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The Development of Mathematical Knowledge for Teaching of Mathematics Teachers in Lesson Analysis Process

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Abstract: This study aims to explore the role of lesson analysis in the development of mathematical knowledge for teaching. For this purpose, a graduate course based on lesson analysis was designed for novice mathematics teachers. Throughout the course the teachers watched videos of group-mates and discussed the issues they identified in terms of student-teacher relationship for a student centered instruction. Analysis over the video made teachers notice points and came to realize the thoughts of students; they had otherwise missed at the classroom. They achieved improvements regarding the awareness of the need to identify the cases presenting the most difficulty to the students in terms of teaching, and the necessity to take precautions regarding such points, to learn about the reason of the difficulty, and to pay attention to the statements by the students. Therefore, it is possible to note that the teachers improved themselves in terms of student' knowledge with respect to the mathematical knowledge for teaching.

Keywords: *mathematics teacher, lesson analysis, mathematical knowledge for teaching*

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Introduction

Breaking with traditional teacher centered practices in mathematics classrooms is a must for implementing instructional reforms based on student centered approaches (Ball & Cohen, 1999). In order to achieve this, learning environments should be organized so as to allow students express their thoughts**,** discuss their ideas, and to make it possible to identify and analyze students' understanding of mathematics (Ball & Cohen, 1999; Lampert, Beasly, Ghousseini, Kazemi & Franke, 2010). In order to analyze students' understanding of mathematics properly teacher needs enough sufficient mathematical knowledge for teaching. Mathematical knowledge for teaching includes an emphasis on both subject matter and pedagogical content knowledge. The other way around, mathematical knowledge for teaching is knowing mathematics from the perspective of helping students to learn mathematics and includes being mathematically ready to teach an idea, method, or other aspects of mathematics. One way to promote student-centered practices as part of mathematical knowledge for teaching lies through the systematic analysis of instructional practices at the classroom (Santagata & Gouarino, 2011). According to Barnhart and van Es (2015), lesson analysis is about understanding and trying to interpret the student's thinking by examining the teacher-student and student-student interactions, with a view to finding out what is necessary to support such thinking. Such an analysis provides teachers an effective method to get to know students better as it provides them with the opportunity to determine and interpret their students' understanding (Sun & van ES, 2015).'Knowing students' means a deeper awareness about the student's prior knowledge, level, interests, learning difficulties, misunderstandings and misconceptions (Ball, Thames & Phelps, 2008; Shulman, 1986).

Llinares (2013) argues that analyzing students' mathematical thinking provides teachers with the opportunity to structure their own mathematical knowledge for teaching. Therefore, participation of teachers to professional studies requiring analysis of teaching will improve their mathematical knowledge for teaching and make them use it effectively. Such events can be particularly useful in terms of identifying students' difficulties, considering these difficulties. Systematic teaching analysis increases teachers' awareness about their own instruction. Since it increases awareness of teachers about the students' understanding and learning difficulties, it also makes teachers more competent at improving student learning and instruction (Llinares, 2013**;** Yeh & Santagata, 2015).

One of the most widely accepted ways of systemic teaching analysis by researchers is performing analysis on video (Sherin, 2001; Van ES, 2012). Video analysis

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provides teachers with the opportunity of paying attention on special topics, activities and students by letting teachers be observers in their own classrooms (Sherin, 2001). Since video makes teachers' applications widely available and since it is possible to watch whole applications, it is recommended to be used as a tool (Sherin, 2004). Additionally, digital records of instructions make some actions possible like slow replay of lesson parts and focusing on special cases (Sherin & van ES, 2009; van ES & Sherin, 2002).

Compared to more experienced teachers, it is harder for novices to notice what students think. Novices mainly focus on what they do in instruction, rather than student learning. Therefore, it is important for novice teachers to participate in practical trainings which improve their skills of understanding students. Having relevant feedback from experts will support their improvement towards awareness about their classroom practices.

