Mid-career teacher learning through collaboratively framed mathematics lessons

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Introduction

Currently, mathematics professional development (MPD) is structured around inquiry-based and collaborative experiences. Teachers are considered active learners who shape their professional growth through reflective participation in professional development programs and practical implementation (Clarke & Hollingsworth, 2002). However, gaining a deeper understanding of what specific MPD tools foster teacher learning is still a future task. Goldsmith et al. (2014) pointed out that existing research tended to focus on program effectiveness rather than on teacher learning. Therefore, a careful examination of the processes that lead to the development of teacher knowledge, beliefs, or instructional practices is needed.

The purpose of this paper is to report on a learning process in an MPD program in which three teachers collaboratively devise a *mathematics lesson framework* (MLF) (Hino & Makino, 2012, 2014). The MLF is a conceptual and interpretive model of the teaching/learning process, and includes the mathematics teaching objectives, lesson organization principles and the teacher's role during the lesson. In this MPD design, teacher practice-based inquiry is defined by centering the MLF in a practice-based inquiry triangle of problems, research, and practice (Figure 1). The teachers engage in less-rigorous theory-making activities, through which they have the opportunity to connect problems to relevant research and practice.

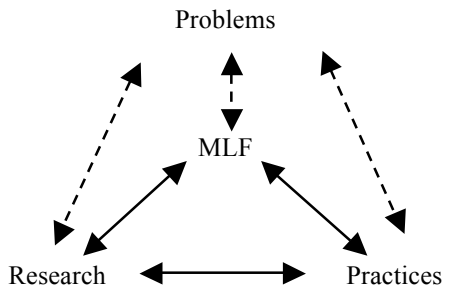

Figure 1. MLF and the practice-based inquiry triangle

The three participating teachers had nearly 15 to 20 years of teaching experience and were among the 20 teachers who participated in this MPD program from 2010 to 2014. These teachers collaboratively investigated the problem of fostering *students' ability to utilize learned knowledge* (hereafter, ULK ability). Over a six-month period, they developed an MLF, used it to plan and assess their mathematics lessons, revised it on the basis of these lessons and then described the outcomes in a report. Their written reflections and a group interview six months after the program demonstrated significant learning from the MPD activities.

Teacher learning in mathematics professional development

To approach teacher learning in the MPD program, we considered it important to adopt a situated cognition perspective (Lave & Wenger, 1991). We regard learning as the process of participating in the practices of social communities wherein the learner shapes meanings and identities (Wenger, 1998). The situated nature of this learning also refers to the knowledge the teacher generates. Leikin and Levav-Waynberg (2007) revealed how strongly the teacher knowledge is dependent on the school practice situation and is disconnected from the sector of theory. However, when teachers have the opportunity to work together with people from a different community of practice (research community) to promote knowledge exchange between the communities, it is also possibile to produce a valuable space in which the teachers can transform their knowledge and perspective.

An MPD design by Sztajn et al. (2014) is the case in point. In the study, they questioned the dichotomy of situating the knowledge required to improve mathematics teaching and learning with either researchers or teachers. By using the social theory of learning (Wenger, 1998), they conceptualized the space created by the two communities as a *boundary encounter*. Here, they recognized that the difficulty of knowledge exchange across communities is precisely the reason for the learning productiveness at boundaries. They wrote,

> Our interest in conceptualizing MPD as a boundary encounter stems from the realization that within these encounters, members from separate communities communicate about, collaborate around, and potentially transform practice. Boundary encounters allow community members to examine and potentially change the ways in which they experience and belong. Most important, participants from separate communities who are involved in boundary encounters negotiate meaning both across the boundary and within their original communities. (Sztajn et al., 2014, p. 204)

To design the MPD, they also used the concepts of *boundary practice* and *boundary object*. Boundary practices are "a form of 'collective brokering' that offer members of different communities 'something to do together'" (Sztajn et al., 2014, p. 204). Boundary objects are the representations of knowledge that are the object of the boundary practice and that "convey meanings across multiple communities" (p. 205). Boundary objects include artifacts such as student work, videos of clinical interviews, or curriculum materials.

