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A US lesson study network to spread teaching through problem solving

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Abstract

Purpose – The purpose of this paper is to describe the design and initial implementation of a lesson study network in the US intended to support implementation of the Common Core State Standards (CCSS).

Design/methodology/approach – Participant observation and artifact collection document the development of the teaching through problem solving (TTP) network over a 14-month period.

Findings – The TTP network draws heavily on Japanese practices (e.g. lesson study) and Japanese materials (e.g. coherent, focussed mathematics curriculum) to support changes envisioned in the US CCSS related to students' mathematical practices and dispositions. The reasons for choice of these key Japanese features are explicated, and teachers' initial reactions described.

Research limitations/implications – The design shows promise for combining teacher "ownership" with implementation of high-quality approaches designed by others; and allowing instructional innovations developed in Japan to flow into US practice. TTP in mathematics has persistently resisted implementation in the US, so the network is designed to target a central problem in implementing the CCSS.

Originality/value – A method for instructional innovations to spread from classrooms in one country to another is suggested.

Keywords Japan, Lesson study, CCSS, Mathematics, Problem solving, Standards implementation, Professional learning

Paper type Research paper

Overview

Decades of reform in the US have sought to change mathematics instruction so that it better nurtures students as problem-solvers who persistently make sense of mathematics, using prior mathematical knowledge to solve novel problems (Common Core State Standards (CCSS) Initiative, 2010; National Council of Teachers of Mathematics, 1980, 1989, 2000; National Research Council, 2001; Stigler and Hiebert, 2009). Yet these reform efforts have not produced widespread or lasting change. The

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authors of *The Teaching Gap* argued that Japanese lessons better embody the goals of US reforms than do US lessons:

> When we watched a Japanese Lesson, for example, we noticed that the teacher presents a problem to the students without first demonstrating how to solve the problem. We realized that US teachers almost never do this. The (US) teacher almost always demonstrates a procedure for solving problems before assigning them to students (Stigler and Hiebert, 1999, p. 77).

This paper describes an ongoing effort to create a network of US educators focussed on building the student mathematical practices embodied in the recent US CCSS (CCSS Initiative, 2010). The design and launch of the network over a 14-month period are described, with a focus on two key design elements: lesson study and use of materials, approaches and expertise designed to support Japanese-style "teaching through problem solving" (hereafter TTP). Together, lesson study and TTP were designed to build both capacity and demand among US educators to nurture students' mathematical practices.

The first part of this paper provides a brief background on problem solving, with a particular focus on TTP in Japan. The next part of the paper explains why we chose to use lesson study in this project and lays out the design of the TTP project. The final sections of the paper address the questions posed to all the implementation projects contributing to this special issue, including the degree of change represented by the new standards, the tension between teacher "ownership" and mandated change, the role of public lessons, the role of grassroots vs nationally initiated lesson study, and the lessons learned.

Background

Problem solving is a central component of mathematics but not one that US students master well, compared to students in other countries. For example, on the 2009 PISA mathematics assessment, which includes problems requiring interpretation of mathematical contexts and application of mathematical knowledge, US 15-year-olds performed significantly below the PISA international mean, whereas Japanese 15-year-olds performed significantly above the international mean (OECD, 2010). The new CCSS for Mathematics (CCSS, 2010) adopted by nearly all US states emphasize the importance of the mathematical practices shown in Table I as a core component of mathematical content. Problem solving is first on the list of mathematical practices that all students should develop. Moreover, the CCSS writing team expects students to learn new mathematics through solving problems (CCSSM, 2012, p. 17). This

Table I. Standards for mathematical practice

1	Make sense of problems and persevere in solving them
2	Reason abstractly and quantitatively
3	Construct viable arguments and critique the reasoning of others
4	Model with mathematics
5	Use appropriate tools strategically
6	Attend to precision
7	Look for and make use of structure
8	Look for and express regularity in repeated reasoning

Source: CCSS (2010, p. 6)

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requires a major shift for teachers and curriculum developers who have seen problem solving as an extra activity to be conducted after teachers teach new mathematics to their students. The classroom instruction that is suggested by the CCSS should provide challenging problems that enable students to learn new mathematics through solving the problems. Thus, US educators anticipate that the CCSS mathematical practices will present a major challenge, since they share many similarities with earlier reforms that have not achieved wide implementation (National Council of Teachers of Mathematics, 2000, 2006).

Teaching through problem solving in Japan

In Japan, nearly a half-century of collaborative work on mathematical problem solving has allowed classroom-based and university-based mathematics educators to negotiate some broadly shared ideas about the nature of mathematical problem solving and how schools can foster it (Takahashi, 2008). Interestingly, Takahashi (2008) notes that many of the ideas about problem solving at the foundation of Japanese mathematics instruction were originally derived from the work of mathematicians and mathematics educators working in the US (e.g. National Council of Teachers of Mathematics, 1980; Polya, 1945; Qu *et al.*, 1991). Over the ensuing decades, Japanese educators have steadily refined ideas about problem solving, along with curriculum and instructional strategies to support them, using lesson study.

