Fostering Mathematical Communication in Primary Mathematics Classroom: A Study on Classroom Teachers

Defne Yabaş and Sertel Altun

Abstract

Higher order thinking skills are of preliminary importance for today' societies. Students need to engage in meaningful learning activities to develop these skills. Creating a fruitful mathematical communication environment, where students express their ideas about their mathematical understanding, is also essential for keeping cognitive demands of mathematical tasks high. The study aims to enhance teachers' skills to foster mathematical communication in their classrooms to maintain the cognitive demand of the tasks high. Within this case study data was analyzed using content analysis. Results of the study show that enhancing mathematical communication in classroom is essential for monitoring students' understanding, and using strategies and talk moves to enhance mathematical communication has a role by maintaining the level of the cognitive demand.

Keywords: Mathematical communication, cognitive demand, mathematics instruction

Introduction

Fostering mathematical thinking skills of children has become an important challenge for 21st century classrooms. Higher order thinking skills such as problem solving, reasoning, analytical thinking, etc. are of preliminary importance for today's societies. To be able to master in complex thinking skills students need to engage in mathematical activities, which focus on meaning, understanding and making connections. This kind of mathematical tasks and activities encourage students to gain experience with higher order thinking skills. A typical mathematics lesson consists of several mathematical tasks focusing on specific mathematical ideas. Stein and Smith (1998), define a mathematical task as a segment of classroom activity with the purpose of emphasizing a particular mathematical idea. Doyle (1988) also indicates that tasks form the basis of students' learning.

Each mathematical task demands students to employ different levels and processes of cognitive skills. That is, while some tasks only require students to do some calculations, in others students are required to use their more complex thinking skills such as problem solving and reasoning (Stein & Smith, 1998). Focusing on different kinds and levels of cognitive skills, each task also gives students an implicit message about the nature of learning mathematics. For instance, tasks requiring procedures without connections and tasks stimulating students' conceptual understanding include

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different kinds of learning experiences, and therefore, different kinds of messages for students about how people learn mathematics.

In contemporary mathematics curricula students are required to engage in higher order thinking activities through various tasks. Higher order educational objectives such as problem solving, reasoning, building connections, synthesizing take an important place in curricular materials. However, it is not always the case that tasks are implemented exactly as planned as in textbooks, lesson plans, etc. In other words, a mathematical task, which is designed for enhancing complex thinking skills, can result in students carrying out procedural operations. From this point on, Stein and Smith (1998) developed a Mathematics Task Framework to monitor how the cognitive demand of a task evolves in classroom implementations through different phases of instruction.

In Mathematics Task Framework factors associated with maintenance and decline of the cognitive demand is indicated. Scaffolding, students' monitoring their own progress, justifications, explanations, questioning, comments and feedback and frequent conceptual connections (Henningsen & Stein, 1997) are associated with the maintenance of cognitive demand and also point out the importance of mathematical communication in the classroom. Studies emphasize mathematical communication as an important classroom factor to foster mathematical thinking skills (Brendefur & Frykholm, 2000; Franke et. al, 2009; Pape, Bell & Yetkin, 2003). Communication is also important for developing students' conceptual understanding, thinking, problem solving and reasoning skills (Jung & Reifel, 2011). These studies suggest that cognitive demand and mathematical communication have a strong connection by implementing mathematical tasks in classroom settings. In other words, creating a fruitful mathematical communication environment, where students express their ideas about their mathematical understanding, is also of essential importance for keeping the cognitive demands of students high. Teachers shape the discourse in their classroom not only by the way they allow the discourse to develop, but also in the tasks they choose and the learning environment that is created for students (Kysh, Thompson, & Vicinus, 2007; Varol & Farran, 2006). In other words, they have an important responsibility both designing high quality tasks and engaging students in fruitful mathematical communication.

In this vein, the purpose of the study is to enhance teachers' skills to create a mathematical communication atmosphere in their classrooms in order to maintain the cognitive demand of the tasks high. Research questions of the present study are stated below:

1. What are teachers' understandings of mathematical communication in classroom settings?
2. How do communication moves influence the maintenance and decline of the cognitive demand?