The last sentence of the quote above is appealing to us because it raises questions such as "in what way such negotiations of meanings are taking place during MPD activity" and "how it is reflected on by the teachers." By using the representation of the learning trajectory on "equipartitioning," the participants of the Sztajn et al.'s project were reported to have learned new ways of positioning students as knowers in their classrooms. We believe that the opportunities to negotiate meaning through the exchange of knowledge between the communities can be embedded in various MPD settings. By using the lens of learning at boundaries, we examined the teachers' learning process in an MPD setting wherein the teachers created and used the MLF. In this paper, we present several episodes regarding the communication and negotiation of meaning that occurred within the three teachers' activities.

Three teachers develop an MLF

Three teachers (two primary and one lower secondary) participated in our MPD from October 2013 to March 2014. To participate, the teachers were granted leave from their jobs for the entire period. The theme for these teachers was "to design mathematics lessons aimed at fostering ULK ability." This theme emerged through informal discussions in which problems and concerns were shared and compared, and in which all teachers reflected on both their accumulated teaching experience and the current emphasis in the Japanese Course of Study.

Table 1 is a rough sketch of the period and content of the major activities that the teachers engaged in when developing the MLF.

Table 1. Period and content of major activities by the three teachers

Months	**Content of activity**	
10–12	Defining student ULK ability	By examining the rationale and definition of the ULK ability and the research results of the national assessment of academic ability (NAAA) that had been distributed by the Ministry of Education (MEXT, 2014), the teachers defined the students' ULK ability based on six components (for the six components, see Figure 3).
11–12	Initial proposal of lesson framework to develop ULK ability	Teachers thought it necessary to intentionally develop situations that fostered the six components in the lesson. By investigating reports by the Ministry of Education and in several schools in different prefectures, they identified five situations in the lesson for the components: "Grasping," "Foreseeing," "Solving, "Cultivating," and "Expanding."
11–12	Collecting data on the ULK ability of *their* students	While developing the lesson framework, the teachers collected data on the actual ability of *their* students' ULK ability using NAAA question items and some additional questions. One item was to compare the areas of two parks using the area of a parallelogram and the other was to find the height of the wall using the number of stairs. They conducted further interviews with some of the students.
12–2	Examining the student data	Teachers ordered the collected data and discussed numerous student responses. We discussed what the differences were in the responses from the viewpoint of the ULK ability. Our discussion sometimes extended to the teaching of mathematical concepts at different grade levels.
1–2	Designing a research lesson	The teachers decided to conduct a research lesson in a sixth grade classroom. Since the class had been the subject of the data collection, the teachers had information on their ULK ability. The teachers developed and modified a lesson plan using the "comparing the areas of two parks" question item.
2	Conducting the research lesson	The research lesson was conducted on February 7. Besides the teacher who taught the students, two teachers and the first author observed the lesson. The lesson was video recorded and a post lesson discussion was also conducted.

2–3	Examining the effect of the lesson by collecting students' data	To examine the effect of the lesson, the teachers collected student data prior, during, and after the lesson. Several students were chosen as focus students and their activities were recorded during the lesson using IC recorders and field memos.
3	Summarizing the content of their inquiry in the form of a report	The teachers reflected on all activities and summarized the content of their inquiries in a report (Hirose et al., 2014), which included the MLF, i.e., the ULK ability and the teachers' roles in fostering the components in the different lesson situations. Figure 2 represents the final version of the MLF as it appeared in their report. The teachers also created a table that gave a detailed description of teachers' roles in the lesson.