The 1999 TIMSS video study drew world-wide attention to the problem-solving style instruction in Japanese classrooms, calling it "structured problem solving" (Stigler and Hiebert, 1999). Stigler and Hiebert (1999) argue that the Japanese classrooms in the TIMSS video study better enact US research-based visions of problem solving than do the US classrooms. One basic feature of Japanese problem-solving style instruction is that problem solving is not an "add-on." Instead, problem solving is how students learn new mathematical content within the curriculum; teachers typically introduce important new mathematical content by having students solve a problem especially designed to illuminate the new content (Liu and Ma, 2006; Takahashi, 2008). For that reason, we use the term TTP to refer to Japanese problem-solving style instruction (a term used, e.g. by Ma (2010) and Van de Walle *et al.* (2010)).

A concrete example of TTP may illuminate how it differs from other models of problem-solving instruction. Before students have been taught about common denominators, the teacher may ask students to devise a method to add unlike fractions (e.g. $1/2 + 1/3$). The students' strategies (such as subdividing a drawing into sixths, using a number line, adding measured quantities and measuring the total, or incorrectly surmising that $1/2 + 1/3 = 2/5$) are presented and discussed, with the teacher orchestrating a discussion that lays the foundation for understanding why common denominators are needed, how to calculate them, and why numerators and denominators cannot simply be added. As illustrated in Figure 1, the sharing of solutions is not the culmination of the lesson, but the start of *neriage* (kneading or polishing) that draws on student solution strategies to build key mathematical ideas. Lesh and Zawojewski (2007) note that "problem solving [is] important to developing an understanding of any given mathematical concept or process" (p. 765). A form of instruction such as TTP that simultaneously emphasizes both mathematical content development and problem-solving may offer an escape from the pendulum swings between emphases on basic skills and problem solving identified by Lesh and

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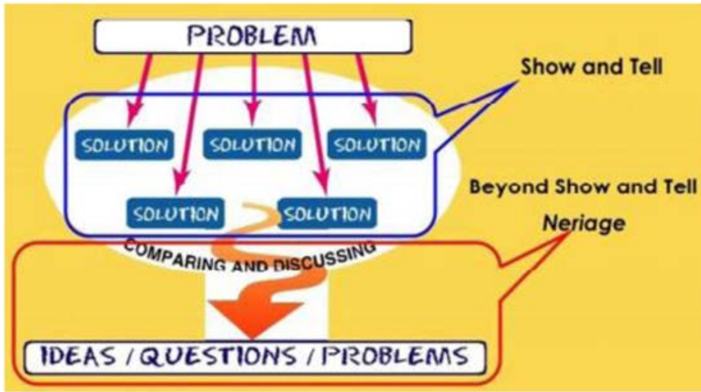

Figure 1.
Teaching through problem solving

Zawojewski (2007) as a major detractor from the improvement of mathematics instruction in the US.

Needless to say, TTP and other forms of teaching through problem solving are very challenging, since teachers must know the relevant mathematics well enough to grasp student solution methods in real time and to recognize whether and how they relate to the key mathematical points that need to be learned (Silver *et al.*, 2005). Yet generalist elementary teachers across Japan routinely use TTP to develop key new mathematical concepts, a situation that was not true 40 years ago. Three related advances have enabled Japanese teachers who, as students, did not learn mathematics through TTP style instruction, to implement it as teachers.

First, Japanese teachers now have available a well-tested set of problems for supporting TTP. Typically, each key new mathematical concept within a textbook has a corresponding problem-solving lesson or series of lessons to introduce it (Hironaka and Sugiyama, 2006). For example, students learn to figure out how to compare crowdedness by solving a problem using two independent measurements, the number of people and the size of the room. The unit continues by giving several different problems so that the students share and discuss their solutions, analyze the commonalities, and eventually develop strategies to compare quantities using the idea of per unit quantities such as population density and speed (see Figure 2). Problems like this often originated in lesson study and have been incorporated into Japanese textbooks as TTP has become a more widespread approach.

Second, the shared textbook problems have enabled teachers to build a shared knowledge base about the mathematics and student thinking related to each problem. For example, the Teacher's Manual provides various strategies students are likely to use and highlights key mathematical aspects of the strategies that teachers need to know to support a productive discussion (Lewis *et al.*, 2011).