Within the present study, a training through a graduate course was organized for novice mathematics teachers. The course entailed novice teachers recording their own classes as video segments, analyzing them on their own, and presenting them to their colleagues in group meetings. They also watched videos of group-mates and discussed the issues they identified. The course aimed to improve lesson analysis skills of teachers, to provide a chance to reflect on their own practices with teaching knowledge, and to inform them about how to manage student-teacher relationship for a student-centered instruction. Additionally the course intended to improve teachers in terms of determining students' difficulties, considering these difficulties, and taking proper precautions to overcome them. In a nutshell, the teachers are expected to use and improve their mathematical knowledge for teaching.

In the related literature, there have been studies based on video-oriented trainings to contribute to professional development of teachers. Van Es and Sherin (2008), for instance, organized a community within which teachers record segments of their instruction at the classroom and share them in video club meetings. The meetings were used by the researchers to investigate how video is used to improve noticing skills of teachers. The present study, however, stands out from the previous ones in that the participating teachers watched their own instruction recorded on video, and analyzed them before sharing the videos with the rest of the group. In addition, this study not only focused on the noticing skills of techers but also intended to make teachers use and improve their mathematical knowledge for teaching. Accordingly the research inquiry of this study is; "How does mathematical knowledge for teaching of teachers improve during lesson analysis process?"

Methodology

A graduate course based on lesson analysis was designed for novice mathematics teachers. The researcher as teacher educator of the course worked with 5 secondary school mathematics teachers through 14 weeks. The pseudonyms and teaching experiences of these teachers were: Gul (2 years), Meral (2 years), Hulya (3 years), Pelin (3 years) and Yilmaz (3 years). In the first four weeks of the course the theoretical framework of mathematics knowledge for teaching and lesson analysis were introduced. The framework for mathematical knowledge for teaching consists of two sub components as *subject matter knowledge* and *pedagogical content knowledge* (Ball, Thames and Phelps, 2008). In this framework, subject matter knowledge includes three categories: common content knowledge that is the mathematical knowledge should be known by everyone; specialized knowledge that is the knowledge of mathematics content should be known by teachers as specific to the work of teachers; and horizon content knowledge that is the knowledge should be known by teachers to understand how different mathematical topics are related each other. In this framework, pedagogical content knowledge includes three categories: knowledge of student should be known by teachers to understand how students learn mathematical topics and concepts; knowledge of teaching which involves the sequencing of topics and the use of representations; and knowledge of the curriculum of mathematics as a whole. During the remaining 10 weeks the activities listed below were carried out:

- Each week, each teacher recorded a mathematics lesson of their own, analyzed the lesson on her/his own, and submitted a report to the researcher.
- Each week two teachers who participated in the study shared video segments of their instruction at the classroom, which they had already analyzed. Then all of the teachers discussed over the instruction.

In order to facilitate the discussion of the videos watched in the course, the researcher provided some guidance with the following questions.

- What are the issues that you did not notice during the instruction but you became aware of when you were analyzing the video recordings? (addressing the teacher who made the presentation)
- What are the issues you have found remarkable in the video? (for the rest of the teachers)
- How would you teach this mathematical concept?
- What were the points the students had difficulty in learning?
- Why do you think the students had difficulty with these points?

After then the teachers wrote in their course diaries about the pros and cons of this environment, from their own perspective. At the end of the term, the teachers were also asked to write their own evaluation report

on the activities of the course. Therefore, sources of data are the teachers' reports of video analyses, the transcripts of meeting discussions, the online diaries of the teachers, final evaluation reports of the course activities and the researcher's field notes.

In order to identify the contributions of the course had on the professional skills and knowledge of mathematics teaching on part of the teachers, first of all, evaluation reports were analyzed. The data thus gathered were subjected to qualitative analysis through content analysis, and assigned codes, which were reviewed with reference to their associations, to come up major themes encompassing certain codes. These efforts led to the development of views where the teachers had all but concurred. The accuracy of the results reached through the triangulation process were substantiated through comparing the data from different sources.

Findings

The findings of the study are presented under the three sub headings as about difficulties students face in mathematics learning and reasons for these difficulties, effective question asking to students, and developing lesson plans.

