Invited Lecture

Designing Student Learning: A Practical Research Case Study of a Mathematics Professional Development Program

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ABSTRACT This paper purposed to examine the process employed by two lower secondary school teachers in designing a lesson for students through discussion with three university researchers. The teachers conducted practical research at a professional development program in mathematics and collaboratively designed a lesson for Grade 7 on the geometrical transformation of figures. The results revealed the incorporation of considerable changes to the lesson objectives and development, indicating the emergence of different perspectives. The paper employs the study results to discuss the significance of designing lessons that enhance student problem-solving to the professional learning for teachers.

Keywords: Lesson study; Perspective; Professional development.

1. Introduction

Researchers have synthesized the features of effective mathematics professional development (MPD). These elements include a focus on content and student learning, the provision of active learning opportunities for teachers, or the fostering of collective participation (e.g., Sztajn et al., 2017). However, the details of teacher learning beyond such broad features remain unclear (Goldsmith, et al., 2014). Scholars have also recommended the facilitation of professional development through the interplay between theory and practice (Huang and Shimizu, 2016; Sztajn et al., 2017); however, the means of realizing such interplay vary. More detailed information is needed on teacher learning in specific MPD contexts. The present paper examines an MPD case in Japan in which teachers conduct practical research (Miyakawa and Winsløw, 2019) with university scholars and clarify the process and product of designing student learning pathways through problem-solving lesson. This paper attends to such learning by mid-career teachers who have accrued mathematics teaching experience of 15–20 years. The present investigation is intently focused but intensive in its analysis of one aspect of Hino, Makino, and Kawakami's study (2020): designing a research lesson.

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2. Study Framework

2.1. Researching: a critical aspect of lesson study

Lesson study is a practice-based, research-oriented, and collaborative style of professional development (Huang and Shimizu, 2016). The aspect of research activity by teachers is critical to the process of lesson study. Fujii (2016) specified five components of lesson study (Fig. 1), asserting that research lessons and post-lesson discussions denote the two most visible components and attract attention from many teachers and educators in other countries. He insisted that other components are nonetheless critical. According to him, the autonomous formulation of questions by teachers is especially essential, and this component distinguishes lesson study from teacher training (see also Takahashi, 2019). Miyakawa and his colleagues (Iwasaki and Miyakawa, 2015; Miyakawa and Winsløw, 2019) stressed the importance of teachers performing practical research for professional learning. The phrase *practical research* is "a broader term that denotes the study and research on teaching practices, carried out mainly by an individual teacher or a group of teachers for the purpose of improving their teaching practices" (Miyakawa and Winsløw, 2019, p. 283). All the above stated concepts have emphasized the research activities of teachers as a critical dimension of lesson study.

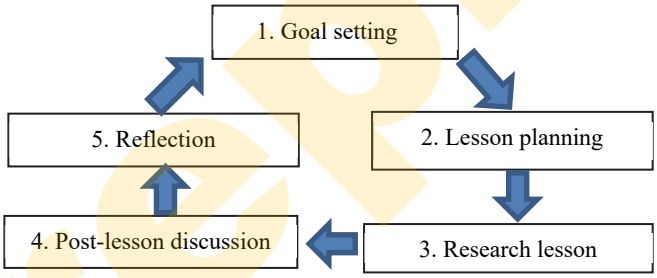

Fig. 1. Five components of lesson study (cited from Fujii (2016))

2.2. A lens to capture teacher learning

This paper references Lin et al.'s work (2018) and builds on their idea of perspective to apprehend learning by teachers. Lin et al. explain that perspective means to "specifically describe how one deals with a situation by coordinating a set of ideas and actions" (p. 198). They explore perspectives relating to the use of theory by mathematics teacher educators and researchers to facilitate the development of teachers. In the present study, the notion of perspective is expected to contribute to the exploration of the core ideas attained by teachers so they can view and deal with a situation occurring in their teaching practice. The study aims to capture the growth of the perspectives of the participating teachers during the course of their practical research activity: how newer perspectives emerge, how a certain perspective is extended, or how different perspectives can be related or even merged.

2.3. Research questions

— How can practical research activities teachers can perform be designed for a MPD?
— What teacher perspectives on the teaching/learning of mathematics emerged in the goal setting and lesson planning phase, and how did they materialize?