Finally, a well-articulated set of instructional practices has grown up around the Japanese TTP approach. These include, for example, the teacher's questioning strategies and use of the blackboard as a model to help students learn how to record, organize, and write about mathematical ideas; tools to help students represent their thinking graphically and explain it to classmates; strategies for development of classroom mathematical norms that support TTP; and journal writing practices that help students to record how and why their own thinking changed and to compare

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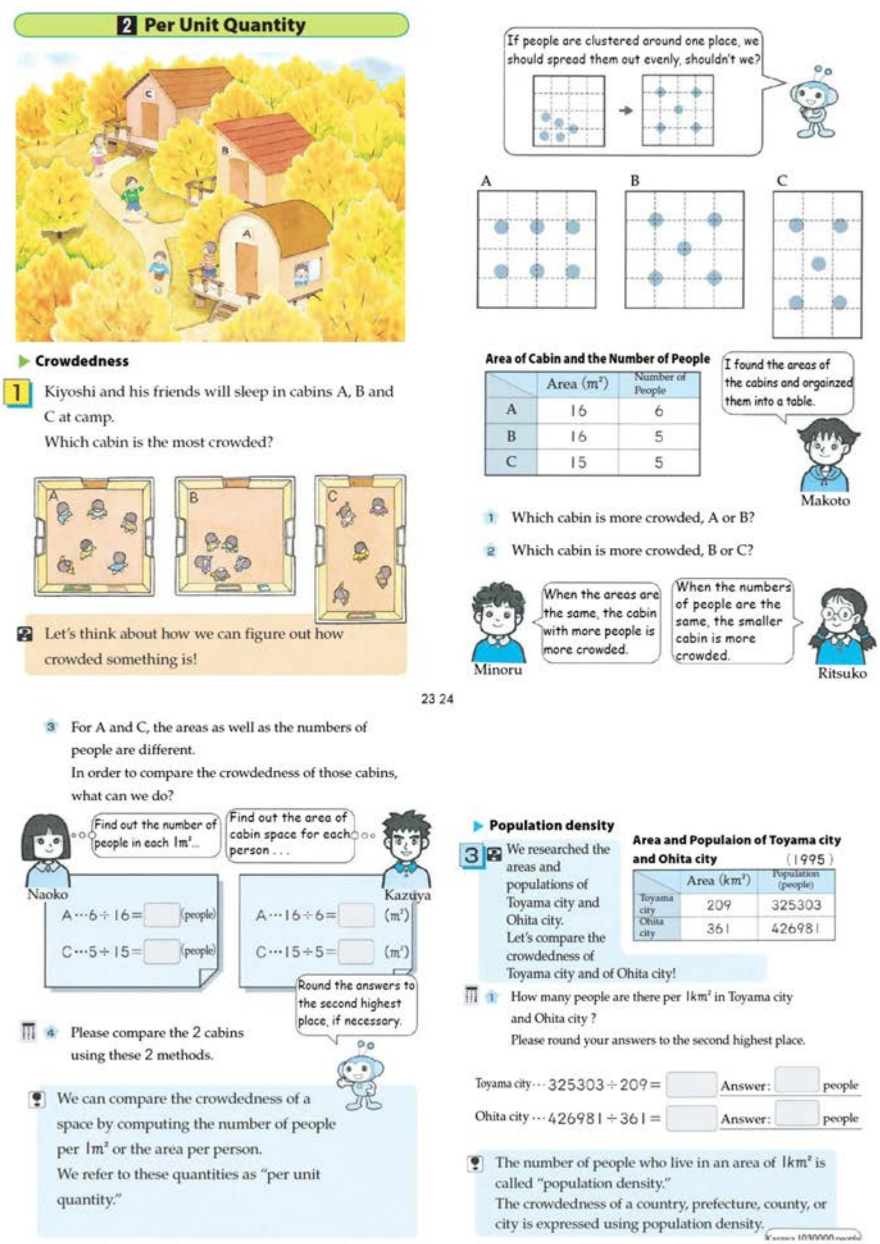

Source: Hironaka and Sugiyama (2006)

Figure 2.
Per unit quantity in Japanese elementary textbook

their own solution strategies with classmates' strategies. In TTP, a crucial part of the lesson begins after students have individually solved the problem and explained their solution strategies to classmates (Takahashi, 2006; Shimizu, 2002a). In the final phase of the lesson, called *neriage* (kneading or polishing), student solution methods are

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discussed and compared, and the teacher organizes the resulting discussion so that the key mathematical ideas underlying the new concept are highlighted, developed, and consolidated. *Yusaburi* (shaking) of students' ideas is often also a key feature of this phase, so that students are confronted with challenges to their ideas, and must reexamine and articulate their ideas in order to respond to the challenges. The various instructional practices needed to conduct TTP have developed and spread in Japan through live lesson study, and have also been captured in print and on video (Mills College Lesson Study Group, 2003a, b, 2005; RBS, 2003; Shimizu, 2002a, b; Takahashi, 2006, 2008).

More than a decade has passed since Stigler and Hiebert (1999) observed the consonance between TTP and the visions of mathematical problem solving embodied in many US standards. During this period, some US practitioners have become very interested in TTP and have integrated it into their own mathematics teaching after studying examples on video or seeing it in live research lessons (Chicago Lesson Study Group, 2010; Global Education Resources, 2007; Mills College Lesson Study Group, 2009). However, despite practitioners' interest, the TTP approach has not spread widely in the US. This is perhaps not surprising, given that the approach requires a confluence of supports, including: well-designed problems; knowledge about the mathematics of the problem and about likely student thinking; and coordinated development of instructional strategies to support presentation, discussion, and revision of student ideas.