Difficulties students face in mathematics learning and reasons for these difficulties

The explanations by the teachers proved that their awareness increased in realizing the difficulties students face in mathematics learning, considering and proposing solutions over reasons for these difficulties. Pelin explained this situation as follows:

> Before this course I used to plan my lessons in my mind in advance, but during this course I began to put the activities, questions and problem cases I will use in the lesson on paper, before the lesson. I came up with this idea in response to an incident in the video of the second week. As the first example of summation of decimals I asked students to add 3.2 to 17.45, which were two arbitrary numbers I made up there and then. At that moment I could not understand why the students had difficulty in adding these two numbers. Then I realized that these two numbers were prone to mistakes when used as the first example of this type of operation. I realized that it was better to use two numbers with the same number of digits after comma. Thereafter, the question "Would my question cause students to have learning difficulties?" started to be a real concern for me when I was getting prepared for the lesson of the day. I started to pay attention to see if everyone understood the topic, how I can do it better, and how students think and make mistakes.

Pelin stated that, through the course she came to realize the significance of points that students have difficulty in terms of their understanding of mathematics, and she duly began to consider over these points. Her interpretation of the matter, over the video, is as follows:

The student executed the operation as follows:

$$\begin{array}{r} 17.45 \\ +\ 3.\ \ 2 \\ \hline 20.47 \end{array}$$

> Upon realizing the student's mistake, I repeated the steps, and made him find out the mistake he committed. The reminder helped him carry out the operation correctly. Throughout the class, I realized that the students had trouble in getting a good grasp of the digits in decimal notation.

Pelin failed to provide a solution to the problem she described as the student having. She interpreted the difficulty the student was having as a consequence of his insufficient grasp of the concept of digits in decimals. When the video of the lesson was watched at the graduate course, the group-mates and the teacher educator realized the actual problem. The causes of the difficulty the student had, and the possible solutions to it were discussed in that context. Another teacher, who took part in the study, offered the following explanation regarding the difficulty the student had.

> 17.45 and 3.2 would pose a difficult problem as the first example of summation with decimals. First example offered should be simpler, and should not involve unused digits after the comma. I guess a better approach would be to begin with numbers which have comparable digits after the comma, for, as we see, the student who attempted to solve the problem wrote two under five, with a view to starting the addition with the right-most digit.

The teacher argued that the example Pelin chose for the lesson was not a good one as a first example of summation with decimals. At the end of the session, a consensus was reached that this was a sub-optimal example as the first case to deal with in teaching summation with decimals. Furthermore, the teacher educator noted that the student's apparent lack of experience with decimals, as witnessed by his statement of 3.2 as is, rather than 3.20, could be another reason misleading the student, for the student considered 2 as denoting the units, and put it under 5.

Through video analyses, all teachers realized certain shortcomings they had in understanding the thoughts of the students in the class. Lesson analyses over the videos allowed the teachers to get a better grasp of what the students were thinking. For instance, Meral describes the following process with respect to how she noticed the cause of the difficulty the student had with the multiplication of a natural number with an algebraic expression, through video analysis.

> Video analysis made me realize many points I had formerly missed about the answers given by the students. It helped me understand more clearly why the students gave wrong answers in certain contexts. Furthermore I noticed some points that I had no inkling of before. For example:

> For the operation "2.(a-1)+3.(a+1)=" the students tried to multiply both brackets by two. I could not understand the reason during the lesson and I just mentioned order of operations. However my the students thought the plus sign in +3 as a positive sign instead of an operation and perceived the whole operation as "2.(a-1)(+3)(a+1)".

Meral mentioned that she had an opportunity to see the reason of students' mistake during the video analysis. In the same vein, Yilmaz noted that he did not realize the mistake of the student during the course, but he noticed it during video analysis; an event he recorded in his 4th diary entry:

> For the equation "7.(6-2) = 7.6 – 7.2 =42x-14" I thought that my student Zehra wrote x as multiplication sign. I thought that it was not so important and I simply said to her to erase x. But when I watched the video I realized that she did not write that x as an operation sign but she wrote it as a variable. This was an important problem. I really shouldn't have superficially dismissed it. I should have made my student realize her mistake.