Conceptual Framework

Cognitive Demand

A typical instructional setting in a mathematics classroom consists of mathematical tasks, which are defined as segments of classroom activities focusing on teaching a particular mathematical idea (Stein & Smith, 1998). Doyle (1983, p.161) indicated that 'tasks influence learners by directing their attention to particular aspects of content and by specifying ways of processing information'. From this perspective, one can infer that cognitively demanding tasks in current mathematics curricula aims at both engaging students in complex thinking skills and enhancing their dispositions towards learning mathematics as a form of using higher order thinking skills. Although the majority of curricular materials contain cognitively demanding tasks, it is very common that during the course of implementation, these tasks decline into tasks requiring lower level thinking processes than desired at the beginning (Stein, Grover & Henningsen, 1996). To understand the factors associated with maintenance and decline of a mathematical task, Mathematical Task Framework is developed, which shows a task's evolution during the course of implementation (see fig.1).

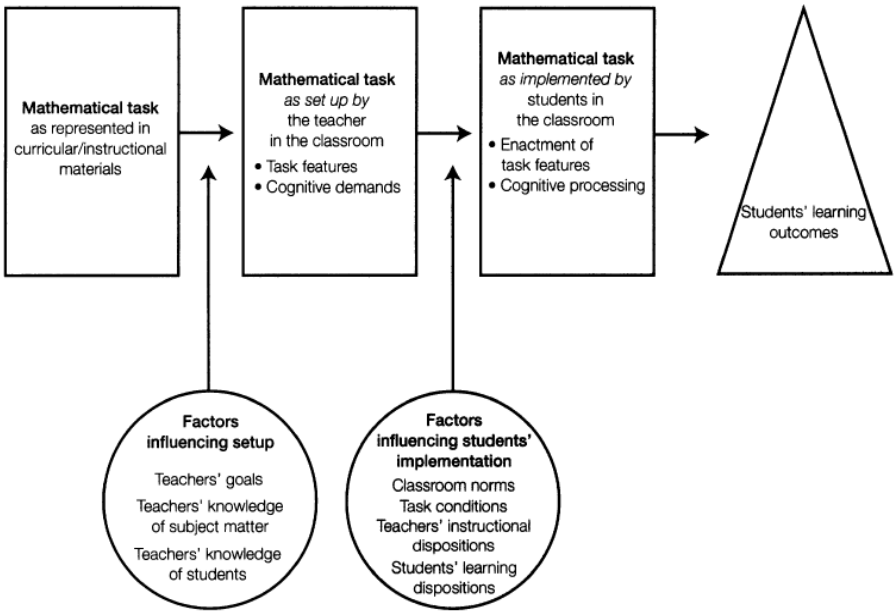

Figure 1. Mathematical Task Framework

Various task-related factors can be effective on maintenance and decline of a mathematical task during the classroom implementation through three different phases: (1) task as represented, (2) task as set up by the teacher and (3) task as implemented by students (Stein & Smith, 1998).

To analyze the level of cognitive demand of a task The Task Analysis Guide is used. There are two low and two high levels which are indicated below (Stein & Smith, 1998):

Lower Level Demands
1. Memorization
2. Procedures without connections

Higher Level Demands
3. Procedures with connections
4. Doing mathematics

Mathematical Communication

In a classroom environment where a fruitful mathematical communication takes place, students are expected to listen, comment and reflect on their friends' mathematical thinking (Pape, Bell & Yetkin, 2003). Chapin, O'Connor and Anderson (2003) defined effective mathematical communication as "a respectful but engaged conversation in which students can clarify their own thinking and learn from others through talk" (p.5). Cooke and Buchholz (2005), similarly, described mathematical communication as students' effective communication of their mathematical thinking process to their peers and teachers. The purpose of discourse is to develop students' understanding through open-ended questions and allow students to make their own contributions. Mathematical talk, fostered by these open-ended questions engages students in the mathematical concept and allows student contributions to be validated through multiple solution paths (Piccolo, Harbaugh, Carter, Capraro, & Capraro, 2008).

