Through Quality Questioning: Deepening Student Engagement* and *Quality Questioning: Research-Based Practices to Engage Every Learner*.

The concepts of quality questioning were then connected to the TEKS Process Standards. The Process Standards emphasize that students should "use multiple representations, including symbols, diagrams, graphs, and language to display, explain, and justify mathematical ideas in various ways" (TEA, 2012). Thus, students need to be engaged in multiple forms of mathematical communication and using questions that align to the TEKS Process Standards may prove beneficial to reach this objective. Teachers analyzed the TEKS Process Standards and participated in grade-level discussions to share ways of incorporating standard-based questioning throughout the various sections of the school's problem-solving model. For example, one process standard states that students should "analyze mathematical relationships to connect and communicate mathematical ideas" (TEA, 2012). Thus, questions such as "can you relate this problem to another problem you have solved" and "can you think of a mathematical equation to match the story?" were considered and discussed for application in the classroom. Furthermore, grade-level word problems and student samples were presented while teachers practiced selecting and creating questions that promoted mathematical thinking and dialogue throughout the FAST process. Examples in the *Solve* stage of the FAST problem solving process included questions such as "how can we draw a model that represents this problem?" and "can you convince your partner that your solution makes sense?" This teacher training activity led to a compiled collection of questions that aligned to the first grade-level open-ended problem that teachers would use in their classrooms.

Lastly, characteristics and examples of open-ended problems were highlighted and discussed. This section of the training focused on the importance of selecting and using mathematically rich word problems that provide teachers with opportunities to ask meaningful questions and engage students in various forms of mathematical communication throughout the problem-solving process. This included ways to engage students in purposeful discussions that provide students with opportunities to reason, connect, explain and justify thinking (NCTM, 2014). Additionally, the school's mathematics supplemental resources, often underutilized, were showcased. The teachers then generated open-ended problems, based on the conceptual support that these materials can provide, to use in their classrooms. The training concluded with an overview of the school's problem-solving plan, termed *Problems of the Month,* which incorporated the concepts discussed in the training.

Problems-of-the-Month Campus Plan. The *Problems of the Month* initiative included a sequence of open-ended problems in grades K-5 for teachers to use bi-monthly in their classrooms along with a district rubric to assess mathematical understanding. A total of 18 problems were selected from the resources, Exemplars' (1999) *Exemplars Differentiated Problem Solving* and Pearson's (2012) *Ready Freddy: Daily Problem Solving* (see Appendix D). The first problem for each grade level along with the initial questions was completed during the training. The teachers were challenged to present the *Problems of the Month*, engage students in the problem-solving process, and use standard-based questioning to promote multiple forms of mathematical communication.

Teachers implemented the *Problems of the Month* in their classrooms were encouraged to use the strategies provided in the training. Teachers modeled the process for the first two months producing teacher samples that were turned in to the mathematics specialists. Subsequently, teachers had the choice to complete the problems in a variety of ways including in whole, partner, and small groups. As students worked through each problem, teachers would select one student work sample from the problem solving session to display on the school's mathematics bulletin board. The result was a monthly board showcasing a collection of completed problems solved in a variety of ways from kindergarten to 5th grade that demonstrated student mathematical representations in a variety of ways. Throughout the year, teachers reflected on their questioning skills and observed their students' mathematical progress. Teachers informally discussed their experiences in monthly meetings facilitated by the campus mathematics specialists.

*Data Collection***.** Three types of data were collected during the seven-month project. The first artifact was a collection of student work samples. The artifacts were taken from the mathematics bulletin board where teachers displayed their selected student pieces. The second artifact was a set of five teacher surveys ranging from first through fourth grades. The surveys were given at the end of the school year, and focused on teacher beliefs about questioning strategies as well as their perceptions of their students' mathematical communication during *Problems of the Month*. Half of the survey questions were in open-ended format. The remaining questions included a 5-point Likert scale; these were sorted by question and quantified (see Table 1). The last artifact was an assembly of field notes based on observations during the monthly reflective meetings with teachers.

Data Analysis. Data, which included student work, teacher surveys, and field notes, were analyzed using thematic analysis. After examining each artifact, we selected our units of analysis for each component of the data. The student work samples were grouped by teacher and placed in chronological order. We searched for patterns that emerged in the data; including both positive and negative evidence of students' mathematical representation in written, modeled, and other text form. More specifically, we categorized the ways that students were representing their thinking, and the strategies that they were using in the problem solving sessions. We did not use a predetermined set of criteria for this analysis; rather, the strategies and representations emerged from the work itself. We looked for sophistication in representation over time, abstractions, and strategy development, especially as these related to communication of mathematical ideas. For example, we found that open-ended problems encouraged more and diverse methods of communication over time, and elicited multiple representations. Teacher surveys were transcribed and re-organized by question to code within a focused topic. We paraphrased the responses separately and then met to confirm our results. Thus, the findings were double-coded for consistency. Themes were emergent, but we also utilized constant comparison throughout the data analysis process. Field notes were analyzed similarly and provided triangulation for emergent themes.