Several recent changes in education have made this an opportune time to support the development of TTP in the US. First, many states have recently embraced CCSS in mathematics (CCSS, 2010), paving the way to reduce content overload and give teachers the time to introduce core mathematical concepts through TTP. Second, the Japanese mathematics textbooks through grade 9 are now available in English (www.globaledresources.com/products.html#Books), giving US teachers access to well-designed problems on core mathematical concepts as well as extended examples of student thinking (see Figure 2). Finally, the growing network of lesson study practitioners across many regions of the US provides an established infrastructure for the adaptation, study, spread and refinement of TTP to occur, much as it has in Japan (Lewis and Tsuchida, 1997; Lewis *et al.*, 2012; Takahashi, 2008). In other words, the US now has conditions similar to those that, 40 years ago, allowed a pioneering group of Japanese classroom teachers and university-based educators to start the TTP movement in Japan, a movement that spread through lesson study and eventually reshaped both textbooks and instruction.

Why lesson study?

Three major pitfalls of prior reform efforts in the US led us to include lesson study in the design of the TTP project. First, previous attempts to implement reform of mathematics instruction have often altered surface features of instruction without changing the core aspects of instruction intended for reform (Cohen, 1989; Fullan, 2001). For example, educators might add manipulatives to mathematics instruction without making the deeper shift from procedural knowledge to conceptual understanding that the manipulatives are supposed to support. Changing core aspects of instruction – such as shifting from a focus on teaching mathematical procedures to having students do mathematics – is likely to be difficult because several aspects of instruction (e.g. tasks, goals, teacher, and student contributions) must be changed simultaneously.

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Lesson study using Japanese materials and approaches has the potential to support such complex change, since it allows for multiple cycles of inquiry by teachers over time (rather than one-shot learning), and for teachers to collaboratively make sense of new materials, plan and observe classroom instruction, and analyze student thinking. For example, doing mathematics requires high-quality tasks within a coherent curriculum, the mathematical, and pedagogical knowledge to implement these tasks skillfully, and the disposition and skill to elicit, analyze, and respond to student thinking, among many other things (Lampert, 2001). Teachers are not likely to develop such a complicated array of knowledge, skills, and dispositions simply by watching a video or demonstration lesson or reading standards or articles; they are likely to need repeated cycles of study, trial in the classroom, reflection, refinement, and trial again (Clarke and Hollingsworth, 2002; Etchberger and Shaw, 1992; Fennema *et al.*, 1996; Jaberg *et al.*, 2002).

Second, lesson study allows educators to develop a common vision of what reform ideas actually look like in practice. An experience from our prior research highlights both these problems. During a large public classroom research lesson in 2001 designed to bring to life the California state standards related to problem solving, lesson observers (who included practicing teachers, site administrators, and university-based mathematicians) disagreed sharply about whether the public lesson had been relevant to "problem-solving" (Mills College Lesson Study Group, 2003a). While most audience members, including the mathematicians, argued that the research lesson epitomized mathematical problem-solving processes such as using prior mathematical knowledge, searching for patterns, and organizing data to solve a novel problem, some (including one author of the state mathematics framework) argued that "problem-solving" in the state framework referred to solving word problems in order to apply previously learned mathematical content. This discrepancy in views illustrated the need to see instruction together – not just draw on one's own mental images – to discuss and develop a shared understanding of problem solving. As one Summer Institute participant wrote after the first day's research lesson: "We had a common ground from which we were able to compare our experiences with the lesson observed today."

Third, prior reforms have often found it hard to join the strengths of teacher "ownership" and research-based knowledge. Because changing instruction is hard work, it requires sustained motivation on the part of teachers. Reforms need to build teachers' leadership and sense of "ownership" of change, if the hard work of changing practice is to be sustained and spread. However efforts to build teachers' ownership, through means such as co-development or adaptation of the reform by teachers, can undermine key reform features, if teachers alter novel features to fit their familiar instructional models (Fullan, 2001). Lesson study with high-quality materials provides a way to join the strengths of teacher "ownership" with introduction of well-tested, high-quality resources and models.

Design of the teaching through problem-solving project

During Year 1 of the TTP project, we recruited (from across the US) six lesson study groups interested in developing TTP in their practice. Each group included at least one elementary teacher (teaching grade 3, 4, or 5) and made a commitment to attend a four-day Summer Institute in 2012 and to conduct two lesson study cycles during the 2012-2013 school year, as well as to attend a second Summer Institute in 2013 and to recommend some colleagues to join the TTP network. This paper

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focusses on two key features of the TTP project: lesson study and the use of instructional materials, approaches, and expertise from Japan. These project features were designed to respond to core challenges of reform by providing a means to support repeated cycles of practice-based learning and a way to help teachers integrate high-quality outside knowledge with their own knowledge and practice.

