Lesson Study as a Tool for Professional Development: A Case of Undergraduate Calculus

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1. Introduction

The study of student learning of and difficulties with undergraduate calculus has been a major part of mathematics education research for over a decade (Ferrini-Mundy & Graham, 1994). The professional development of mathematics teaching assistants (M-TAs) is also a growing concern. Lesson study is a professional development and research approach developed in Japan that is increasingly being used in the United States in K-12 (Fernandez, 2002) and undergraduate (Roback, Chance, Legler, & Moore, 2006) settings. This study used the experiences of a group of graduate teaching assistants participating in a lesson study for a calculus lesson to investigate the potential of lesson study as a professional development tool for M-TAs.

2. Background

2.1 Mathematics Teaching Assistants

For the purposes of this paper, mathematics teaching assistants (M-TAs), are defined as graduate students in mathematics who are appointed to teach undergraduate mathematics courses. Across institutions, M-TAs teach courses from fundamental algebra to upper-level calculus. The foundational mathematics courses may be the last course many undergraduate students will take in mathematics or they may be stepping-stones to additional mathematics courses in undergraduates' academic careers. Furthermore, graduate students across the United States are often appointed as teaching assistants where they are solely responsible for the instruction of undergraduates. Therefore, supporting M-TAs in their development as teachers of

mathematics could have a positive impact on undergraduate students' development of mathematical knowledge as well as an appreciation for mathematics writ large. Typically, M-TAs have at least a Bachelor's degree in mathematics, and are, thereby, assumed to be mathematically proficient in the material they teach. Although M-TAs may be confident in their knowledge of mathematics content, they may have little or no pedagogical training prior to teaching. Furthermore, they may have few professional development opportunities (outside of potential learning opportunities from experiences in their classroom while teaching) and little support as classroom instructors (Speer, Gutmann, & Murphy, 2005).

Based on the academic background and lack of prior teaching experiences of typical M-TAs, it is likely that their teaching could benefit from opportunities to grow in their pedagogical content knowledge, such as understanding common student misconceptions or multiple representations for a concept (Ball, Hill, & Bass, 2005; Shulman, 1986b). Despite significant research related to K-12 teachers' mathematical knowledge (Ball, Lubienski, & Mewborn, 2001; Fennema & Franke, 1992; Ma, 1999; Munby, Russell, & Martin, 2001; Shulman, 1986a, 1991) there has been little research regarding collegiate-level mathematics instructors' knowledge for teaching mathematics (Speer et al., 2005; Speer, Strickland, Johnson, & Gucler, 2006). It is important to examine M-TAs' knowledge for teaching mathematics and determine how to encourage M-TAs (as current teachers of undergraduate students and as potential future faculty) to become informed consumers of texts, old syllabi and assessments, and shrewd investigators of student thinking and learning.

2.2 Professional Development

Professional development (PD) literature has stressed the need for PD opportunities to be transformative and grounded in the work of teaching (Ball & Cohen, 1999; Thompson & Zeuli,

1999). In particular, Ball and Cohen stress the importance of situating teachers' professional learning opportunities within their work of teaching: helping the teachers to change their practices and supporting a sustained change using integrated and applicable professional development. Thompson and Zeuli stress the importance of determining what core content and pedagogy teachers need and providing PD that encourages a deeper understanding of these core ideas. The core content and pedagogy needed should provide knowledge, understanding, and strategies for teachers that would help them provide opportunities for students to think and engage with the content (Thompson & Zeuli, 1999). While these authors studied K–12 classroom teachers, there is no reason to believe their findings would not transfer to undergraduate classrooms.

The suggestions for PD strategies cited above imply that PD opportunities for M-TAs should include opportunities to examine their teaching practices and implement and adopt a variety of potentially new teaching strategies that support student learning. The purpose of this study was to determine how the implementation of such transformative PD strategies was possible at the college level. Since the lesson study process (see Fernandez, 2002; Roback, Chance, Legler, & Moore, 2006) encourages teachers to carefully analyze their own teaching practices and student thinking, we explored the potential for this process to be a viable professional development strategy.