Results

A major theme that appeared consistently in the analysis was aligned to the notion of *opportunity*. Our observations, teacher surveys, and student work samples demonstrated that *Problems of the Month* provided teachers not only more time, but instructional ventures to explore in-depth the open-ended problems, ask meaningful questions, and engage students in various forms of mathematical discourse. These learning opportunities impacted both teachers and students' abilities to communicate mathematics in a multitude of ways. In this section, the findings are presented by thematic topic with support from work samples and the results of the end-of-study teacher survey shown below (Table 1).

Table 1. Teacher Beliefs about Questioning and Student Communication

Question	Strongly Agree	Agree	Disagree	Strongly Disagree	Did Not Use/Uncertain
1. The POM supported mathematical class discussions	0	5	0	0	0
2. The POM provided opportunities to probe student thinking	2	3	0	0	0
3. The POM provided opportunities to connect student mathematical ideas	1	4	0	0	0
4. The POM provided opportunities to ask open-ended questions	2	3	0	0	0

7. The POM increased mathematical communication in my classroom	1	4	0	0	0
The POM improved mathematical communication in my classroom	1	4	0	0	0

Teacher Questioning. A key finding that emerged from the data showed that using open-ended problems with standards-based questioning refined teachers' questioning skills. Teachers had to think critically about their selection of questions since the nature of the problems encompassed multiple solution routes. The majority of teachers who were surveyed felt that the *Problems of the Month* positioned them to ask better questions. One particular teacher stated, "many of the problems were multi-step, and that challenged me to scaffold their learning and understanding at every step at which they had difficulty." Another teacher revealed that she felt her questioning skills improved throughout the year because she was "able to ask many open-ended questions to discuss the different ways to work out the problems." Furthermore, our field note observations revealed that since the mathematics problems were not easily solvable, teachers had to think, plan, and be selective of the questions they asked; these experiences helped to improve their own inquiry skills.

Secondly, the data revealed that using open-ended problems allowed teachers to ask diverse and specific types of standard-based questions to support mathematical communication. Out of the five teachers surveyed, two strongly agreed and three agreed that *Problems of the Month* provided opportunities to ask questions for specific purposes. One teacher mentioned, "I was able to ask many open-ended questions and evaluation questions. Since there were different ways to solve the problems, it was easy to ask quality questions." This teacher made a distinction about question types, noting differences among the intention of the question, in this case, to evaluate student knowledge. This idea is further supported by another teachers' reflection. "I think the problems of the month improved my questioning skills because it allowed me opportunities to ask more probing questions, which allows me to observe how my students can and can't support their thinking." This teacher also categorized a type of question, probing, for a specific purpose, to look at the strengths and challenges of students' ability to support their math ideas. However, not all teachers felt that the problems of the month sharpened their questioning skills. For example, a teacher participant noted that the problems of the month did not greatly impact her questioning skills, but it did allow for more opportunities to have enriching math conversations with students. In all, identifying and using question types purposefully helped teachers analyze and evaluate student thinking throughout the problem-solving process.

Student Communication. Teachers who used a combination of quality questioning with open-ended problems created a learning space to engage students in various forms of mathematical communication. The findings showed that the multiple choice of strategies and solutions were critical factors in student discussion, symbolic model creation, and written mathematical communication.

