Developing Inquiry-Based Teaching Through Lesson Study

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Inquiry-based teaching is widely promoted in mathematics education to help students develop a deep understanding of mathematics and mathematical thinking. In inquiry classrooms, students construct mathematical meaning through reasoning, communicating, exploring and collaborating with peers and teachers while working on inquiry-oriented tasks, including nonalgorithmic problems and investigations (NCTM 1991). However, adopting an inquiry perspective is challenging for teachers because they were taught mathematics that way. This can create a difficult situation when preparing today's students and tomorrow's workers for the demands of the 21st century unless teachers are provided with meaningful learning opportunities to deepen their understanding of inquiry-oriented pedagogy. This article describes such a learning opportunity based on the experience of a group of elementary teachers. Specifically, it discusses a lesson-study approach and the type of knowledge of inquiry teaching and actual teaching resulting from the experience.

Lesson Study

Japanese teachers use lesson study as professional development to systematically examine their teaching to become more effective in teaching mathematics (Stigler and Hiebert 1999; Fernandez and Chokshi 2002). It offers teachers a structure to transmit, reformulate and share craft knowledge through practice and collaboration with peers (Shimahara 2002). It has recently been introduced to North America and is becoming popular for promoting teacher-driven instructional change. Teachers use it to enhance their mathematical knowledge and pedagogical skills, which leads to student-centred teaching in the classroom (Stigler and Hiebert 1999). It fosters improvement in increased development of instructional knowledge and understanding of subject matter (Lewis, Perry and Hurd 2004).

Lesson study involves recursive cycles of planning, teaching, analyzing and revising of lessons that contribute to a continuous improvement model of professional development for teachers. A small group of teachers work collaboratively to plan, teach, observe and analyze the lessons. They start by identifying a goal or problem to explore. This is followed by a recursive cycle composed of four phases: collaboratively developing a lesson plan, implementing the lesson while colleagues and other experts observe, analytically reflecting on the teaching and learning that occurred, and revising the lesson for reimplementation (Curcio 2002; Stigler and Hiebert 1999). During each cycle of implementation, a different teacher teaches the lesson to students in a normal classroom setting while the other group members observe and take notes. Finally, the teachers produce a report on what they have learned from the study lessons, particularly with respect to their goal.

Finding the time to engage in lesson study is a challenge. Unlike North American teachers, Japanese teachers build time into their weekly teaching schedule for professional development. However, the experience of the group of teachers described below shows that lesson study can be adopted effectively.

The Study Group

In spring 2002, 14 Calgary elementary teachers formed a mathematics study group as part of their school's requirement to develop and implement a professional growth plan. Their broad goal was to develop and foster a commitment by all staff to participate in professional growth opportunities to improve the quality of teaching and learning in classrooms. To achieve this, the initial intent was to reflect on their teaching during group meetings. Divisions I and II teachers were represented in the group. Three teachers assumed the role of group leaders to organize meetings and activities. A mathematics education professor joined the group as a mentor in fall 2002. The group met once every three weeks for about one and a half hours at the end of the day.

To highlight the role of the group leaders, the professor will be referred to as the *mentor*, the group leaders as the *team* and the participants as the *group*.

The mentor's role was to provide support, theoretical validation and help in abstracting general ideas from the teachers' thinking and experiences. In general, the mentor acted as a colleague and group participant in sharing ideas and learning from the experience as opposed to being in authority. The mentor had no previous experience with lesson study or teaching at the elementary school level but had taught mathematics methods courses for prospective elementary teachers.

The mentor introduced the idea of lesson study to the group as an approach that can be used to design collaborative learning experiences and encourage growth and continuous improvement. After reading the description of lesson study in Stigler and Hiebert (1999) and with the support of the principal, the group decided to try it. Because this was a new idea for all involved and time was an issue, they decided that the team would participate in the first round of the lesson study and provide feedback to the group. If the approach proved effective, the others would participate in future rounds. The team was granted two days of release time from teaching during the 2003 winter term to implement the first round. This time was allocated as follows:

1. Half day for initial planning to identify a focus, process and schedule
2. Full day for researching, developing relevant ideas and planning
3. Half day for classroom implementation, observation and debriefing

These sessions occurred at different times during the term to accommodate the mentor's schedule and arrangements for substitute teachers for the team.