Although there is a wide consensus on the need of designing cognitively demanding tasks, which require students engage in higher order thinking processes, it is still important to do research on factors associated with the implementation of those tasks. A considerable amount of research on cognitive demand emphasizes mathematical communication as a factor for maintaining the high level of the tasks. Factors, such as scaffolding, students' monitoring their own progress, justifications, explanations, questioning, comments and feedback and frequent conceptual connections (Henningsen & Stein, 1997) are directly associated with mathematical communication in the classroom. For instance, Pape, Bell and Yetkin (2003) used mathematical communication to improve the below mentioned skills of the students:

- Drawing connections between concepts
- Developing ways of thinking mathematically
- Developing multiple approaches to problem solution
- Describing solution strategies
- Observing and monitoring their own strategies

Reviewing the conceptual framework, it can be inferred that to achieve the higher order objectives of mathematics education it is important to design and implement cognitively demanding tasks. In addition, mathematical communication in the classroom is an essential component of implementation, which helps teachers to maintain the level of the tasks.

Method

Research Design

The study is a case study design using qualitative data. According to Creswell (2012), qualitative methodology is suitable for addressing research problems in which researchers do not know exact variables affecting the phenomenon. Therefore, qualitative methodology includes deeper exploration techniques to infer variables framing the central phenomenon. The case study has a flexible research design, allowing the researcher to retain the holistic characteristics of real-life events while investigating empirical events. Case studies also help researchers investigate phenomenon within its real-life context, in which multiple sources of evidence are used (Yin, 1984, p. 23).

Participants and Procedure

Participants of the study were two 4th grade teachers teaching in a private school in Istanbul in 2015-2016 academic year. One of the teachers is female and the other one is male. Both were experienced classroom teachers (5-10 years).

The study was carried out through five meetings with teachers, which are described below:

- 1st meeting: Sharing the purpose and the procedure of the study.
- 2nd meeting: Pre-observations and pre-interviews with teachers
- 3rd meeting: Introduction to mathematical communication (background information, classroom videos, lesson plan ideas)
- 4th meeting: Preparing actual lesson plans under the supervision of the researchers.
- 5th meeting: Implementation of the lesson plans, post-interviews.

Data Collection

The data was collected via semi-structured interviews with teachers and classroom observations done by the researcher. The interviews with teachers took place before and after implementation. The pre-interview consisted of in-depth questions about teachers' preliminary perceptions of mathematical communication. Questions are aimed at exploring teachers' definitions of mathematical communication and whether they are aware of its usage and benefits. The post-interviews included questions related with teachers' views about strategies to enhance mathematical communication, difficulties they experienced and their suggestions for further implementations. For both interviews an interview guide was prepared by the researcher and later revised by five experts on the field of curriculum and instruction to ensure the validity and reliability of interview questions. The questions in the interview guide were used as a starting point for further discussion about the topics raised. The interviews lasted approximately 20-30 minutes. Each interview was audio-taped. The participants were informed about the research process and assured that the information they give will be kept confidential.

The researchers did classroom observations before and after the implementation. During the implementation of the lesson plan developed by the research process, the 40 minutes lessons of each teacher were videotaped. Researcher also took field notes during classroom observations to underline the essential parts of the lessons. Interviews with teachers, classroom observations and researchers' field notes served as multiple data sources to contribute the credibility of findings.

Data Analysis

After finishing the interviews the audio recordings were transcribed. The transcriptions were read many times and then classified accordingly to identify the themes. The analysis of data is done manually. For the analysis, steps of (1) exploring the general sense of data, (2) coding the data and (3) specifying the themes were followed (Creswell, 2012).

The video-recordings of classroom observations were also transcribed. After the transcriptions the level of cognitive demand was determined using the Task Analysis Guide (see fig.2) (Stein, Smith, Henningsen & Silver, 2000). Coding was done according to descriptions of the levels specified in the guide. The transcriptions were also analyzed in detail to explore which communication moves of teachers affected the maintenance and decline of the cognitive demand of the mathematical task.