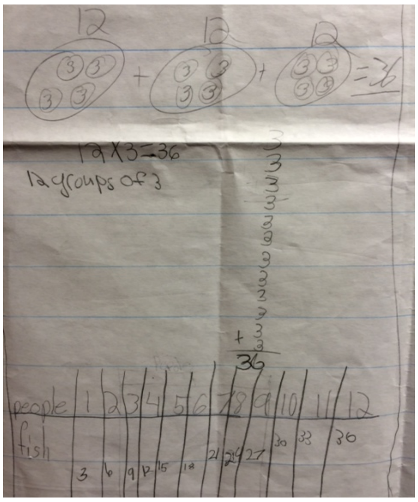
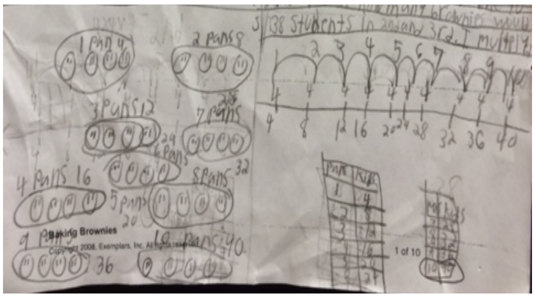
Mathematical Discussions. One form of communication that was positively impacted was student dialogue with teachers and peers. The data showed that during *Problems of the Month*, students used mathematics language to discuss different solutions, strategies, and generate new ideas. The teacher participants noted that they used the multiple solution paths of the open-ended problems to engage students in rich discussion. The survey demonstrated that 4 out of 5 teachers agreed that the word problems provided opportunities for students to connect mathematics ideas. Most teachers had similar responses, acknowledging that the choices the mathematics problems offered were a contributing factor to student discussion. One teacher's observation reinforces this notion:

> "The problems of the month enabled my students to have discussions about why they did certain operations. They would engage more actively when they were trying to support their answers. I think the discussions led them to see how others approached the same types of problems. They realized that there was more than one way to solving a problem. It was very enlightening observing their discussions."

Along with the teacher survey results, the field notes from informal discussions revealed that overall, teachers felt that the *Problems of the Month* allowed for multiple opportunities for mathematical discussions before, during, and after solving the open-ended problems. A teacher comments that the problems lend themselves to "discussing different problem-solving and planning strategies," while another teacher adds that since there were many ways to solve the problems, it "helped generate new ideas and approaches to solving." More so, teachers felt that students had a time and space to participate in discussions and share their thinking with others.

Multiple Representations. Students' increased production of mathematical models and symbols to communicate mathematical thinking was also seen in the data as the year went on. Teachers who asked questions that encouraged multiple forms of symbolic representation (e.g. "can you show me a different way?", "who can draw a different model?") impacted student responses in an assorted of ways. Two examples are seen in Figure 1 (enlarged figures can be found in Appendix A).

Figure 1. Samples of 3rd grade work.

3rd Grade, Group Activity	3rd Grade, Individual Activity
	

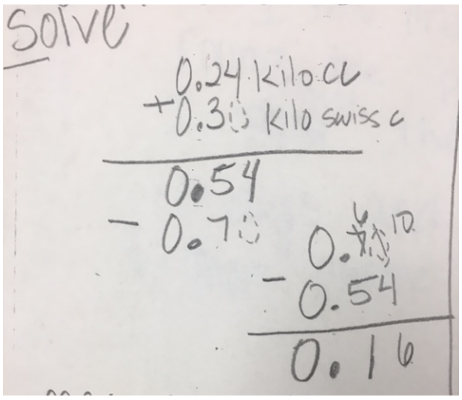
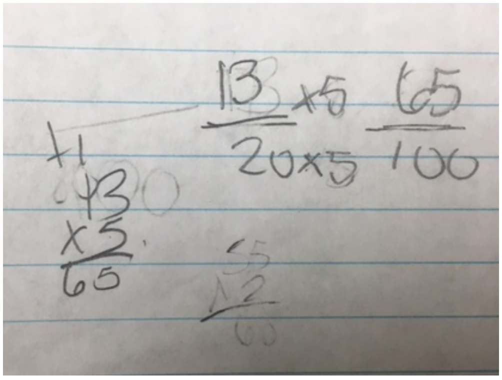
This idea was also visible in the teacher survey, were every teacher felt that the *Problems of the Month* provided a unique opportunity to engage and expose students in creating multiple mathematics models. A teacher emphasizes this notion by claiming the following:

> "The POM was an excellent tool for problem solving with pictures and drawings. Before students drew the picture--the problem was very abstract. I noticed that for my students who drew pictures, it was much easier for them to solve the POM's. This is an excellent strategy that I reinforce daily."

Furthermore, the student examples discussed above are representative of student work where the teacher not only spent time guiding students through the process of developing multiple mathematics models, but also setting expectations for students to show more than one representation of their solutions. On the other hand, the data showed that teachers who did not model the creation of multiple representation nor set the expectation to produce them had less intricate student samples in regards to multiple forms of mathematical representations, as shown below.

In Figure 1, the teacher asked her third grade students to share ideas and create various ways to represent solutions to the problem. The students worked in groups, compared strategies and selected different ways to show their mathematics thinking. Through teacher scaffolding and use of questions that connected student ideas, the learners were able to discuss and create models, tables, and number sentences that represented their solutions. The second example displays an individual student's work with similar results. This third grade student used a table, model, and number line to communicate his method and solution.