The Summer Institute was observed and video recorded and teachers were asked to write daily reflections on their learning. For the local lesson study work, teams video recorded their lesson study meetings and research lessons, submitted their research lesson plans and submitted lesson artifacts (such as student work). In addition, participants completed individual written reflections at the end of each lesson study cycle, focussed on the following prompts:

- What we learned about teaching through problem solving; What we learned about the mathematical topic and how to teach it; and
- Implications for our next lesson study cycle on teaching through problem solving (e.g. topics to investigate, modifications to the lesson study process, etc.).

Excerpts from these data sources are used below to illustrate the experiences of participants.

1. Lesson study

Lesson study is a collaborative, practice-based inquiry cycle that centers around study, planning, observation, and analysis of actual classroom lessons (research lessons). Lesson study plays two roles in the TTP network. During the Summer Institutes, research lessons are used to bring to life TTP strategies, in order to provide a more vivid and multi-dimensional experience than can be provided solely through print or video materials. For example, teachers can actually observe students during the research lessons and collect data on student thinking, can query the instructor about the rationale for various instructional decisions, and can discuss and debate elements of TTP with other educators who have seen the same lesson, but may have a different viewpoint, or may have observed a student with a distinctively different experience.

During the school year, teachers conduct two cycles of lesson study at their site, in order to practice, observe, and refine their use of TTP strategies. In this local work, teachers try out strategies they have seen at the Summer Institute or studied in the materials, and they have the chance to adapt these as needed to their own site. In the two local lesson study cycles, teachers use materials designed to support lesson study on fractions and area of polygons. Materials on lesson study (drawn mainly from Lewis and Hurd, 2011) are integrated with materials on fractions and area of polygons, drawn from the Japanese elementary curriculum and from US research (see, e.g. Figure 3). Learning about TTP is expected to occur for teachers as they engage in lesson study on these two mathematical topics, supported by the mathematical resources. So, for example, teachers anticipate student solutions to the problem as shown in Figure 4, decide which student solutions should be presented to the class, and also consider the sequence of presentation.

A common feature of the two lesson study experiences is collaboration. Teachers draw on each other's ideas at every phase of the lesson study cycle: as they study the

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⇒ We recommend that members of your lesson study team individually solve each task and note how you solved it before discussing it with the group.

⇒ [3]Problem 3

Jim has $\frac{3}{4}$ of a yard of string which he wishes to divide into pieces, each $\frac{1}{8}$ of a yard long. How many pieces will he have?

A) 3

B) 4

C) 6

D) 8

Notes on your solution method:

⇒ Discussion Questions:

- Explain what 70% of responding 4th grade students might have been thinking when they answered the above question incorrectly on a national assessment. (27% of 4th students answered correctly; 3% did not respond). (No additional detailed student work was available for this problem.)

Source: Problem from National Center for Educational Statistics (2003)

Figure 3. Excerpt from project lesson study materials on fractions

curriculum and content during the early part of the lesson study cycle, plan the lesson, observe and gather data, and refine their approach.

Another common feature of the two πes of lesson study is the opportunity for teachers to notice student thinking, and the information and motivation it provides. As one participant in the Summer Institute wrote:

> Watching the children provided great insight into student thinking. I am learning to slow down and more deeply consider the student perspective (7.18.12).

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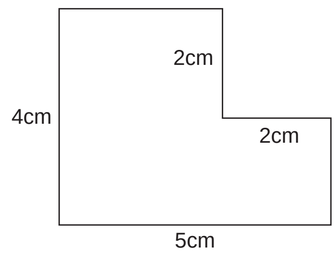
Problem 2

Make the following shape on a geoboard (or dot paper) and find the area. (From "Can You Find the Area?" series of lessons on video by Akihiko Takahashi.)



Problem	What This Problem Might Build/Reveal
2: Area of L-shape	Do students see that the L-shape can be decomposed in various ways? That it can be conceived as part of a larger rectangle? Do they see the additive nature of area? Do they accurately structure the space inside the figure into square units? Do they understand what needs to be done in order to use multiplication to find area of the L-shape? Do they write mathematical expressions for the total area?

Figure 4.
Excerpt from project lesson study materials on polygon area

2. Instructional materials, approaches, and expertise from Japan

Research suggests that, over the last three decades, many Japanese elementary teachers have successfully made the shift from mathematics teaching as the teaching of procedures toward TTP (Shimizu, 2002b; Takahashi, 2006). Japanese textbooks are designed to support teaching through problem solving, and an extensive body of knowledge has been built up within the Japanese teaching profession about how to support students doing mathematics (rather than simply learning mathematical procedures). Rather than re-invent the wheel, we drew heavily on Japanese materials, approaches, and expertise, as detailed below.

How much of a change are the mathematics CCSS?