The positive result of this first round of lesson study on the team's learning led to planning the other rounds to include the whole group. The after-school meetings were used to take the group through the process. In addition, all the teachers received a half-day release time from teaching, during which they planned the mathematics lessons to be studied. Each team member worked with a subgroup of teachers to plan the lessons. The teachers covered each other's classes to obtain the release time to observe the lessons. This way, over three years, 22 teachers had the experience and learned from it. This number was a result of teachers leaving because of other commitments and others entering.

The Lesson-Study Approach

This section describes the different stages of the lesson-study approach in the initial round and summarizes the follow-up rounds.

Identifying a Topic to Study

The team members were interested in inquiry-based teaching but wanted to focus on a specific feature for the lesson study. They identified this feature by examining the philosophy section of the mathematics curriculum document *Alberta Program of Studies for K–9. Western Canadian Protocol for Collaboration in Basic Education* (Alberta Education 1996), which incorporates a perspective of mathematics learning that supports inquiry-based teaching. This document states: "Students learn by attaching meaning to what they do; and they must be able to construct their own meaning of mathematics. The meaning is best developed when learners encounter mathematical experiences that proceed from the ... concrete to the abstract" (p 2). The goals for students include using "mathematics confidently to solve problems and communicate and reason mathematically" (p 2). The curriculum also emphasizes seven mathematical processes (p 4): communication, connections, estimation and mental mathematics, problem solving, reasoning, technology and visualization, all of which can play an important role in inquiry-based teaching if they are interpreted as intended. Thus, the curriculum provided validation and a basis for the starting point to identify a topic to study.

The team members focused on the seven mathematical processes in the curriculum, and after a lengthy discussion and reflection on their teaching, concluded that communication in an inquiry-teaching context was the key process that they would like to study in the first round. As stated in the curriculum, "Students need to communicate mathematical ideas clearly and effectively, orally and in writing" (Alberta Education 1996, 4). But this communication is different from the traditional mathematics classroom where the focus is on transmitting information, copying notes and recording solutions to exercises or routine problems. The team was interested in focusing on other features of communication that allowed students to think and actively engage in their learning. Once a topic for the lesson study was established, the next stage was determining specific features of communication and inquiry-based teaching to use in designing the lesson to be studied.

Video Case Study

The team and mentor discussed possible ways to obtain relevant information about specific features of communication and inquiry-based teaching. Instead of beginning with reading theory on these topics, the team members preferred to study a video as the basis of their learning. The mentor suggested the DVD

series, *Mathematics: With Manipulatives* (Burns 1988). The team chose *Pattern Blocks* and *Cuisenaire Rods*, two of the six DVDs in the series. To have focus in studying the videos, the team and mentor attended to the following: lesson goal, students' role, teacher's role, specific questions posed by the teacher to stimulate and extend students' thinking, classroom environment, nature of inquiry tasks and key features of the inquiry lesson.

After studying the videos, the following key components for inquiry-based lessons were identified:

1. Three modes of communication: oral, written and nonverbal (for example, observing, listening and acting/gesturing)
2. Tasks that allow for open and guided exploration, prediction, discussion and evaluation
3. Student roles, teacher roles and environment (specific features identified are provided in Figure 1)
4. Questions and prompts (examples are provided in Figure 2)

Following the video study, the team later read and discussed the National Council of Teachers of Mathematics (2001) standards on discourse. However, the outcome of the video study formed a key basis for planning the experimental inquiry-based lesson.

Planning the Experimental Lesson

The Grade 1 teacher on the team volunteered her classroom for the first round of lesson testing, thus the team chose a topic from the Grade 1 curriculum to develop an inquiry-based lesson. The topic "explore and classify 3-D objects according to their properties" was selected to correspond with the teacher's class schedule. The team brainstormed different approaches to teach the topic. Each teacher on the team described what she might do in her class.