Figure 2. Teacher and Student Solve Samples

5th grade Teacher, September 2013	5th grade student, March 2014
	

This selection shows a fifth grade teachers' modeled *Problem of the Month* at the beginning of the year compared to an end of year student sample from the same class. In particular, the *Solve* section of the teacher-modeled problem shows only an algorithmic solution, with little to no detail of textual representation of the problem or solution strategy. The student sample is strikingly similar in regards to using only the operation to arrive at the solution with minimal emphasis on communicating mathematical ideas using multiple models and strategies.

Mathematical Writing. Student mathematics communication in the form of writing was also positively impacted through the use of the Problems of the Month and teacher questioning. Teachers who probed student thinking and encouraged students to write their procedures and justification increased the quantity and quality of their students written explanations. When asked how the *Problems of the Month* impacted student writing, teachers responded positively. One teacher made the following statements.

> "The problems of the month positively impacted my students writing skills because they had to utilize math vocabulary to support their answers and their way of thinking. They had to be very specific on their steps and thus made them think more carefully about the steps they took in solving problems."

Another teacher added, "writing in detail about their problem solving not only helped their writing skills, but helped students remember and think about steps they took to solve problems." Accordingly, students not just solved problems, but reflected and explained their thinking in written form. The findings revealed that teachers who used open-ended problems and probed thinking through questioning increased the quality of their students written explanations regarding the problem solving process. An example is seen through a fourth grade student's work over time (Appendix C).

Here, a fourth grader's samples are sequenced chronologically. The artifact shows that both the student's quantity and quality of their written explanations increased throughout time. This student not only wrote more as time progressed, but provided more detail in the method taken to solve problems, the operations and strategies that were chosen, and demonstrated more elaborate explanations regarding their mathematical justifications. This student's teacher further added that students in her class had the time during *Problems of the Month* to explain their thinking regarding mathematical concepts, which helped with their overall academic writing.

The results of the study were multifaceted with implications for mathematics classrooms, districts, teachers, and administrators. Overall, in the context of problem solving, student communication about mathematics occurred at a higher level. Moreover, teacher communications, such as questioning techniques, ability to engage students in meaningful discussion and connect student strategies, were improved in frequency of specific question types. More so, the results demonstrated the mediation of certain teacher moves related to choices around student grouping and questioning techniques.

Discussion

Overall the findings showed that classroom teachers who used the *Problems of the Month* with diverse questioning to engage students in discussion, model-making, and written form, had positive feelings towards the use of open-ended problems. Consequently, their students showed increased improvement in all three forms of mathematical communication. This has implications for classroom teachers in that it supports the notion that teaching mathematics through open-ended problem solving sessions, as opposed to traditional lecture and worksheet driven instruction, increases not only student mathematical understanding but also teacher practice. Further, when teaching mathematics through problem solving, teachers are inherently and continuously assessing students by circulating, listening, and asking questions about thinking.

The implications at the district level are similar – mathematics curricula should be written with a problem solving focus in order to support student understandings and pedagogical development. Teachers should be trained in this type of instruction, and should be able to elicit mathematical ideas from students. This type of teaching is more equitable because the students are doing the cognitive work, and therefore maintain a greater level of power in the classroom. Rather than the teacher "holding" the knowledge, it is co-constructed through discussion.

Teacher education programs have adopted this type of pedagogy more readily, but should be conscious to place student teachers in classrooms where mathematics is taught through problem solving. Further, more research is needed to understand the development of teachers as problem solvers.

Limitations and Challenges

Though the results of this study overwhelmingly support the practice of teaching mathematics through problem solving at the elementary school level, there were some challenges that arose and should be addressed. Many of these were at the campus level, but do speak to the fact that success in implementation is based on many factors, some of which are out of a teacher's immediate control.

Campus Challenges. Although the use of open-ended problems with standard-based questioning proved to have positive results, classrooms showed different levels of quality in their work. Mathematics specialists' field notes and examination of all student work helped form a better understanding of the varied degrees of mathematical communication. Teacher expectations, student grouping, and years of experience were factors that impacted the quality and quantity of student mathematical communication. One such finding revealed that teachers who did not set high expectations at the beginning of the year through their modeled samples had lower mathematical communication than teachers who set high expectations. Teachers who took time to engage students in discussion, used questioning to connect ideas, and modeled correct forms of detailed representations had superior results. Additionally, the research showed that teachers grouped students in different ways; students worked in pairs, small groups, or individually. This led to varied degrees of mathematical discussion. Students who worked in pairs or small groups engaged in more peer dialogue than students who worked on the activities individually. The grouping of students also led to exposure to varied forms of mathematical communication from other peers.