2.3 Lesson Study

Lesson study is a Japanese professional development activity that has its roots in the early 1900s and has widespread use in the Japanese elementary and middle schools. The purpose of lesson study is to systematically examine teaching practice and student learning. It is both an opportunity to do research and a form of professional development that is situated in the practice

of teaching. The authors of this paper learned about Lesson Study though Fernandez & Yoshida (2004) and subsequent conversations with Makoto Yoshida. Unless otherwise cited, claims about Lesson Study in this work are from one of those two sources.

Lesson Study is a cyclic process with four stages: *study*, *plan*, *teach*, and *reflect*. The process begins when teachers choose an overarching goal to guide their lesson. The goals may be part of the school's mission or they may be specific to the domain in which the Lesson Study will be enacted. Some examples of overarching goals that have guided Japanese Lesson Study groups are: to develop lessons that encourage students to learn from each other, to develop mathematical lessons that that provide students a feeling of satisfaction and enjoyment of mathematical activities, while fostering their ability to have good foresight and logical thinking, and to focus on problem-solving-based learning in mathematics in order to promote students ability to think autonomously, invent and learn from each other. Once the Lesson Study group has identified the overarching goal that will underlie their lesson, they chose a lesson topic and then set student learning goals for the lesson.

The study phase of the Lesson Study cycle incorporates the Lesson Study teachers' knowledge of students and student learning and previous experience teaching of the topic. In addition, the teachers consider the entire chapter or unit that surrounds the lesson. They think about how the lesson they are planning fits into the unit and the competencies on which the lesson builds. Furthermore, they examine the books and activities available for teaching the lesson before planning their own lesson. In the planning stage of the Lesson Study minute attention to detail is employed. Not only is an exhaustive lesson plan created, the teachers also choose manipulatives, sometimes having to develop and create their own, and specify what will be written on the chalkboard and in what arrangement, particularly what will be visible at the end

of the lesson. The Lesson Study lesson plan uses a four-column format with the following column headings: (a) learning activities and key questions, (b) student activity and expected responses, (c) teacher's responses and things to remember, and (d) goals and evaluations.

Once the lesson has been planned, it is taught by one of the teachers while the other teachers observe. During the observation the other teachers circulate through the classroom to evaluate the students' learning. They may talk to the students in order to ask clarifying questions about student understanding, but they may not help teach the students. After the lesson has been taught, during the reflect phase of the Lesson Study, the teachers discuss the lesson and their observations. Often, changes are made to the lesson based on the observations and the lesson is re-taught by one of the other teachers. In the re-teaching of the study lesson, more guests, such as other teachers in the school or district or district supervisors, may be invited to observe the lesson and then reflect on their observations. Through the larger observations and a summary booklet of the Study Lesson, the reflections of the Lesson Study group are disseminated to other teachers and become part of the next Lesson Study cycle in the study phase. Japanese teachers consider lesson study very beneficial and an important part of improving their practice (Fernandez, 2002).

3. The Case

The remainder of this article details a case of the use of Lesson Study with M-TAs. We consider this paper, along with the companion paper, Otten, Park, Mosier, and Kaplan (2009), the opportunity to disseminate the findings of our Lesson Study project to a wider community with the hope that we will contribute to another cycle of Lesson Study.

3.1 Participants

The Lesson Study described in this paper was enacted as part of a one semester graduate

class called Teaching College Mathematics that was designed as professional development for mathematics education Ph.D. students who plan to teach in a mathematics department in their future academic careers. The first author on this paper was the instructor of the graduate class and oversaw the Lesson Study process. The third author on this paper taught the study lesson described and the second author enacted the case study of the second author. In addition, the Lesson Study team had three other mathematics education graduate Ph.D. students. The five graduate students were in their second and third years in the mathematics education Ph.D. program and were either currently, or had recently been, M-TAs for a variety of courses. Four of the graduate students had masters' degrees in mathematics, three were certified to teach high school and one had high school teaching experience. The instructor of the study lesson was the least experienced teacher in the group. He taught at the college level for the first time in the Spring 2008 semester for a *Survey of Calculus* course and, at the time of this study, he was teaching the number theory course for prospective elementary teachers.