	Level	Description
High	(4) Doing mathematics	Exploring novel mathematical ideas and engaging in complex, mathematical thinking and reasoning strategies such as conjecturing, justifying representing, or looking for patterns. Tasks typically involve only a few problems.
	(3) Procedures with connections to meaning	Using formulas, algorithms, or well-defined procedures and understanding why they work, making sense of the procedures in relation to mathematical concepts. Tasks typically involve only a few problems.
Low	(2) Procedures without connections to meaning	Using formulas, algorithms, or well-defined procedures that have been previously learned or exemplified without providing conceptual explanations. Tasks can involve dozens of similar exercises.
	(1) Memorization	Committing facts, rules, or definitions to memory or reproducing previously learned facts, rules, or definitions without the use of a procedure. Tasks can involve dozens of similar exercises.

Figure 2. Task Analysis Guide.

Results

Results for First Research Question

Results for the first research question were categorized around three broad thematic topics: (1) Mathematical communication for monitoring students' understanding, (2) facilitating students' talk, (3) benefits, difficulties and limitations.
Theme One- Mathematical communication for monitoring students' understanding

When teachers were asked to describe positive aspects of the lesson plan they implemented both of the teachers consistently indicate that enhancing mathematical communication in classroom enables teachers monitor students' understanding about a particular concept more easily. Teachers pointed out that with the help of the discussion in the beginning of the lesson plan they can identify students' misconceptions early in the course of the lesson. "I've noticed students' common misconception right at the beginning of the lesson, thanks to the introductory conversation we made" and "I had opportunity to see and restructure misconceptions of the students." were among their assertions underlining this aspect.

Teachers also indicate that they can also identify which student can express his/her understanding more effectively and how they can build on their friends' understandings. "Students had opportunity to make interpretations and to share their opinions" and "We can observe classroom dynamics more easily" are among the teachers' expressions by explaining this aspect of mathematical communication in detail.

Theme Two- Facilitating students' talk

Teachers also gave answers for how to facilitate students' talk and discussions in classroom and which strategies are mostly effective to encourage students to express themselves. Both teachers find sentence frames provided for students to facilitate their expressions most effective by encouraging students to share their answers. "Sentence frames helped students express their ideas more easily" and "Sentence frames are different from other lessons we plan" were their statements supporting this argument. Classroom observations of the researcher also supported this aspect. Students used the sentence frames hanged on the wall willingly, and this helped to create a more fluent discussion environment.

Another strategy teachers find effective is the "think-pair-share" activity. They find it useful because, this activity also provides a structure for students to share ideas and motivates students to talk. One of the teachers said: "Think-Pair-Share activity was very useful to initiate discussions" underlining the fact that it is important for teachers to have a set of strategies to initiate and maintain fruitful discussions in the classroom.

Theme Three- Difficulties, limitations and suggestions

During the interviews teachers also mentioned about some difficulties and limitations by fostering mathematical communication and gave some suggestions. Time limitations were among the first factors teachers indicate as discouraging to cultivate fruitful discussions. Underlining this point one teacher said: "We can have difficulties during the implementation due to the time limitations".

Teachers also pointed out that it is also difficult to plan for students' talk in advance and anticipate what obstacles can occur and how to solve them. Teachers actually have a hard time at lesson planning session by selecting the questions they will ask and the strategies they will use to get all students express their ideas. "I had difficulty during planning the lesson" and "Alternative questions should be planned in order to facilitate discussions" were their statements emphasizing this point. These expressions of teachers also suggest that teachers need support for planning for cultivating mathematical communication in their classrooms.

Before the implementation teachers indicated that classroom management issues would be an important limitation in enhancing mathematical communication. However, in the implementation there were no major classroom management problems disturbing the communication process. One of the teachers clearly indicated this aspect by saying: “I thought that there would be noise in the classroom while students talk, but it was a very fruitful communication environment”. This means that on the contrary of common opinion that encouraging students to express and share their ideas do not always create classroom management problems with the help of careful planning and implementation.

Results for Second Research Question

For the results of second research question video-recordings of the actual lessons were transcribed and talk moves and strategies associated with the maintenance and decline of the cognitive demand are presented.