Furthermore, the findings revealed that first-year teachers had lower student mathematical communication compared to the classrooms of more experienced teachers. Student samples from two first-year teachers exposed their misunderstanding of the district's problem solving model as well as less detailed work, which in turn, negatively affected their students' mathematical communication.

Another area of concern dealt with the organizational aspects of the *Problems of the Month*, mainly seen with alignment and frequency issues. The teacher survey revealed that although the *Problems of the Month* were seen as beneficial for student mathematical communication, the sequence of the plan did not always align with the district timeline. This caused some issues for teachers, since at times they were solving challenging problems that required skills that were not yet taught. Although it pushed students to solve problems using innovated ways, teachers expressed concern due to the time and challenges it created. Teacher feedback also revealed that completing the *Problems of the Month* bi-weekly caused some setbacks in keeping up with the district timelines and assessments. Since the open-ended problems required ample time, teachers often either shortened or condensed the daily district mathematics lessons.

Campus Changes. The implementation of the problem-solving plan proved to enhance teacher questioning skills and student mathematical communication; however, this inquiry also exposed campus issues that require further action. Thus, modifications to the campus problem-solving plan and staff trainings opportunities were created to respond to the research findings.

First, the selected *Problems of the Month* were re-evaluated and modified to align with the district timeline. This change has helped teachers present relevant mathematics problems to students after they have acquired some background knowledge and skilled practice. Additionally, the database of problems is available to teachers for modifications to the plan, thus the goal is for teachers to consider the selected problems, but also allow for teacher autonomy. Secondly, the *Problems of the Month* changed from a bi-weekly to a monthly activity. Although the research exposed the benefits of standard-based questions and open-ended problems, the *Problems of the Month* are not the only avenue to accomplish this positive impact on mathematical communication. A campus goal for next year is to encourage teachers to use the *Problems of the Month* as opportunities to engage students in deep mathematical understanding and communication, but the expectation is to apply the research-based strategies across the mathematics curriculum. Furthermore, the mathematics specialists have developed a plan to address new teacher misconceptions by modeling effective strategies and providing support for novice teachers throughout the year.

Lastly, a focus for next year's staff development will incorporate training relevant to the research findings. This includes sharing anonymous examples of quality student work and teacher models with all staff to expose and discuss effective strategies to further enhance mathematical questioning and student communication at the campus.

Conclusion

The procedures and findings of the action research project add to the educational literature by exposing valuable considerations for administrators, math specialists, and teachers to develop and support mathematical communication at the elementary school level. First, the need for administrators and math specialists to cultivate campus-wide goals and support staff in the implementation of reform-based mathematical instruction is important. Specifically, the results showed that the math specialists' role of setting initiatives, conducting staff development, and providing mathematical resources were factors that supported teachers in the implementation of effective instructional strategies. Thus, math specialists need to stay current with mathematical practices and collaborate with administrators to dispense mathematical knowledge to classroom teachers.

Secondly, the project disclosed instructional techniques that benefit educators who work with elementary school students. The use of open-ended problems in combination with meaningful questioning proved to increase the quality of teachers' questioning skills and reflective planning. Hence, creating spaces for teachers to discuss and collaborate with other educators is a central component to enhance instruction. Likewise, challenging and encouraging teachers to implement teaching techniques in various combinations improves instruction and learning. Furthermore, practicing this strategy was also found to increase students' mathematical dialogue, written explanations, and symbolic representation. Thus, the results expose the benefits of using this reform-based strategy to help students explain and justify their mathematical reasoning through multiple avenues.

Overall, the project revealed that the integrated use of standard-based questioning with open-ended problems positively impacted the campus' mathematical communication. Teachers enhanced their questioning skills and engaged students in mathematical discussions, model-making, and written explanations. Moreover, the *Problems of the Month* provided teachers the time to ask diverse sets of questions and guide students through complex problem solving. Students were given opportunities to engage with teachers and peers in dialogic interactions that led to the co-construction of strategies and solutions in multiple forms. The research further showed that each classroom varied in degree of mathematical productivity. Factors such as teaching experience, grouping, and classroom expectations impacted the quality and quantity of mathematical communication.

The findings led to develop a plan of action to further support the use of open-ended problems and quality teacher questioning at this campus.