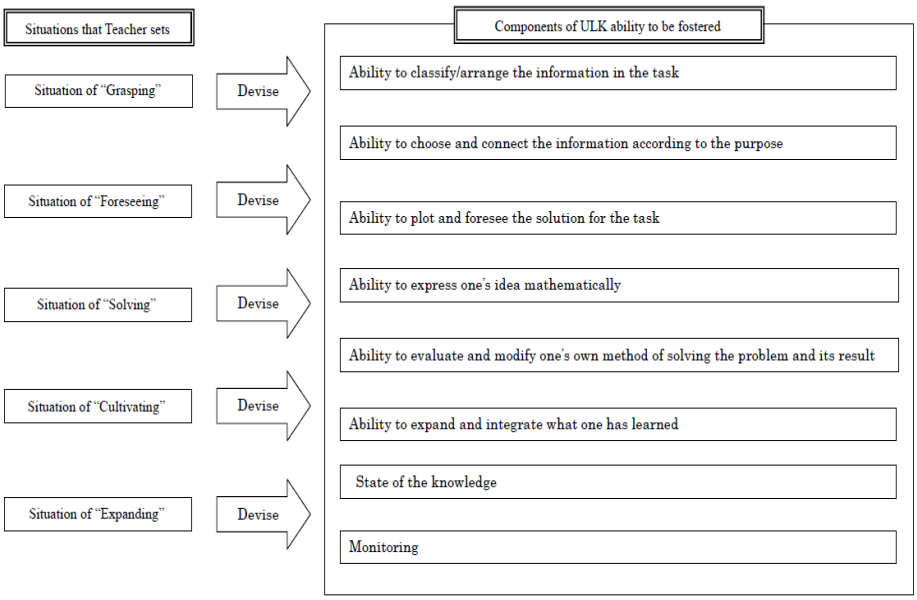

Figure 2. Relationship between the situation that teachers set and the ULK ability fostered in students (Hirose et al., 2014, p. 109, translated into English by Hino)

Communication and negotiation of meaning by the mid-career teachers in constructing an MLF

The teachers and the research team collaboratively designed the activities in Table 1. Over the sixth-month period, we conducted 10 regular meetings of about two to three hours each. The teachers also took time to discuss their themes together, and we also had informal discussions with the teachers. In this section, certain communications and negotiations of meaning episodes from the meetings are described. Teachers addressed these episodes during the post group interview as the moments of learning.

Metaphor guiding the definition of ULK ability and for interpreting student responses from the ULK ability components

In the earlier part of the inquiry, the definition of ULK ability was the object of discussion. During the discussion, the researcher provided a metaphor of a *drawer* and illustrated this with a case of a person looking for something by the opening of drawers. Then, we talked about the different behavior of the person in terms of the drawers, e.g., how many drawers the person has, what they have in the drawers, or which drawers they try to open. These talks helped us imagine the different abilities and determine the learned knowledge suitable for application to the problematic situation.

In January, we discussed the student data the teachers had collected in the meetings. Here again, this metaphor was used. The researcher posed (genuine) questions such as "Did the student who made a mistake really open the drawer? Did he take out something different? What is the difference between those who made mistakes and those who did not?" For example, we discussed the student mistakes when using the slanted side (instead of the height) to calculate the area of the parallelogram as opening the wrong drawer and not being able to judge correctness. The drawer metaphor appeared repeatedly, and gave a direction to the inquiry.

Communicating and generating the stages for the state of knowledge

In the meetings held in January, we discussed the ULK ability differences among the students. The researchers brought in a vocabulary *template* from their community of practice, and we talked about the parallelogram templates the students had with them. The teachers gave examples of student behavior concerning "height" from their daily lessons, which led us to conjecture several stages for the state of knowledge. On the basis of the discussion, the teachers reexamined their data and identified four stages, as shown in Table 2. These stages were used to design the research lesson.

Table 2. State of knowledge stages (Hirose et al., 2014, p. 45, translated by Hino)

State of knowledge	Description
K-stage 4	To solve the task, the student can think by connecting different knowledge or choosing the necessary knowledge, and can explain the thinking process to others.
K-stage 3	To solve the task, there remains some vagueness on connecting the different knowledge or choosing the necessary knowledge. They are unable to explain the thinking process to others, but can solve the task on their own.
K-stage 2	To solve the task, there remains some vagueness on connecting the different knowledge or choosing the necessary knowledge.. They are able to sometimes solve the task on their own.
K-stage 1	To solve the task, there remains some vagueness on connecting the different knowledge or choosing the necessary knowledge. They are unable to solve the task.