Many of the ideas underlying the CCSS have been advocated for a long while in the US However, these ideas represent a major departure from current instruction (CCSSM, 2012; CCSS Initiative, 2010). In the CCSS, mathematical practices are regarded as a key aspect of mathematical content, not simply as a process by which mathematical learning occurs. Data from a pilot study for the TTP project reveal that US teachers, even in an affluent, high-tech community see the mathematical practice standards as only a very occasional part of their current practice. During a lesson study cycle focussed on the TTP pilot materials, teachers discussed the questions "What mathematical dispositions and habits of mind do you want students to develop?" and "What do you currently do to help students develop these dispositions and practices?" Surprisingly, the first responses had to do with "problem of the month"– something done only once a month, and with measurement activities that might happen to occur during science, and with "any kind of group work, even if it's not mathematical." One teacher reflected on how their routine math program did not necessarily evoke problem solving: "I'd hate to think you can turn off your problem-solving brain when you start Every Day Math […]" Likewise, teachers at the

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first Summer Institute wrote that TTP represented a major departure from their current instruction, and would not be easy to implement:

> When I think about all the attributes of TTP that I've learned about, they all seem so important to incorporate into my classroom practice. I'd like to use them all effectively. However, I know it's probably smart to narrow in on certain ones now and take it as an incremental process.
>
> The […] questioning presentation confirmed that our teachers talk too much and Show and Tell too often. Allowed us to reflect on how we must move […] away from this–easier said than done! (7.18.12).

One additional challenge of this project is that the content to be learned by students is not specific mathematical content but rather the mathematical practices laid out in Table I. These practices might be thought of as a set of habits or dispositions that are central to the discipline of mathematics. Teachers must nurture these mathematical practices at the same time that they help students learn about particular mathematical concepts (such as fractions and area). The mathematical practices laid out in Table I are unlikely to be learned in a single lesson or even a series of lessons; students develop these mathematical practices over time, in many different classrooms. So collaboration among teachers during lesson study allows them to investigate the kinds of teaching that will build students' mathematical practices, and to implement such teaching consistently across various grade levels. For example, teachers may be able to build students' sense-making if they agree that the blackboard should provide a clear record of a lesson, so that students can revisit the problem, examine the solution approaches, and consider the connections between different mathematical and visual representations.

How is the tension between teacher "ownership" and mandated approaches handled?

At the beginning of the Summer Institute, teachers filled in the following thought: "A mathematical practice, habit of mind, or disposition I would like my students to develop and carry into their future study:_________________." Teachers then considered what kind of instruction nurtures these desired qualities, and they watched the first day's research lesson with this question in mind. The CCSS mathematics practice standards were provided for reference, so that teachers could use them to spark their thinking about desired mathematical qualities, and to consider qualities of good instruction.

So the project began with teachers thinking about their own long-term goals for students' development as mathematics learners. The CCSS and the TTP resources were introduced as ways to help teachers meet their own aspirations, not as mandates. Lesson study was designed to provide a motivating context in which teachers could connect their own aspirations for students to the teaching strategies they saw and studied at the Summer Institute.

Resources on the following major ideas were presented during the first Summer Institute and included on the project web site Ning (a web site with interactive capabilities):

- information on the Japanese mathematics curriculum and its support for a mathematically coherent learning trajectory, including a curriculum trajectory for area, lesson plans, lesson video, and live research lessons;
- teacher questioning strategies;

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- *neriage* (kneading) discussion and summary of lesson;
- student journal writing; and
- board writing.

The use of research lessons in the Summer Institute allowed teachers to become interested in the topics above in a very natural way. They noticed strategies used by Bill Jackson, the instructor, and asked about them during the post-lesson discussion. For example, Bill wrote student ideas on the board, with student names and mathematical expressions accompanying them, and students appropriated these conventions into their own notebook writing. Figure 5 shows a sample student journal from the final lesson, which shows how students appropriated the strategies Bill used on the board (such as comparing different students' ideas). When participants commented on Bill's skilful use of journals to help students record and reflect on their learning, Bill revealed that he had begun to focus on journal writing after Akihiko Takahashi taught a series of guest lessons in his classroom several years previously. Bill thought Akihiko's strategies – reading the journals each day and making brief comments, and selecting several to be reproduced each day for the class – were powerful but seemed like a lot of work. He reported that:

> [Akihiko] issued a challenge: Try it for a month and if you do not find it useful, then don't do it anymore. I accepted the challenge and have used it ever since.

> I accepted Akihiko's challenge because I wanted my kids to have a better experience in their math class. Seeing Akihiko teach my students was a real eye opener. Afterwards, I felt that the students were being cheated when I taught. Akihiko did certain things that really engaged them and cemented their learning, one of which was the journal writing. I wanted to learn to teach better, like him.

Bill then passed on the challenge to the participants of the Summer Institute, and many took it up. As participants wrote:

> The journal is becoming more of a tool for learning for students. I love using their language and reflections for the opening of a lesson. It makes their words important plus you can devise a "story" about the concept using parts of different students' thinking (7.18.12).