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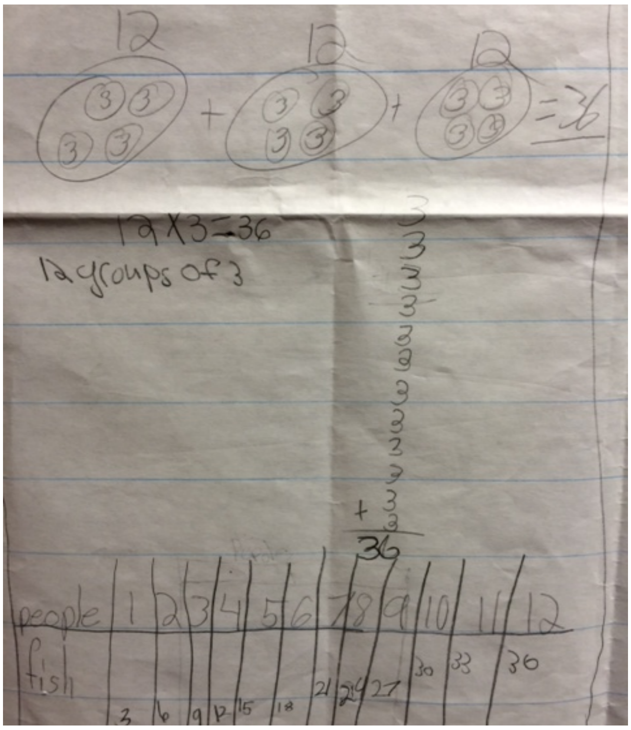
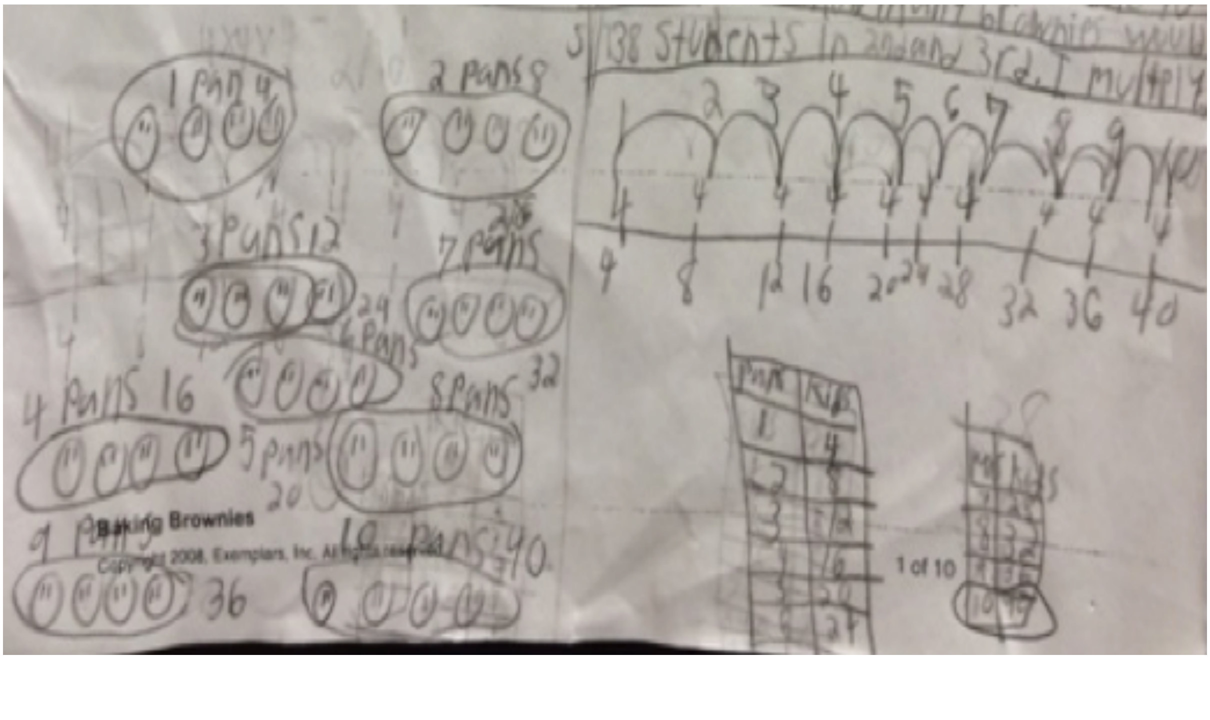
Appendix A: Examples of Third Grade Work as Seen in Figure 1