Teacher One

- Observe objects in classroom
- Discuss why these objects have certain shapes
- Post pictures of objects in the real world around the classroom and use to identify shapes
- Name geometric objects
- Link to objects in class
- Refer to chart with formal names
- Investigate attributes
- Relate to real world—why things have certain shapes

Figure 1: Roles and Environment

Student Role	**Teacher Role**	**Classroom Environment**
Communicate in all three modes	Pose questions and prompts	Manipulatives
Engage in inquiry	Allow time for exploration	Small groups
Collaborate	Select appropriate tasks	Whole-class sharing
Take risks	Allow time for communication	Supportive/risk free
Show curiosity	Observe and listen to	Lots of mathematical talk
Reflect	Support/encourage	

Figure 2: Questions and Prompts

1. What do you notice?
2. What else do you notice that is different?
3. Who can explain how (or why) this makes sense?
4. What do you think the answer (or pattern or outcome) could be? How do you know?
5. How do you know it will (will not) work?
6. Where (or when) would you use this _____?
7. Suppose I want to_____, how can I start?
8. Who can describe it so that I can do it?
9. Present your idea.
10. Explain the problem to your partner (the class).
11. What do you know about _____ (for example, this topic)?
12. Can you make a general statement about _____?

Teacher Two
- Describe geometric objects in groups or pairs
- List names of objects and descriptive words on a chart
- Build a model of one object (a skeleton representation)
- Discuss, comparing skeleton and actual object
- Introduce formal names

Teacher Three
- Pose a problem, for example, build a house with this object
- Discuss attributes
- Explore attributes
- Classify attributes
- Describe common features

Reflecting on these approaches and the outcome of the video study, the team and mentor identified the following set of key components for inquiry-based teaching to use to structure the experimental lesson:

Goal
- Prerequisite
- Free exploration and discussion
- Prediction of properties of concept
- Application of concept
- Testing predictions
- Evaluation of knowledge of concept
- Extension of concept to new situations

Using this structure and key questions to promote inquiry-based communication, the team designed a plan for the experimental Grade 1 lesson on introduction to geometric solids. Figure 3 provides an abbreviated outline of the plan.

Figure 3: Outline of Experimental Lesson Plan

- Free exploration objects (10 minutes) (Talk, experiment and observe in small groups.)
- Discussion (5 minutes). (What did you notice? Record answers.)
- Prediction (5 minutes). (Will objects roll or slide? Record individually.)
- Pose problem/real world application (5 minutes). (Suppose I want to build a house on a mountain, what would I need to know about objects?)
- Test prediction, record results (5 minutes).
- Comparison (5 minutes). (Discuss solutions with partner and support answers.)
- Evaluation (10 minutes). (Venn diagram, sort shapes and make general statements about "What I know about 3D objects.")
- Extension (homework). (Look for things at home and around school that roll or slide.)

Conducting and Observing the Experimental Lesson

The Grade 1 teacher of the team taught the lesson to her students in her classroom. The other team members and the mentor observed and made notes on an observation sheet (Figure 4). The intent was to focus on how the lesson was conducted and how effective the questions and prompts were for communicating the components of the lesson to facilitate meaningful and worthwhile inquiry and learning of the mathematics concepts.