Yilmaz stated that he dismissed the student writing x as a variable, believing it to be a multiplication sign. However, when he watched the lesson once again on the video, he realized that the student had written variable x on purpose. Yilmaz then proceeded to criticize his handling of the issue and his failure to investigate the cause of the mistake as carelessness. His statements on the video analysis describe the case as follows:

> When I watched the video, I realized that Zehra was surprised once I told her to erase the multiplication. I didn't notice it back then, but upon watching the video, it was clear to me that to her, x was not a symbol of multiplication, but a variable in an algebraic expression. Had I realized this during the class, I would have made her discover that under no circumstances an x would go there. I should confess that I overlooked the issue during the class.

He noted that only when watching the video he realized that the student had intentionally written x as a variable. It is evident that video analysis made Yilmaz realize he should investigate the mistakes of students more thoroughly.

Effective question asking to students

All teachers reported improvements regarding their skills of effective question asking, listening to students, and providing feedback to the statements of students. While in the first videos, all of the teachers mainly used to prioritize directing questions to whole class and expecting answer from all students, by the end of the term they started to direct questions to individual students and take answers instead of the whole classroom. The participating teachers also noted in the final evaluation report and in the diaries that they realized their weaknesses regarding this issue and that they started to pay attention to focusing their questions. Among the participants, Meral wrote in her third diary entry that her questioning manner started to change.

> For me, the most significant realization of the lesson was asking questions towards the whole classroom and expecting answer from the whole classroom. We discussed this attitude. I realized that I frequently did so in my instruction. Actually, we expect every student to say the same thing in collective answers. However, even if every student would say give the same thing they should express it in their own sentences. This point showed me I should have been more careful regarding the asking of questions in my classes.

In a nutshell, she began to notice that directing questions towards the whole classroom and expecting collective answers was not the best way to go.

The teachers stated that they realized just how important was to listen to the responses and remarks of the students, and to provide due feedback. When they watched the videos of their own instruction experience, the teachers noticed that they did not pay due attention to the remarks by the students. For instance, Hulya expressed the situation as follows:

> Listening to the responses of the students thoroughly, and providing feedback.That is one of the shortcomings I noticed through video analysis. At times I did not listen to the response by the student as much as I should have, and judged her to be wrong. For instance, when I reviewed the video of one of my classes, I realized that the response provided by the student was actually quite sensible, but I had failed to notice that at the time.

She noted that through video analysis, she came to realize her shortcomings regarding providing feedback for the responses of the students. As an example, Hulya notes that she realized through video analysis, how she failed to adequately listen to the explanation provided by a student on the development of the area for the parallelogram:

A line representing height was drawn on the parallelogram on the blackboard. I asked if we could multiply other height lines with the same 'a' side. A student volunteered and took the blackboard, and drew the height for the side 'a', from outside the parallelogram, and assigned letter 'h' to represent it. A second students asked if the extension of the side 'a' could be considered a side of the parallelogram as well, given the fact that we drew the height from outside (Figure 1).

Figure 1.

> Student: When the problem we have assigns a unit or a quantitative figure to the sides, should we also take into account this section (referring to the extension of the side)?
>
> Teacher: That is not a bad question indeed. What do you think?

At this junction, another student said we should not take the extension into account, but failed to provide an explanation. He was also quite unsure. Another student remarked that we should, but he also failed to make a coherent statement. He said the height would be fixed, regardless of how extended the line was. Yet another student said the following:

> Student: We should not take it into account, for we represented it with a dashed line, which means we should not take it into account in calculations. Furthermore, when calculating the area, we take the inside of the shape into account. That extension lies outside the shape.
>
> Teacher: You are correct, but don't think of this merely in the context of area calculation.