3.2 Procedure and Lesson Study Process

The Lesson Study group began the study phase of the Lesson Study cycle at the beginning of the Fall 2008 semester. The team spent four weeks reading about the Lesson Study process and, once a calculus topic had been chosen for the Study Lesson, reading research on calculus learning. In addition, each graduate student completed an individual literature review in order to narrow the focus of the observation and reflection phases of the Lesson Study. It was through the literature review process that the second author decided to enact a case study of the third author and that the third author was chosen as the Study Lesson teacher.

The Lesson Study group had four collaborative planning sessions of 2½ to 3 hours in length, one each week for four weeks beginning September 30. In between the planning

meetings, organizational tasks were completed individually by the Lesson Study participants. On October 28, the third author taught a practice version of the study lesson. The other members of the planning team and a few invited guests, who provided feedback on the lesson, were in attendance. Following the practice lesson, the Lesson Study group met for an hour to reflect on the practice lesson. The Lesson Study team met for 90 minutes on October 31 to complete the planning of the actual Study Lesson. The lesson was taught on November 3 and we held the final reflection session for 105 minutes on November 4.

In addition to these meetings, the second and third authors completed three semi-structured interviews. The first took place after the Study phase of the project, but prior to the beginning of the planning phase and covered the instructor's prior experience teaching a Survey of Calculus course during the spring of 2008 and his expectations for the Lesson Study process. It lasted for 30 minutes. The second interview took place after the initial month of planning and prior to the teaching of the practice lesson and gave the instructor a chance to discuss how he felt the Lesson Study process was going and lasted 18 minutes. The final interview took place immediately after the teaching of the Study Lesson. It gave the instructor a chance to discuss how he thought the lesson went and it lasted 15 minutes.

Figure 1 provides a representation of the timeline for the Lesson Study and Case Study process. With the exception of the third interview, all of the planning and reflection meetings were audiotaped, as were the interviews. The Study Lesson was videotaped using 4 video cameras, one of which was focused only on the instructor. The transcripts and field notes of the meetings, interviews, and lessons form the basis of the results documented below.