Figure 4: Observation Sheet

Notice?	
Make sense?	
Predict?	
How know?	
Make connections?	
Describe/explain	
Generalize/summarize	
Other	

Analyzing the Experimental Lesson

The lesson was analyzed immediately after it concluded. The observers and the teacher of the lesson shared notes, focusing on communication and the components of the lesson. For the most part, the lesson went as planned. It consisted of the following sequence of activities: brief introduction to set the tone; free exploration (in small groups) of 11 3-D geometric objects; whole-class discussion; individual prediction using worksheet with pictures of the 11 3-D objects and columns for rolls only, slides only and rolls and slides; comparison with a partner; whole-class discussion of an application (think of self as builder); prediction if all will agree; focused exploration to test predictions; comparison and discussion of findings with others; whole-class discussion of findings; 3-D vocabulary of objects and building of Venn diagram on whiteboard with pictures; evaluation/reflection/generalization in relation to goal of lesson; and an application task for homework. These components and activities were effective in creating a learner-centred classroom and promoting inquiry and rich mathematical communication. The children were actively involved throughout the lesson doing mathematics, and thinking and communicating mathematically. The teacher of the lesson kept posing questions that stimulated or revealed their thinking as she circulated during the lesson and during the whole-class discussion. This

allowed her and observers to learn from and about the children based on their ways of thinking. The team was amazed and impressed with what the children were able to do and the richness of their thinking.

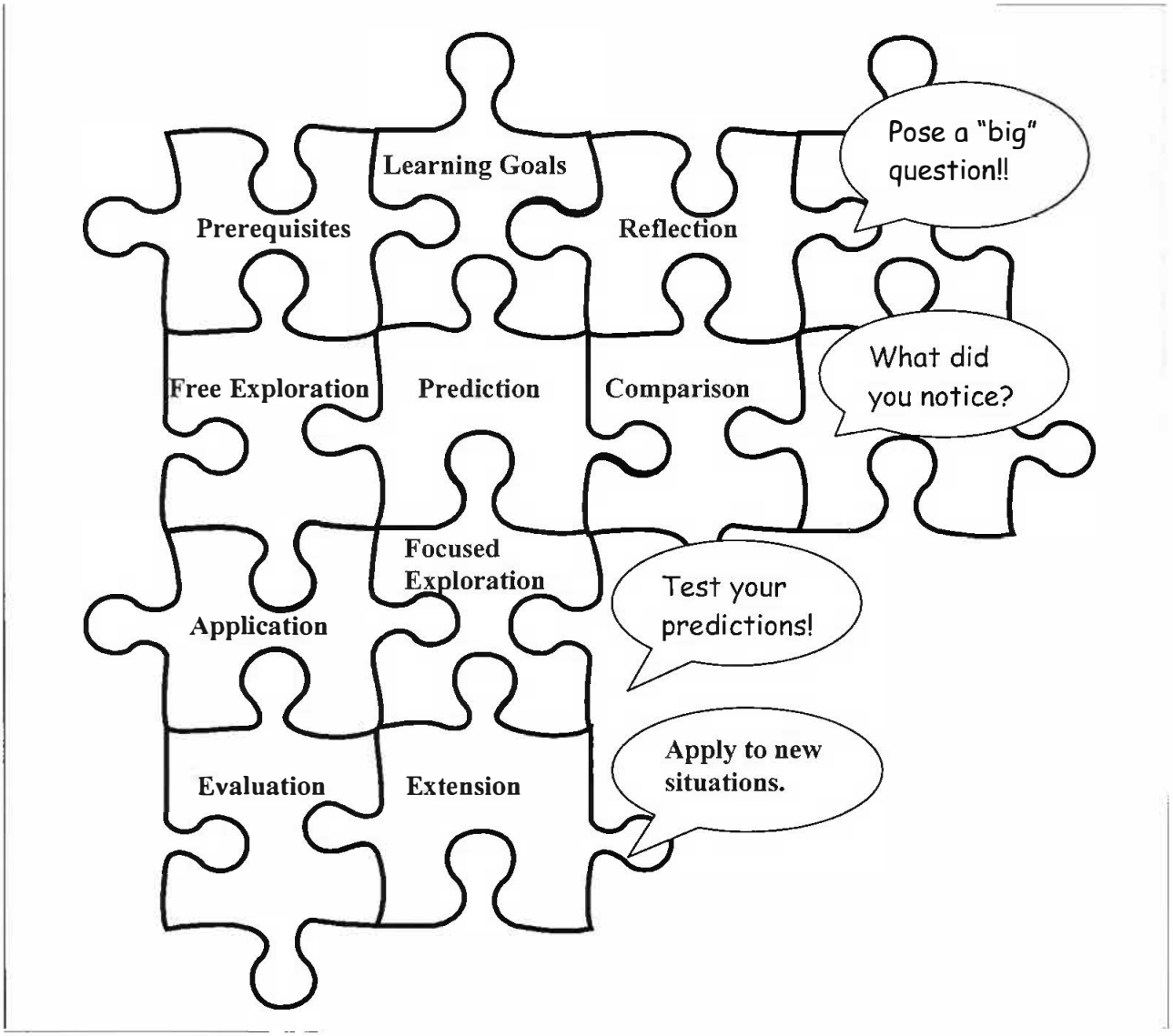
The only change that was identified was to clarify two more components to an inquiry lesson: comparison and reflection. The team members concluded that their inquiry-teaching model was workable, and they felt comfortable and confident implementing it in their teaching. They emphasized that the structure of the lesson is flexible as to which components are used and how they are sequenced. Thus they decided to represent the approach in the form of a jigsaw puzzle, which they called the Jigsaw Teaching Model. The experimental lesson was one way of applying this model.