3. Study Context

3.1. The "Naichi Ryugaku" program: The studied MPD

Numerous professional development (PD) programs exist in Japan at national, prefectural, and municipal levels. Varied types of university-associated PD programs are delivered for practicing teachers, including the traditional master's, a newly developed professional degree, and PD in collaboration with prefectural boards of education. The program described in this paper represents the third type mentioned above and denotes a joint project undertaken by Utsunomiya University and the Tochigi Prefectural Board of Education. Participants are recommended by their principals and examinations are conducted by the Board of Education. Participants are granted continuous leave from their jobs for the entire six-month period (one semester) to focus on PD activities. One or two teacher(s) participate in the studied MPD every semester. The selected teachers are usually experienced, having accrued 15–20 years of teaching practice in primary or lower secondary schools.

The studied MPD encompasses three major activities: attending courses at the university, participating with researchers in several lesson studies in local public schools, and performing practical research. The practical research activity includes the formulation of a research theme, the design and analysis of a problem-solving research lesson on the established research theme, and continuous dialog between the participating teachers and the three researchers in the department of mathematics education (Hino, Makino, and Kawakami). Further, the lesson study cycle presented in Figure 1 is adopted for the research theme, highlighting the components of goal setting, lesson planning, and reflection.

3.2. The two teachers and their practical research activities

Mr. T and Mr. M worked in different lower secondary schools. They participated in the studied MPD during the second semester (October — March) of 2018. They began their practical research activity according to the cycle of lesson study. Initially, each developed a research lesson plan for a geometry chapter. However, Mr. M could not conduct the research lesson because of the circumstances at his school. Therefore, he participated in the development of Mr. T's lesson plan. Thus, the two teachers collaboratively developed a research lesson delivered by Mr. T to his seventh-grade class on December 20. After the research lesson, the two teachers engaged in a post-lesson discussion and also interviewed several students. Thereafter, the two teachers and three researchers took around two months to examine the effects of the lesson by

analyzing the data obtained from students. The teachers finally summarized the contents of their inquiry in the form of a report.

The team of teachers and researchers met 20 times to discuss the contents of the practical research performed by teachers. These gatherings included general meetings attended by all five members (GM), small meetings between some of the members (SM), and on-site meetings at Mr. T's school. This paper focuses on the goal setting and lesson planning discussions and thus describes the first eight meetings (sessions 1 to 8) to grasp how the perspectives of the teachers emerged. There are no video or audio records of the meetings. The paper's descriptions of the contents of the eight meetings are based on summaries prepared by the teachers. Memos inscribed by the researchers during the meetings are referenced to outline the contents of the discussions that transpired.

4. Goal Setting and Lesson Planning by the Two Teachers

4.1. Session 1 (goal setting)

At the first meeting, the three university researchers, Mr. T, and Mr. M met and discussed the theme of practical research that would be undertaken during the semester. Tab. 1 summarizes the reflections noted in their reports by Mr. T and Mr. M vis-à-vis mathematics teaching and their expectations of conducting practical research.

Tab. 1. Reflections on teaching, issues, and expected research themes in the summaries prepared by the two teachers

Content	Brief description
Mr. T	
Reflections on my teaching	I have changed my teacher-centered pedagogy to a more participatory method of mutual learning among students, targeting that no one should be left behind.
Issues of mathematics education	The connection between mathematics and everyday life; individual differences in understanding and motivation; difficulties students face in explaining their ideas.
My teaching objectives	The joy of learning mathematics; developing autonomy in students toward learning that creates competencies; nurturing the personalities of students during lessons by inculcating the importance of cooperation with other people.
My research theme	To foster the competencies of thinking, decision-making, and expressing ideas through mutual learning; to imbibe a sustainable method of teaching mathematics that I can implement in my daily lessons.
Mr. M	
Reflection of my teaching	I have tried to foster thought articulation by students by devising a way of board writing, questioning, providing opportunities for mutual teaching, or recommending explanatory aspects.
My teaching difficulty	Substantial individual differences exist among students. Hence, it is inadequate to merely impart awareness of foundational concepts and principles of mathematical skills.
My interests and research theme	How to incorporate the processes of problem-finding and problem-solving into the lesson; how to foster the knowledge necessary for mathematical problem-solving in students; to develop a teaching plan for an entire unit.