In the lesson plan there is a task about the fractions in which students are expected to discuss and describe a fraction and answer questions such as, what constitutes a fraction?, what does equal parts mean?, etc. According to Task Analysis Guide the cognitive demand of the task in lesson plan is 3, because students are encouraged to make connections and making sense of the procedures in relation to mathematical concepts.

By the enactment of the lesson plan two moves were prominent for the maintenance of high cognitive demand:

- Forcing students for justifications and explanations (Stein & Smith, 1998)
- Asking students to apply their own reasoning to someone else’s reasoning. (‘Do you agree or disagree and why?’) (Chapin, O’Connor & Anderson, 2003)

Teachers encouraged students for making justifications and explanations by using sentence frames and strategies such as ‘think-pair-share’. Providing students sentence frames for expression of their ideas enables students to maintain their sense making process. For instance in the dialogue below, the student could express himself more specifically, when reminded of sentence frame:

> *Teacher:* Did I share my hamburger with my friend fairly? (teacher shows an actual hamburger bread divided into two unequal parts.)
> *Student:* No
> *Teacher:* Please express yourself like, I think ….., because…….
> *Student:* I think you divided your hamburger unfairly, because the parts are not equal in size.

Here, the sentence frame served as a facilitating strategy to help students pursue their thinking processes. In other words, trying to express their thinking process in more detail, students were encouraged to make connections to their past experiences about the concept of ‘half’.

The 'think-pair-share' strategy also forced students to justify and explain their ideas by modeling communications. In this activity students were first asked to think about the question, then explain their thinking to their pairs and finally share their understanding with whole class. By trying to explain and share their ideas, students are encouraged to justify their reasoning and make connections.

Another important talk move associated with the maintenance of the cognitive demand was, asking students to apply their own reasoning to someone else's reasoning. ('Do you agree or disagree and why?') (Chapin, O'Connor & Anderson, 2003). This move also encourage students to maintain their understanding process by comparing actively their ideas with other students. By this way, it also allows students monitor his or her own learning process, which is also an important factor associated with the maintenance of high cognitive demand (Stein & Smith, 1998). Below is an example of one student encouraged to compare his ideas with his friend:

> *Teacher:* What kind of shapes can be divided into equal parts more easily?
>
> *Student A:* It should be a shape like rectangle or square. Not some kind of an uneven shape.
>
> *Teacher:* 'A' says the shape should be even in order to divide it into equal parts easily, do you agree with her 'B' ?
>
> *Student:* Yes, I agree with 'A', because to divide the shape into equal parts easily the shape should be regular.

In Rasmussen, Apkarian, Dreyfus and Voigt's (2016) study, it was also pointed out that, engaging in one friend's reasoning and decentering from their own enabled students to elaborate their justifications and enriching conceptions of particular mathematical ideas.

Besides these two factors related with the maintenance of high cognitive demand there was a factor which decreased the cognitive demand in some parts of the lesson plan's implementation. There was an obvious misconception of students about fractions and teachers did not spent enough time to work on this misconception although both of them noticed that students are confused about the concepts of 'equal' and 'symmetric'. To be more specific, the majority of the students thought that to divide a shape into equal parts, the shape should be symmetric. Because teachers did not clarify these concepts students gave expressions such as below:

- We cannot divide a pizza into equal parts, because the ingredients are different in all of the parts.
- You cannot divide your hamburger evenly, because in one part ketchup can be more
- Your half is smaller than your friends'
- One whole cannot be divided more than two equal parts

These expressions show that students understanding process is disturbed and the cognitive demand of the task is decreased. If the teacher continued to use talk moves to elaborate on these expressions, both students and teachers could understand where these misconceptions originate and helped them fix and deepen students' conceptual understanding.