Group Activity

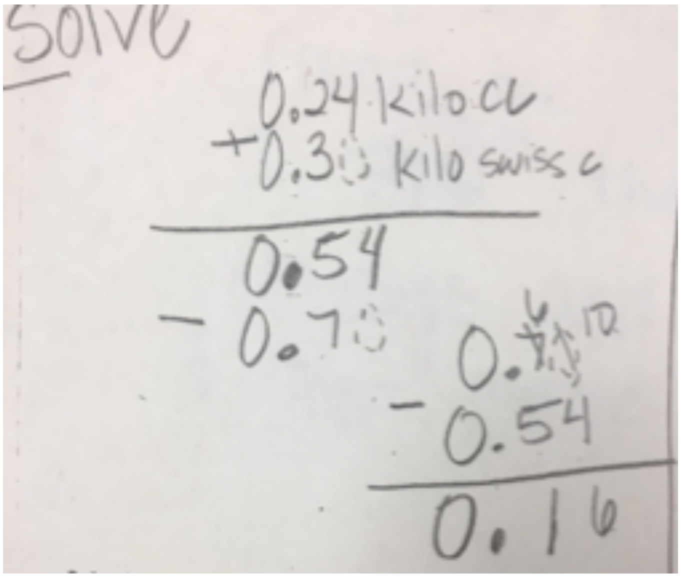


Individual Activity

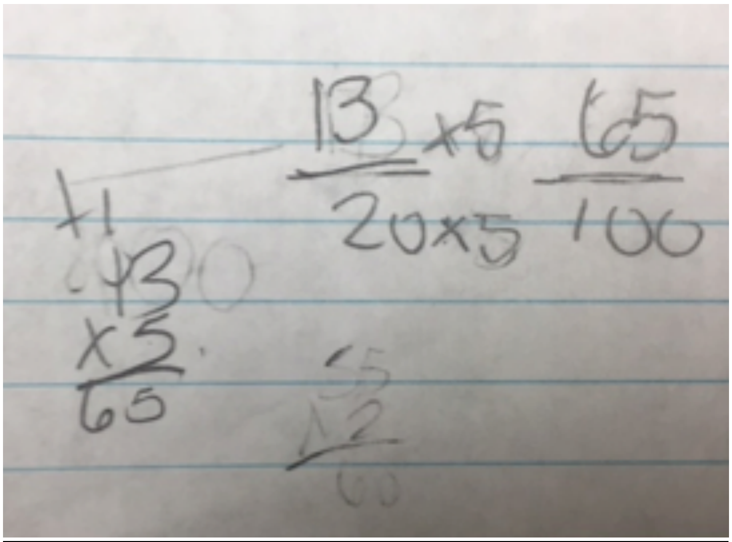


Appendix B: Teacher and Student *Solve* Samples as Seen in Figure 2

<u>5th Grade Teacher - September 2013</u>

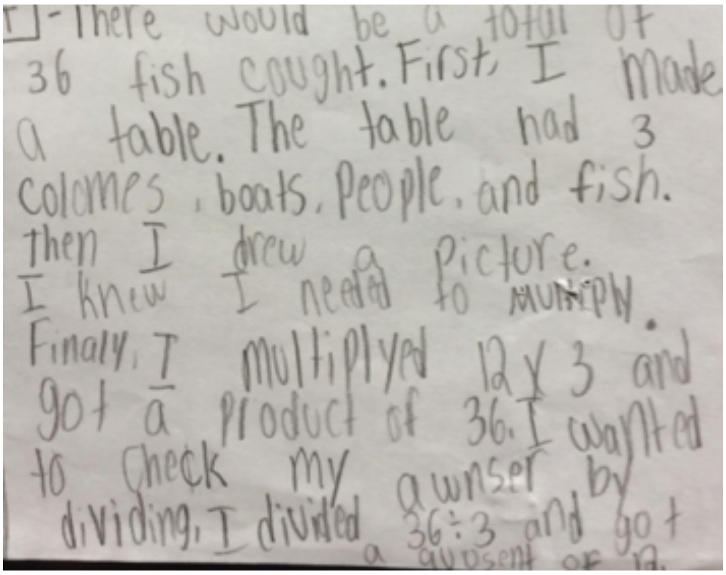


<u>5th Grade Student - March 2014</u>

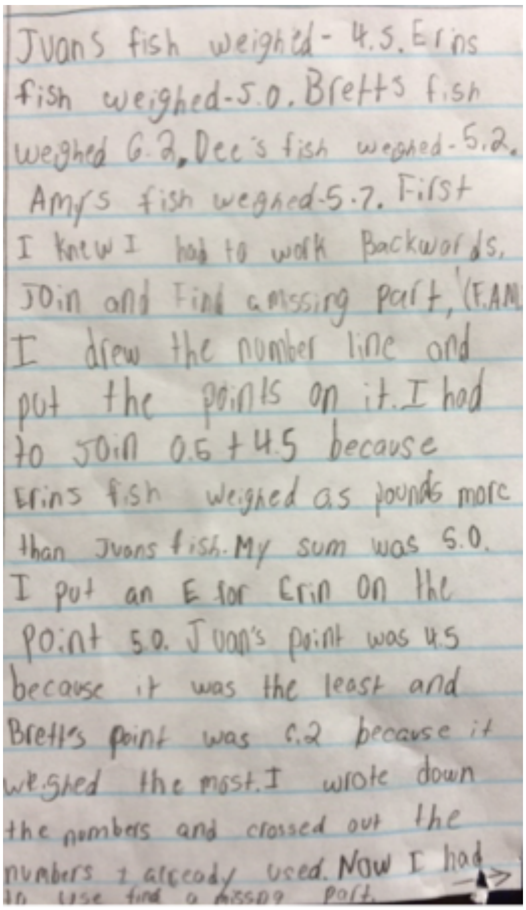


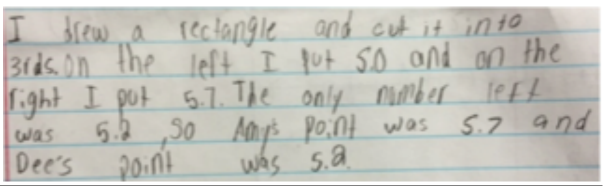
Appendix C: Samples of a 4th Grader's Work Over Time

October 2013


[ ]- There would be a total of 36 fish cought. First, I made a table. The table had 3 colomes, boats, People, and fish. then I drew a Picture. I knew I neeted to multiply. Finaly, I multiplyed 12 x 3 and got a product of 36. I wanted to check my awnser by dividing. I divided 36 ÷ 3 and got a quosent of 12.

January 2014


Juans fish weighed - 4.5. Erins fish weighed-5.0. Bretts fish weghed 6.2, Dee's fish weghed-5.2. Amy's fish weghed-5.7. First I knew I had to work Backwords. Join and Find a missing part, (F.A.M I drew the number line and put the points on it. I had to join 0.5 + 4.5 because Erins fish weighed .5 pounds more than Juans fish. My sum was 5.0. I put an E for Erin on the point 5.0. Juan's point was 4.5 because it was the least and Brett's point was 6.2 because it weghed the most. I wrote down the numbers and crossed out the numbers I already used. Now I had to use find a missing part.


I drew a rectangle and cut it into 3rds. On the left I put 5.0 and on the right I put 5.7. The only number left was 5.2, so Amy's point was 5.7 and Dee's point was 5.2.

Appendix D: Samples of *Problem of the Month*