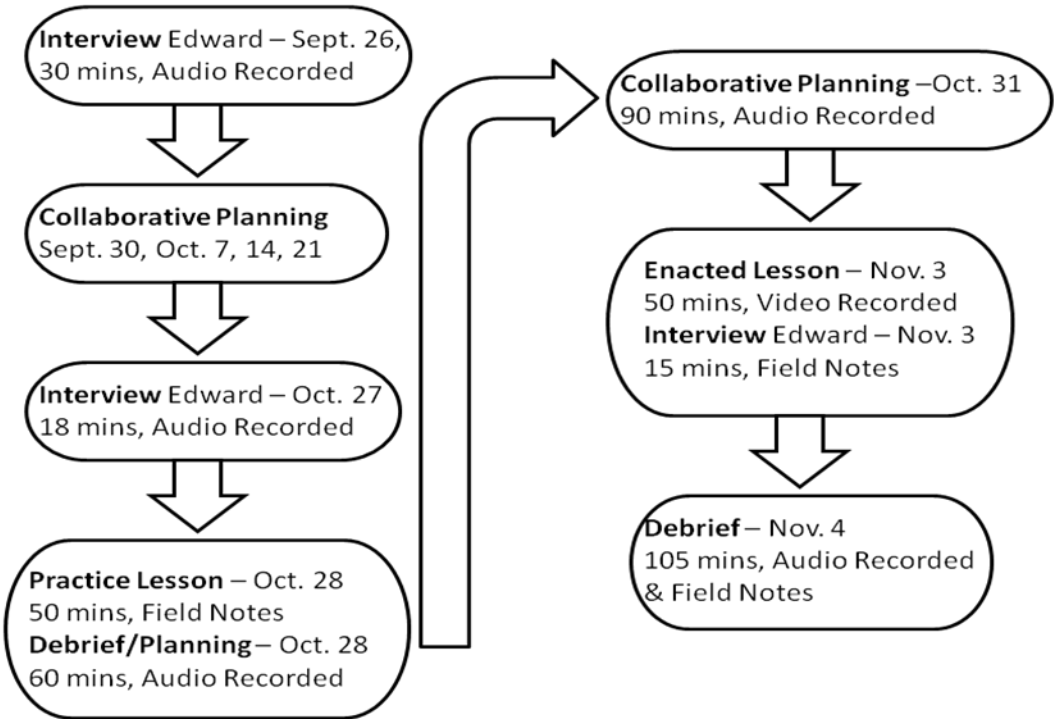

Figure 1: Study design

4. Reflections

The results of this paper can be thought of as outputs of the reflect stage and inputs for a future study stage that could occur if this group participated in lesson study again or that might inform other groups wishing to do Lesson Study in undergraduate classrooms. Reflecting on the Lesson Study process, we identified several major themes that represent learning opportunities Lesson Study can offer as professional development. These themes are collaboration, ownership of the lesson, comfort zone of the teacher, visual presentation, and teacher noticing.

Lesson Study offers opportunities for sharing and critiquing each other's ideas that were different from those offered by the type of course meetings previously experienced by the Study Lesson instructor and participants. As part of the collaboration, the group brainstormed authentic activities that would meet the goals of the Study Lesson. Through the brainstorming, activities for the lesson were generated that the planning team acknowledged they would not have thought

of on their own. One activity centered on the family of normal density curves, another involved the use of dynamic graphical methods and software and the third was based on a research paper detailing a dog's use of calculus at the beach. For a more detailed description of the lesson activities, see Otten, et al. (2009).

While collaboration can lead to a more interesting lesson, for both the students and the teacher, it is not without its drawbacks. The participants in this Lesson Study had similar beliefs about teaching and learning. Even so, we had some difficulty coming to consensus about the lesson. If the members of a Lesson Study group had very different beliefs about teaching, they might have more difficulty coming to consensus. The resulting lesson might be even more mathematically robust and dynamic because of the conflicting perspectives during planning, but it would certainly add to the time commitment of the Lesson Study process.

Another prominent theme that emerged from reflecting on the Lesson Study process was the impact of collective ownership of the lesson and the importance of the instructor to fully own the lesson. As the third author taught the practice lesson, it was evident that he did not have as strong of an understanding of the parts of the lesson that he did not personally create. This lack of ownership of the entire lesson was less noticeable during the actual study lesson, but was still present despite the third author's attention to this issue in the interim. Knowing the purpose and rational for each part of the lesson is important, but that is something that can be lost when a group constructs a lesson. This should not be thought of as a disadvantage to the use of Lesson Study, but rather something that should be kept in mind in future Lesson Study cycles. It is also something that might affect M-TAs when constructing lessons out of a textbook. An interesting research question might be to study whether and how M-TAs consider why textbook authors chose to include certain topics and examples and the order in which they are included in the way

that the third author was forced to think about why certain examples had been included in the study lesson.

Although one can become a better teacher by trying new things, sometimes one can be stretched too far. In this study lesson, we saw several things that pulled the third author too far out of his comfort zone and negatively impacted his teaching. These were stumbling blocks to which we would pay special attention in future lesson studies and which we would advise those wishing to embark on Lesson Study to consider. The third author was teaching content that was new to him to a new group of students. In retrospect, there are ways in which the study lesson might have introduced fewer new variables. For example, the lesson could have been taught in a course that the third author had already taught or focused on content that he had already taught.

In addition, the lesson incorporated technology with which the third author was unfamiliar. Large sections of the practice lesson were written in Geometer's Sketchpad. The third author had never taught using a computer before, and had limited familiarity with the software program Geometer's Sketchpad. Attempting to teach with these new approaches was cumbersome and uncomfortable for the third author during the practice lesson. For the actual study lesson, much of the Geometer's Sketchpad content was presented in static Microsoft Powerpoint slides, a software with which the instructor was more comfortable and familiar. The use of technology in the actual study lesson went more smoothly.