To identify these stages was one of the moments of significant learning for the teachers. In the next meeting, the teachers said that they had intensively discussed the four stages in their informal meetings. One teacher said, "Teacher T (one of the three teachers) gave us a very good example of a student who actually connected different knowledge to solve a task. I was really surprised to know that an example of our stage existed in the reality of the classroom. I am convinced that this [Stage 4] is important.

This is my best yield for today. The student's knowledge can change from disconnected to the connected."

Re-conceptualizing the flow of the lesson in relation to ULK ability
Based on the previous discussions, the teachers proposed a lesson plan for the research lesson. Their initial flow of the lesson was organized in order of the five situations (such as "Grasping" and "Foreseeing"), as these situations were seen to correspond to the six ULK ability components. During the meeting, we discussed the rationale and purpose of setting all these situations, given the reality of the students in the classroom and the length of time of the research lesson (45 minutes). We finally agreed to focus on the situation of "Cultivating" because this situation had the possibility of fostering the ability to evaluate and modify a student's own method. Many students had shown difficulty in this ability, so this situation was stressed in the final flow of the lesson.

In the post group interview, the teachers told us that this change in the flow of the lesson was significant in their conceptualization of the flow of the lesson in relation to the ULK ability. They said that at first they were thinking about a one-to-one correspondence between the situations and the ULK ability components. Even when they agreed to focus on one situation, they said it was not easy to generate an image of a lesson that concentrated on only one situation because they had not experienced such lessons before. However, when examining the effect of the research lesson from the collected student data, they found that the students were actually developing different ability components even though the lesson concentrated on only one situation. In the interview, they said that this time they were far more confident and that their original idea of a one-to-one correspondence between the two needed to be modified, which was a new insight in their teaching practice.

Situations that Teacher sets	Components of ULK ability to be fostered
Situation of "Grasping"	Ability to classify/arrange the information in the task
Situation of "Foreseeing"	Ability to choose and connect the information according to the purpose Ability to plot and foresee the solution for the task
Situation of "Solving"	Ability to express one's idea mathematically
Situation of "Cultivating"	Ability to evaluate and modify one's own method of solving the problem and its result
Situation of "Expanding"	Ability to expand and integrate what one has learned

Figure 3. Initial version of the relationship between the situation that teachers set and the ULK ability fostered in students (Hirose et al., 2014, p. 109, translated by Hino)

This process of re-conceptualization connected directly to their MLF. In their final report, they compared their initial MLF (Figure 3) to the final MLF (Figure 2). In their

initial MLF, the firm one-to-one correspondence was shown using disconnected rows (see Figure 3).

Discussion and summary

By collaboratively making, using, revising, and reporting on the MLF, the teachers were engaged in the inquiry process over time. During the process, both the teachers and researchers were engaged in the discussion, which was aimed at the mutual goal of making a single ULK ability MLF. The participation in the practice in this community accompanied the learning process, which can be conceived as communicating and negotiating meaning between participants who belonged to different original communities. The episodes in the previous section demonstrate that the learning was a result of a continuous interaction between the members and a result of the creative efforts, such as identifying the components, generating the knowledge state stages and designing the lesson flow.

The boundary encounter perspective was effective in identifying the three teachers' learning. When applying this perspective to a different MPD program, however, it is possible to add at least two observations. One is the usefulness of using the representations of knowledge that are created collaboratively by the participants from the different communities as *boundary objects*. Here, the prominent *boundary practice* is making, using, revising, and reporting on the representations. We agree with Sekiguchi (2014), who discussed the importance of informal theory in teacher community learning and highlighted the important role of teacher artifacts in professional development. The other observation from our case is the usefulness of focusing on the mathematics lesson when designing the boundary practice. Among the various instructional practices, teacher problems and concerns were strongly connected to the mathematics lesson design. Furthermore, different ways of thinking surfaced more clearly when the topic of discussion was around the design of the lesson.

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