In this case, the response provided by the student was actually a good one. At the moment, I didn't fully understand what he meant about the area calculation, but when I watched the video, I came to see that he actually put it very coherently. However, as I was seeking a specific response, I disregarded the correct answer the student gave. I should have provided a better feedback.

She stated, upon watching the video, that she realized the correctness of the response provided by the student, and that she was unable to register it at the time as she was preoccupied with a specific response. The teacher reported that she should have provided better feedback regarding the response by the student.

Developing Lesson Plans

The teachers stated that they had the opportunity to compare their lessons with those of their colleagues as they watched the lesson videos. Hulya stated that:

> I had the opportunity of making direct comparisons as we mostly taught classes at the same grade level and had similar educational attainments. For example, we watched two different teachers' videos on multiplication of algebraic expressions on the same day. We were able to compare both lessons. We had a discussion on the method to start with, and how to proceed thereafter. We reflected on the positive in both lessons when preparing our lesson plans.

Similarly, Meral and Pelin described the same situation as follows:

> Since I could be more critical when I analyzed my friends' lessons, I could notice more details… At the same time as I was also thinking about my own teaching, I had the opportunity to compare, and therefore develop a better awareness. Another teacher means another path and observing is much more effective than talking about (Meral).
>
> We discussed and proposed ideas about how to order activities when we watched videos of two different teachers on the same day. Eventually, we reached to common points on which we all agreed. Although the discussions we had were essentially about the topic of the day, getting an idea of what to be careful about and what to prioritize helped me realize what to focus on when planning for other topics (Pelin).

All of the teachers mentioned that they had the opportunity to compare their lessons with those of others when they performed analysis of the lessons regarding a given topic. They also added that they would reconsider these points in their future plans, when they were to teach these topics again. For instance, Meral wrote the following on her diary, describing the effect the teaching by a colleague had on her:

> Hulya's progression from examples with natural numbers to algebraic expressions in the lesson on the meaning of algebraic expressions made it easier for students to understand. For instance, in response to a question asking them to specify the perimeter of a square each side of which is 3 unit, they responded 3+3+3+3 and 4.3. Later on, when asked about the perimeter of a square a side of which was "a" unit, they responded a+a+a+a or a.4. The majority of them responded a.4. Even though a.4 and 4.a were essentially the same, the awareness of the difference of expression is important to instill in: we should try to make them express it as 4.a, suggesting 4 times a. This would prevent potential problems the students may have in the future.

Meral noticed that if she began with summation of natural numbers when describing the operation of adding algebraic expressions, the students had an easier time with making generalizations. This realization gave her the idea that specific types of examples would make teaching easier for the student. Furthermore, the teacher educator noticed that all teachers wrote algebraic expressions in the form "a+a+a+a=a.4", and that they did not intervene in with such expressions by the students. At this stage, the teacher educator provided a detailed explanation of the difference between the meanings of a.4 and 4.a. The teachers who took part in the study responded that they had never considered that perspective before.

Discussion and Conclusion

This study was based on a graduate course offered to support the development of novice mathematics teachers' mathematical knowledge for teaching. In this context, the teachers recorded videos of the classes they taught, and were expected to apply lesson analyses over such videos. One can argue that the teachers improved somewhat through the lesson analysis, in terms of awareness of the thinking of the

students, interpreting their thoughts, and providing suggestions**.** This finding coincides with the conclusions of van ES and Sherin (2010). They found that in the video-club context, the teachers learned to attend to the specifics of student mathematical thinking. On the other hand, the teachers were able to identify the points the students had, but they had in turn difficulty in interpreting the reasons of such points and in providing suggestions. An environment to facilitate discussion over the videos watched within the framework of the graduate course was developed. This environment provided teachers a venue to discuss the reasons of the difficulties the students had with learning and precautions to overcome such difficulties**,** with reference to the videos of their own teaching. This allowed the teachers to be aware of the cases they had in their own classes, as well as the cases in their colleagues' classes, and be able to notice the common difficulties the students face in mathematics learning. They also had an opportunity to think about what to do to overcome such difficulties the next time they taught the same concept. Similarly, Sherin and van Es (2005) pointed out that as a result of watching video cases from classroom instruction can improve teachers' ability to interpret the features of classroom instruction.