The use of a computer during the study lesson, however, contributed to some unexpected difficulties with the visual presentation of the material. As is customary in Lesson Study planning, the group had decided what and how to present the desired content using the computer and the projector, as well as chalk and the chalkboard. One expectation was for the third author to write particular keywords and lists on the chalkboard to help guide class discussions. The

group had not taken time, however, to think through the interaction of the location of the screen, in the middle of the chalkboard, and the written content on the board. After writing a few things on the chalkboard, the third author realized that written material on the chalkboard, on either side of the screen, would be blocked by the screen itself for the students sitting on the opposite side of the room. Not sure of an immediate and reasonable solution, he stopped writing on the chalkboard altogether, which was to the detriment of the lesson. The discussion of this issue in the reflection session after the study lesson, served as a reminder to redouble our efforts as instructors to think carefully about our visual presentations in the classroom.

One of the most important realizations for the group involved what teachers notice in a classroom. Multiple observers in the classroom for the study lesson provided additional observations of student behaviors than are typically capable by an individual M-TA. Having multiple observers allowed the third author to be made aware of several mistaken observations he had made about the students and the lesson. In one case, the third author had asked the class if there were any questions before moving on to the next topic. He thought that no students had responded, but the observers noticed that one student who was out of the instructor's field of vision was raising his hand.

In a second case, the students were given a speed and a distance and were asked to calculate the time needed to cover the distance at the given speed. The error that the Lesson Study group expected students to make, and the reason that time was devoted to the question as an introduction to a group work exercise, was that students would multiply distance by speed rather than dividing distance by speed. During class discussion of the problem, the only student to respond made the expected mistake but then immediately corrected himself without any teacher input. This led the third author to conclude that the students did not have a problem with

that part of the lesson. During the reflection phase, the third author specifically suggested removing the class discussion about calculating time from speed and distance to shorten the study lesson. Through the observations and examination of the students' written work, however, it was clear several students make the expected mistake in their original written work. Had it not been for the observations and reflections, the third author might have discarded a valuable aspect of the lesson.

5. Conclusions

The members of the group that enacted the Lesson Study described in this paper agree that Lesson Study was a valuable professional development activity. We make no claims about its comparative value to other types of professional development. We provide a case study and blueprint for other groups similar to ours to follow and share our experiences, but we leave research on Lesson Study as professional development for M-TAs as a possible future direction for the undergraduate mathematics education research community. The important feature of Lesson Study for us was that it represented authentic professional development within the context of teaching and learning and it allowed us to think deeply about student learning and teaching as mathematics educators.

To be fair, the implementation of Lesson Study is a large time commitment. In subsequent conversations with Makoto Yoshida, the U.S. expert on Lesson Study, he claimed that for Lesson Study to be viable, it must become part of the culture of an institution. While it is difficult to imagine Lesson Study becoming part of the culture of a university mathematics department, it is not impossible. Because the Study Lesson may be taught at any time after the students have mastered the pre-requisites, there can be flexibility in when the lesson is taught. For example, a lesson designed for pre-calculus could be taught to beginning calculus students or

a lesson designed for the beginning of a second semester calculus class could be taught at the end of a first semester calculus class.

Mathematics departments that require M-TAs to take a teacher training course could implement Lesson Study in that course, as did the group described in this paper. More experienced graduate students could advise the Lesson Study groups and graduate students and faculty could be invited to the study lessons and reflection sessions. If an institution does not have a teacher-training requirement, Lesson Study groups could be formed in during the Summer semester, perhaps as reading courses for graduate credit. The study lessons could then be taught in either of the two long semesters, again inviting other graduate students and faculty to observe and take part in the reflection session. In this way, Lesson Study might become part of the culture of a department and provide a professional development opportunity for M-TAs and mathematics faculty that is embedded within the work of mathematics classroom teaching.

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