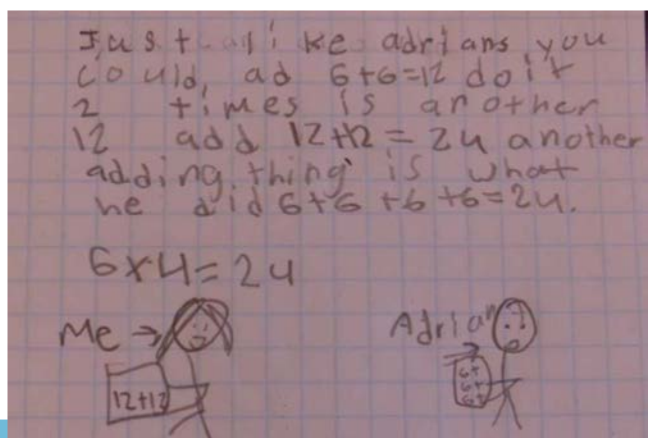

Figure 5.
Student journal from research lesson, Day 4 of Summer Institute

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> I want to incorporate journals into my classroom because I really have seen the value of students keeping a record of their learning. It makes learning very visible (7.19.12).

The preceding quotes reveal how lesson study may create a natural "demand" for improvement of instruction, fueled by teachers' desire to do right by their students, rather than by extrinsic rewards or sanctions.

So that they could concentrate on strategies for building TTP (rather than on crafting a lesson), all groups were asked to focus their first lesson study cycle on area of polygon, and lesson plans, video, and curriculum materials were provided as a starting point for their lesson study work. Participating educators were encouraged to select one pedagogical area from those listed above (questioning, journal writing, etc.) and to join an inquiry group focussed on improving that area of their practice.

How are public lessons used?

Public research lessons (i.e. lessons that outsiders can sign up to attend) were not part of our initial plan for the TTP project. However, two of the six sites decided on their own to open up their first research lessons (taught in fall, 2012) to educators outside the lesson study group. For example, one group elected to teach the research lesson during the State Education Association Professional Development Days, a two-day period when students are out of school:

> We spent the first two hours of the day teaching teachers about lesson study, our lesson progression, and the lesson itself. After this, I had 17 students from my class show up to participate in our lesson. There were approximately 40 teachers in attendance. After the lesson, we conducted a post lesson discussion/debriefing and looked at student work. It was great and we all learned a great deal.

The decision by this team to extend their learning and instructional ideas to 40 other local teachers, and a similar decision by a second team to conduct their research lesson during a public open house, underlines the natural dissemination mechanism of research lessons that can be built into lesson study.

A sequence of four research lessons (one per day) was a central feature of Summer Institute 1. These lessons were observed by all 33 educators participating in the Institute. The framing questions for lesson observation and the post-lesson discussion questions varied over the four days, to provide an opportunity for teachers to focus on various aspects of TTP. For example, on Day 1, observers identified strategies to support students' mathematical practices during the lesson and reflected on elements of the instruction that were similar or different from their own current teaching. On later days, teachers focussed on identification of core mathematical content or on specific strategies such as teacher questioning and lesson summary. Comments such as the following, from a very experienced teacher-leader, suggest that research lessons in the context of a Summer Institute may provide a natural way to connect new instructional ideas to one's own practice:

> Again, I am surprised at the gaps in my teaching. While my students have experienced activities which help them build the formulas for areas, I have not focused lessons on just understanding area. Today reminded me to slow down and think about student understandings for all parts of a mathematical concept. The lesson gave me a new perspective to approach unit planning […]. I deeply appreciate the emphasis on note taking and being explicit with students about key learnings. I am going to figure out how to make this work in my class (BP 7/17/12).

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Another participant wrote about the value of comments from the audience and from master teachers during the post-lesson discussion: "The question 'What would prompt students to use arbitrary units of measure?' has left me thinking deeply about what and how we teach area." Although US teachers are often encouraged to make mathematics lessons relevant to students, apparently the question of what leads students to use particular types of units (arbitrary, standard) was novel. In contrast, the Japanese textbook studied included a lesson explicitly designed to help students notice advantages and disadvantages of arbitrary and standard units (Hironaka and Sugiyama, 2006).

The research lessons at the Summer Institute created a shared classroom example of TTP. We were fortunate to have an instructor who was familiar with TTP and very open to discussion and critique of his instruction, so he modeled not just instructional practices, but also the stance of continuous improvement. We also had three experienced Japanese educators who could provide mathematical and instructional feedback. For at least one of the US participants, experiencing effective feedback in lesson study was a highlight of the first day of the Summer Institute:

> The most useful part was the panel discussion after the lesson because I saw how to be and how to effectively critique and comment on a lesson. So often when my group does lesson study our group discussion gets watered down because the observers are busy trying to be "too kind" and they don't want to offend anyone, especially the teacher. Watching the panel showed how effective genuine critique can be.

Public research lessons are an important way to spread ideas in the future, offering the possibility of rapid scale-up of curriculum materials, instructional strategies, and a learning structure (lesson study) that allows educators to experience first-hand not just materials and instruction, but also the culture and routines of a learning organization.