The discussion revealed that Mr. T and Mr. M shared concerns about fostering the abilities of thinking, decision-making, and expressing ideas (TDE) in their students through their mathematics lessons. It was thus determined that the research activity would begin by establishing a common theme: investigating mathematics lessons that foster TDE abilities in students.

4.2. Sessions 2–8 (lesson planning)

The lesson plan proposed by the two teachers was discussed from sessions two to eight. Both teachers decided to conduct a research lesson on the subject of geometry. Mr. T planned a lesson on the textbook chapter on transformations of geometrical figures (Grade 7). Mr. M's lesson plan concerned the chapter encompassing proof. Each teacher prepared a summary report and presented the specified lesson plan for each meeting. The synopsis essentially comprised lesson objectives and outlined the progression of the lesson. In the meetings, ideas were freely expressed using the summaries as objects of discussion. The summaries also served as artifacts that mediated the boundaries between the teachers and the university researchers.

4.2.1. The transitioning of lesson objectives

Tab. 2 (on the next page) overviews the objectives established in Mr. T's summary for the research lesson. Students were expected to apply their conceptual knowledge of the parallel, symmetric, and rotational transformation of geometrical figures (TGF) to achieve their activity goals.

Tab. 2 displays the changes in lesson objectives through the eight sessions. Mr. T's lesson objective was rather general in the summary report prepared for session 2 (R2)[2]. He began to assert specific objectives only in R3 in which T stated his aim for students to "express their ideas mathematically." Besides, as evidenced by his notation of "today's task," Mr. T conceived of students creating personal emblems that others could recreate. The keyword "recreate" first appeared in the "today's task" section of R3 and this notion appears to have emerged during the session 2 discussions. Mr. T first used the phrase "modify the explanation" in the lesson objectives inscribed in R4 in which he also explicitly inscribed the term "make an instruction manual." These statements reflect the discussions that occurred in session 3, during which the notion of students creating and modifying instruction manuals as an activity was introduced. The report R5 incorporated the term "using mathematical expressions" into the idea of "modifying the explanation." The lesson objectives further clarified the connection to geometrical proof in the Grade 8 curriculum and appeared to reflect Mr. M's interests. Pertinently, Mr. M joined Mr. T's lesson planning efforts around session 5. Moreover, the lesson objectives were described in detail in R5 to establish their connections to the four evaluation standards set by the Ministry of Education (MEXT). However, these associations disappeared in R6, which also introduced a change from the R5 lesson

[2] R1, R2, R3, …R8 are used for the summary reports prepared by Mr. T for all eight sessions.

Tab. 2. The objectives established in Mr. T's summary for the research lesson

Session	Type	Lesson objectives
2	SM	Students can (i) solve a problem by integrating previously learned knowledge and (ii) think autonomously by appreciating multiple views and ideas.
3	GM	Students understand specific situations in which TGF can be used and make personal emblems. Through such a process, students can acquire the ability to express their ideas mathematically and to think and make decisions. Today's task: make an emblem that others can recreate, and explain its structure
4	SM	Use interactive discussions to explain the process of creating a motif and modify the explanation for better effect so students can enhance their TDE abilities and acquire problem-solving skills through the application of previously acquired knowledge. Today's task: Use mathematics to create a motif and make an instruction manual so that others can recreate your design.
5	GM	Students use TGF to create a motif and collaboratively elucidate their process. In so doing, they enhance their logical thinking abilities and produce geometrical proof; they also improve their articulation skills by modifying their explanations using mathematical expressions. Therefore, the lesson adopts two objectives: students can use TGF to create a design that others can recreate (skill) they can devise a better way of drawing the pattern and can explain the process so that others can recreate it (mathematical viewing and thinking)
6	SM	Students take the viewpoint of TGF to capture the components of traditional patterns or insignia and make an instruction manual. They also evaluate and revise their manual so their friends (others) can recreate their design.
7	SM	Students employ the standpoint of TGF to grasp the components of traditional patterns or insignia and produce an instruction manual. They further evaluate and revise their manual so their friends (others) can recreate their design. In so doing, students apply acquired knowledge of TGF, acquire critical thinking skills, and imbibe the perspective of self-assessment by utilizing the evaluations made by others.
8	SM	Using TGF, students can generate better instruction manuals to help their classmates recreate their designs. (mathematical viewing and thinking)

objectives by adding the word "evaluate." Another modification in R6 involved the addition of the word "friends." Both insertions reflect the discussions held in session 5. Specifically, one researcher asked the question, "who are 'others'?" (Makino), and the meaning of the term "others" apropos the student activity was made explicit. The lesson objectives became longer in R7, which introduced new phrases: "critical thinking" and "self-evaluation." These inclusions indicated the contemplation of session 6 discussions. However, the phrases disappeared in R8.