On the other hand, the practices to improve lesson analysis skills made the teachers aware of the need to analyze the lesson from the perspective of the student. In other words, one can argue that they achieved improvements regarding the awareness of the need to identify the cases presenting the most difficulty to the students in terms of teaching, and the necessity to take precautions regarding such points, to learn about the reason of the difficulty, and to pay attention to the statements by the students. Therefore, it is possible to note that the teachers improved themselves in terms of knowledge of student with respect to the mathematical knowledge for teaching. According to Ball et al. (2008), teachers must anticipate what students would probably think in a given case, and what they would be confused about.

As teachers analyzed their own teaching on the basis of videos, and then discussions on their practices made it possible for them to expand their insights on many aspects they would otherwise may not have noticed. For instance, analysis over the video made teachers notice points and came to realize the thoughts of students, they had otherwise missed at the classroom. Furthermore, thanks to video analysis, the teachers realized their shortcomings regarding providing feedback in response to the answers by the students. In short, the teachers got the chance to enhance their own practice. The related literature supports these findings that video analysis provides teachers with the opportunity of paying attention on their own teaching and student understanding (Sherin, 2001; Sherin & van ES, 2009; van ES & Sherin, 2002).

As Santagata & Guarino (2011) noted, all reflections on the application leads to learning through practice. The first lessons recorded on video were characterized by an impatience regarding learning about the thoughts of students; the habit of addressing all students when asking questions and expecting collective responses; and providing the response without giving time to students for them to think. The graduate course provided a venue to underline that such attitudes would not suffice to develop an in-depth understanding of the perspective of individual students. Subsequent video analyses, on the other hand, made the teachers realize these problems on their own as well, and tried to reflect on this. According to Erickson (2011), novice teachers tend to overgeneralize regarding learning of students, as they focus on the learning of the whole classroom, rather than thinking about the views of individual students, and understanding the meaning of their ideas. A similar case was observed in this study as well. One can therefore conclude that teachers engaging in lesson analyses with reference to their own lessons would be able to develop the awareness of the need to review the lesson from the perspective of the student, adopting a student-centered perspective in teaching.

The teachers stated that, through the graduate course, they had the chance to make comparisons between their own practices and those of their colleagues. In particular, they were able to reach a consensus on which example or model would be more effective and which strategy would be more advantageous with reference to the teaching of mathematical topics. This suggests that the teachers had the opportunity to develop lesson plans concerning certain mathematical concepts. Choosing examples to facilitate the students' understanding and establishing the ways of representing are elements of pedagogical content knowledge (Ball et al, 2008; Shulman, 1986). That is why one can argue that the course supported the development of the teachers' mathematical knowledge for teaching, with reference to certain mathematical concepts. The graduate course sessions, compared to video analyses performed by individual teachers, were, arguably, more useful in terms of developing lesson plans. On the other hand, had the teachers showed up at the sessions without analyzing videos of their own teaching, the sessions would certainly be less effective. At this point, the teachers voiced the will to have a longer graduate course as they did not have the opportunity to discuss all topics they were supposed to teach in mathematics classes. Therefore, offering courses to cover all mathematical concepts the teachers are required to teach, would be a sensible suggestion. As the present study revealed, the teachers' may suffer shortcomings in terms of their pedagogical content knowledge with respect to identifying the reasons of the difficulties they observed students to have, and to coming up with suggested solutions to such reasons. That is why, the proposed courses should, as a rule, be offered under the guidance of an expert in the field of knowledge of teaching mathematics. Furthermore, experience was never sufficient for effective mathematics teaching. The term

novice teacher erroneously refers to those in the first years of one's career in teaching, while anyone who fails to give proper thought on her own teaching, or pay attention to what the student thinks, and who fails to communicate with the student should be considered a novice of the profession. That is why one of the means to becoming an expert teacher in teaching can be found in the lesson analysis skills.

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