What is the role of government-sponsored vs grassroots-initiated lesson study

Funding for this project came from US Department of Education competitive grant funding for improvement of teacher quality in mathematics. These funds allowed us to try an innovative method (lesson study, using Japanese TTP materials) to achieve a widely established goal (the mathematical practices within the CCSS).

To conduct the project, we recruited educators already interested in lesson study and/or in improving students' problem-solving capacity. As noted, we tried to help them see lesson study and Japanese TTP materials as resources to help them meet their own goals for students' development of mathematical practices – rather than as something they were required to do. A written reflection from Day 3 of the Summer Institute suggested that some teachers did indeed experience the project as a way to support their own goals for students:

> I have deepened my own math concepts through observing the lessons, having discussion w/my colleagues, learning about TTP, board-writing, neriage. This has enhanced my love of teaching and fueled my determination for doing the right thing in the classroom in the aim of children's deeper understanding.

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Lessons learned

In this section, we draw not only on the TTP project, but also on the experiences of schools and districts in the Chicago area that have begun to use lesson study as a means to examine the implementation of the mathematics CCSS in practice, in preparation for the full implementation of CCSS in the 2014 school year. In this way, we are able to see how the national TTP network interacts with one local area's lesson study.

Chicago public school teachers have been practicing lesson study since 2002. At the beginning of their lesson study endeavor public research lessons were held only at the Chicago lesson study group annual conference, which is scheduled only once in a year with two to three research lessons. One of the major challenges was to find time for teachers to visit other schools to observe research lessons. In the past three years, teachers and administrators at some schools have arranged to conduct research lessons on district professional development days, with voluntary student participants. Meanwhile, a core group of teachers who have been practicing lesson study are willing to teach their research lessons publicly as a way to enrich their own learning and as a way to contribute to the community of practice.

As a result, a few Chicago public schools have started to hold public research lessons during the school year. Since 2010, there have been several research lessons in Chicago public schools to examine approaches to implement the CCSS. These research lessons were opened to other Chicago public school teachers by holding the lessons on district-wide professional development days. These public research lessons attracted about 50 teachers from schools in the area. Although no school in the Chicago area has yet implemented lesson study on a school-wide basis, a number of schools have teams of teachers who are voluntarily practising lesson study with the school administrator's support.

One of the schools that volunteered to join the TTP project is among these Chicago schools. In this situation, government-sponsored and grassroots-initiated lesson study came together, since both administrators and teachers became keenly interested in effective implementation of the CCSS in classrooms. Because the CCSS are seen as very different from the existing state standards, and require major shifts in classroom practice, both administrators and the teachers find lesson study to be an effective way to explore how they can prepare for the full implementation of CCSS. At the same time, the school district's decision to have district-wide professional development days during the school year helps these interested teachers find time to conduct lesson study. Another important supporting factor in Chicago is external people or organizations that bring outside experts to the schools to support lesson plan development and to provide final commentators for research lessons. The Chicago based not-for-profit organization Lesson Study Alliance has been playing an important role to offer these supports.

The Chicago experience suggests that lesson study can be used to spread new teaching practices if: both administrators and teachers see the need to improve instruction; the district and school can find time for public research lessons; and external support organizations contribute expertise for conducting research lessons.

At the same time, university-based mathematics educators working to build lesson study in the Chicago area report that they experience difficulty conducting *Kyouzaikenkyuu* with classroom teachers. Although researchers and leaders of lesson study have highlighted the importance of *Kyouzaikenkyuu* (Takahashi *et al.*, 2005; Watanabe *et al.*, 2008), most US classroom teachers do not have experience of studying

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the curriculum materials for knowledge about subject matter and student thinking when they prepare lessons. Instead, teachers tend to focus on preparing activities and worksheets, rather than studying the content they will teach. When Japanese teachers conduct *Kyouzaikenkyuu*, they seek clear answers about critical questions for teaching, e.g. why I need to teach this topic to my students now, what are the key mathematical ideas that I expect my students to develop through solving this problem, and what are the potential challenges that my students have to overcome?

In order to overcome this challenge, establishing a support structure for teachers is crucial. In fact, school-based lesson study in Japan is usually based on a highly structured support system that provides teachers opportunity to receive feedback from both internal and external knowledgeable educators while developing lesson plans. Through this process, teachers experience effective *Kyouzaikenkyuu* and establish deeper understanding of the content and the instructional materials.

The movement toward implementing the CCSS gives Chicago schools a great opportunity to establish such a system because both administrators and teachers have begun to see the need for a support structure within school buildings, since no single teacher can effectively implement the new curriculum by him/herself. In fact, three Chicago public schools have begun pursuing the possibility of establishing school-wide lesson study in order to effectively implement the new curriculum.

The preceding observations suggest that lesson study in Chicago public schools may be at a turning point from a model of lesson study practiced by groups of volunteers to a model of school-based lesson study. The TTP project, supported by a federal grant, plays a potentially important role by allowing these schools to build their knowledge of TTP and showcase their effort to other Chicago public schools through public research lessons focussed on using TTP to effectively implement the CCSS in Mathematics.

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