(Adapted from *Exemplars*, 1999 and Pearson Learning Solutions, 2012)

K-2nd Grade Problems

1. Class Pets
FAST Freddy's class has 7 goldfish. Help FAST Freddy put them into 3 bowls.

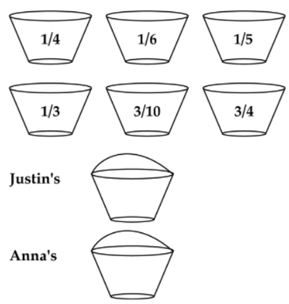
- Each bowl must have at least 1 goldfish
- No bowl may have more than 3 goldfish

How many fish would you put into each bowl?

2. Coins
You and your friend are on your way to the store to buy some milk. When you get there your friend realizes that she is 40 cents shorts of what she needs and asks if she can borrow some money from you. You have pennies, nickels, dimes and quarters. What are different ways you can combine these coins to loan your friend 40 cents?

3rd-5th Grade Problems

1. Lugging Water
Justin and Anna were camping with their family. They joined their dad at the camp water pump where he had partially filled 6 containers. The containers had no handles. As he filled each one, he labeled the fractional amount to which each container was filled. The amounts are shown below.



Justin and Anna each had a container that was the same size as the ones their dad filled, but theirs had handles. Their task was to pour the water from the 6 containers into their 2 containers so they could easily carry the water back to camp. Which containers should Justin and Anna pour into each of their containers so together they can transport the water in one trip? Show your math thinking.

2. Fish Dilemma
There are 3 boats. There are 4 people fishing on each boat. Each person may catch up to 3 fish. How many fish could be caught?

Be sure to explain your reasoning using words, numbers, diagrams and/or charts.