4.2.2. The transition of lesson development

Scrutiny of the lesson outlines inscribed in the reports reveals considerable transformations through the eight sessions. However, space constraints allow the description of only two transformative aspects. First, the major cognitive processes to be experienced by students during the lesson were modified. At the beginning (R2), Mr. T thought students would be provided a ready-made emblem and would be asked to apply their knowledge of TGF to discover its structure. In R3, he first introduced the

activity of students creating an emblem on their own for others to recreate. Then the student activity described in R4 included the acts of producing and revising an instruction manual that others could follow to recreate the emblem. These processes of production and modification denoted major aspects of the student experience of the lesson. Nevertheless, it was still not apparent how these facets would be incorporated into the lesson. In R4, Mr. T proposed the procedure for the creation of an instruction manual, its revision, and a presentation on how the manual could be amended delivered by both the teacher and the students. He planned two consecutive lessons for these activities, but the discussions in session 4 pertained to how a primary process could be realized from the intricate lesson flow. In R5, Mr. T separated the activities into two parts after contemplating the abovementioned discussions: first, students would be asked to create an instruction manual (lesson 1); subsequently, they would be required to think of a better version (lesson 2). This proposal by Mr. T in session 5 caused all members to further discuss the processes that students should experience from the lesson. It was decided that students should concentrate on the design they created, and not the teacher. The team members confirmed that the production and revision of the manual should both be designated as principal processes for all students. It was also determined that group activity should contribute more to the realization of the desired processes than individual work. Mr. T's lesson plan in R6 explicitly included an activity in which a student group would recreate a motif by reading the manual generated by another peer group.

Second, the task and teaching materials used in the lesson were altered. In R5, Mr. T thought students would freely create an emblem by using parts that were given. In session 5, this issue was debated and it was ultimately decided that students would be provided certain figures to help them focus on the activity of creating and modifying their instruction manuals. Mr. T deliberated on this discussion and stated in R6 that TGF could be used to create two figures (Fig. 2). R6 also included an introductory activity of recreating a simpler figure as pair work. This activity was aimed at motivating students to generate an effective instruction manual because it was assumed that students would find it difficult to communicate how the figure could be made to a friend who would have to draw the figure without looking at it. Mr. T also decided that the introductory phase of the lesson would use a well-known fretwork typical of the Kanuma area in which the school is located (R7).

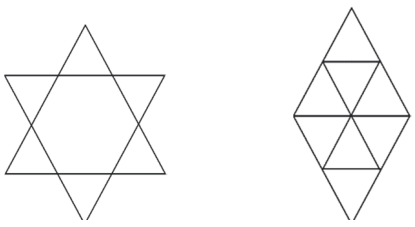

Fig. 2. Two figures used for instruction manual

Tab. 3 outlines the flow of the two consecutive classes implemented by Mr. T for his research lesson.

Tab. 3. The flow of the research lessons

Activity	Brief description	Form of activity
Lesson 1		
Introduction to the Kanuma fretwork	The teacher introduced the traditional and well-known fretwork of the Kanuma area.	
re-creation game	Students worked in pairs. One student was shown a figure and was asked to explain its construction to the other student. The other student then attempted to recreate the figure.	Pair
Presenting today's task and goal of the lesson	The lesson objective was: "Using transformations of geometrical figures to create a better instruction manual to help classmates recreate an original figure."	Full class
Make instruction manual	Six groups of students were formed, with four students per group. Three groups were assigned the pattern shown on the left in Figure 2; the other three groups were assigned the motif on the right. Members of each group worked together to create an instruction manual. The diagram parts were also provided in concrete form in case students needed to manipulate them to attain additional ideas.	Group
Reflection of the lesson	The teacher and students shared information about the events of lesson 1.	Full class
Lesson 2		
Re-creation of the diagram by using the instruction manual	Student groups exchanged instruction manuals and recreated the diagram created by another group by reading the instruction manual. The groups were then shown the original motifs to check for accuracy.	Group
Evaluation of the manual and provision of feedback	Each group thoroughly studied the instruction manual it had used. Members commented on it and returned it to the group that had created it. Students summarized the elements that should be included to make the instruction manual more effective.	Group
Revision of the manual	Each group utilized the comments of their peer group to reassess and modify their instruction manual. Students noted important points that would help them produce better instruction manuals that could help others recreate their motifs.	Group
Summarizing the lesson	Students summarized the aspects to be incorporated to create a better instruction manual.	Full class