Discussion and Conclusion

Results of the study point out that enhancing mathematical communication in classroom is essential for monitoring students' understanding. This was the most important point reported by the teachers participated in the study. When students talk, monitoring and noticing students' understanding is more effective because, by talking, students give teachers evidence about their understanding, errors and misconceptions (Mooney, Briggs, Fletcher, Hansen & McCullouch, 2009; Pape, Bell & Yetkin, 2003). While appreciating its benefits, teachers indicate that they need support to plan for more communication in the classroom. As a matter of fact, they reported that strategies they learned during the sessions before the implementation were useful by facilitating students' talk, and indicated that they need more strategies to improve mathematical communication atmosphere in their classrooms. Chapin, O'Connor & Anderson (2003) also underline the importance of planning to enhance students' talk. Georgius, (2013), in her study, also indicates that teachers struggled most to make changes in their lesson plans. Therefore she worked closely with the teachers especially in the planning sessions, giving suggestions and allowing teachers to reflect on their work. As a final result about their views on mathematical communication, teachers point out that time limitations, lesson planning and classroom management issues could be difficult by the implementation process. These obstacles can be due to the felt pressure to finish the curriculum as indicated in the study of Kaya and Aydın (2014).

The results of the second research question suggest that using strategies and talk moves to enhance mathematical communication has a role in maintaining the level of the cognitive demand. In the present study, encouraging students for justifications and explanations and asking students to apply their own reasoning to someone else's reasoning were the prominent factors related with the maintenance of the cognitive demand. The literature also points out that enhancing mathematical discourse in classroom is closely associated with the level of cognitive demand (Stein, Grover & Henningsen, 1996; Stein & Smith, 1998). Georgius, (2013), also indicated that teachers can increase the level of cognitive demand by having students engage in meaningful mathematical discourse. Therefore, it is important to encourage teachers to foster students' talk to share their understandings of mathematical concepts. Many researchers found mathematical discourse as an important classroom activity to support mathematical understanding of students (Grant et al., 2009; Smith & Stein, 2011; Varol & Farran, 2006).

By interpreting the results, it must be considered that there are some limitations of the study. First of all, the study group is limited to two classrooms and two teachers. With a bigger sample size, the generalization of the findings could be ensured more confidently. Another limitation is related with the duration of the study. With more classroom observations, deeper explorations can be done to interpret mathematical communication dynamics in the classrooms.

Further studies on relationship between mathematical communication and cognitive demand will be valuable to achieve higher order goals of mathematics curriculum. Despite the emphasis on higher level thinking processes, it is very common that, students end up memorizing formulas and doing unconnected calculations in mathematics classrooms. Therefore, it is very valuable to study what happens to high level tasks during the actual classroom implementations and how to achieve intended student outcomes in curricular materials.

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İlkokul Matematik Sınıflarında Matematiksel İletişimi Teşvik: Sınıf Öğretmenleri Üzerine Bir Çalışma

Öz

Öğrencilere üst düzey düşünme becerilerinin kazandırılması günümüz toplumları için önemli bulunmaktadır. Üst düzey düşünme becerilerinin gelişimi için öğrencilerin anlamlı öğrenme yaşantılarından geçmeleri gerekmektedir. Öğrencilerin kendi düşünme süreçlerini ifade etme olanağı buldukları verimli bir matematiksel iletişim ortamı ders boyunca yapılan etkinliklerin bilişsel talebinin sürdürülmesi açısından etkili bulunmaktadır. Bu nedenle, çalışmanın amacı, öğretmenlerin sınıflarındaki matematiksel iletişimi arttırma konusundaki yeterliklerini geliştirmek olarak belirlenmiştir. Bu şekilde, matematiksel görevlerin bilişsel talebinin sürdürülmesine katkıda bulunmak da hedeflenmiştir. Çalışmada durum çalışması deseni kullanılmış ve veriler içerik analizi ile incelenmiştir. Çalışmanın sonucunda matematiksel iletişimin arttırılmasının öğrencilerin anlama sürecini gözlemlemede faydalı olduğu ve matematiksel iletişimi arttırma amacıyla kullanılan stratejilerin etkinliklerin bilişsel talebinin sürdürülmesinde de rolü olduğu yönünde bulgulara ulaşılmıştır.

Anahtar Kelimeler: Matematiksel iletişim, bilişsel talep, matematik öğretimi