4.3. The emergence of diverse perspectives

The above-described examination of modifications made to the lesson objectives and development allows the extraction of three core ideas (perspectives) attained by Mr. T and the other members. These viewpoints aided in the consideration and handling of situations occurring in their teaching practices. In particular, they helped resolve the circumstances of designing an activity for students in a TGF lesson for Mr. T's class.

The first perspective involves "using the language of mathematics." Mathematics offers a common and universal language that enables the clear transmission of one's intentions to others. The lesson objectives outlined in R2, and more explicitly in R5

and R6, indicated that Mr. T aimed to enhance the use of geometrical figure transformations by students to enable clearer, more specific, and more accurate communication. The lesson development sessions involved discussions of aspects that would constitute a "better manual" from the point of view of the language of mathematics (R5). Mr. T further thought about the extent to which students were requested to use TGF words such as "rotation" (R7). These observations in Mr. T's reports suggest that this perspective had existed from the beginning of the sessions because it is closely connected to his motivation for practical research. This perspective thus seemed to underpin the emergence of other viewpoints.

The second perspective is described as "revising the initial method to create a better version." Amending the manual to create a more effective version constituted a core activity of the research lesson. It first appeared in the R4 lesson objective and became the predominant standpoint from its conception. Session discussions entailed how this activity could be actualized and ensured for all students during the lesson. It also became evident that this activity would offer students the opportunity to reflect on their reasoning.

The third perspective denotes "thinking with doubt." It is vital to question phenomena instead of taking them for granted. A statement of this ability first appeared in the R7 lesson objectives. The inclusion of the terms "critical thinking" and "self-assessment" in the lesson objectives appear to mirror an opinion tendered by a researcher (Kawakami) in session 6 that the student activity of evaluation and revision of the instruction manual could be considered relevant to critical thinking, an aptitude that increasingly attracted Japanese mathematics educators. This perspective was thus borrowed from the researcher's point of view and was foreign to the standpoint of the teachers at first. It thus disappeared in R8. Nevertheless, critical thinking ability became a focal point in the sessions conducted after the research lesson because of its theoretical and research-related association with mathematics education (Hino et al., 2020). The evolving nature of this perspective indicates that teachers came to comprehend the significance of theories for their practical research activities.

5. Concluding Remarks

This paper examined the process of designing student learning via the development of a lesson plan for the Grade 7 topic of the geometrical transformation of figures. The lesson objectives and development changed because of the discussions that transpired through the eight described sessions. The analysis showcased in this paper relied on written materials developed by the teachers and the personal notes taken by the author during the discussions. Nevertheless, three perspectives attained by Mr. T (and all other members) could be discerned. These perspectives aided the contemplation and handling of the situation of designing a student activity for the research lesson.

The three perspectives did not develop simultaneously. The perspective of language emerged in the earliest session and underpinned subsequent discussions. Initially, this core view represented the lesson objective. Later, it became the object of discussions on lesson development. The perspective of revision also became evident in the early sessions and continued to be debated and stated both in the lesson objectives and the development of the lesson outline. The notion of doubt appeared

later and appeared to have been instigated by a researcher. Discrete but related perspectives were thus evoked in different contexts and at diverse times. Fujii (2016) insisted that lesson planning is a critical component of lesson study. This study's discernment of the three perspectives validates Fujii's (2016) claim of the vital role of lesson planning.

The analysis of changes in lesson objectives and outline development reveals the critical functions discharged by the university researchers in the discussions (see also Iwasaki and Miyakawa, 2015). The researchers proposed individual ideas and interests that contributed substantially to the development of perspectives in the teachers. Moreover, the study's analyses indicate the significance of the problems and interests vis-à-vis mathematics teaching the teachers brought into the MPD (see also Makino and Hino, 2018). They remained pivotal as they engaged in their practical research.

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