The Jigsaw Teaching Model

Figure 5 is the final version of the Jigsaw Teaching Model developed by the team to represent the key components of an inquiry-based classroom and key questions and prompts. The model is in the form of a jigsaw because the pieces do not have to follow a linear pattern but can be organized differently, combined or omitted depending on the topic being taught. The pieces represent different components that are important in inquiry teaching.

The model requires the teacher to (1) identify learning goals that include conceptual understanding, (2) expose students' prerequisite knowledge/conceptions for the concept being taught in an inquiry way, (3) have students make predictions about possible

Figure 5: The Jigsaw Teaching Model



outcomes related to the concept, (4) allow students to engage in free exploration of the concept (through discourse and/or using manipulatives), (5) engage students in focused exploration, (6) have students work on application of concept, (7) engage students in comparison, evaluation and reflection of their learning and (8) suggest extension of concept to other situations or related concepts.

Follow-Up Rounds of Lesson Study

The team did not follow the recursive cycle of the lesson study in terms of revising and teaching the same lesson. Instead, they made the Jigsaw Teaching Model the basis for subsequent rounds of the lesson study with the group. These rounds of experimental lessons included (1) the meaning of five (kindergarten); (2) estimation with mass (Grade 3), representing a multidigit number in different ways (Grade 3) with goals that students will understand why the value of a digit changes depending on its position in a number and the meaning of regrouping among hundreds, tens and ones; (3) mental arithmetic (Grade 5) and (4) measurement (Grade 6), for example, perimeter and area.

Later, the teachers also worked on exploring lessons on problem solving in their classrooms. Figure 7 describes a lesson taught four years later by the Grade 1 teacher who taught the first experimental lesson, which shows that the approach was being sustained. The teacher explained:

> The students' thinking started us off on a new game of trying to stump the rest of the class with our ordering rules. Students began to use mass, capacity, width, height, cost, temperature, time and so on to place the objects in order. The discussions that followed were lively and informed. We all learned more than the original activity, and it was a fabulous culminating activity. The following day students were presented with a puddle question about how they could measure a puddle after a rainy day. They recorded their answers in their math journals in the form of a mind map or brainstorming diagram. They used words, pictures, diagrams and so on to show their thinking. Finally they shared their ideas with several partners and discussed similarities and differences. When we listed our combined ideas on a chart, they included length (using their feet), width (using their hands), depth (using pile of rocks), area (using boxes), capacity (using cup measure), weight (using scale to weigh cup and multiplying or repeated addition), temperature (using a thermometer) and time (counting how many minutes/hours for sun to dry up puddle).

This shows what these children are able to accomplish when *their* thinking, not only the teacher's, becomes the focus of the lesson.

Figure 7: Grade 1 Lesson (four years later)

> Learning goals: Students will use knowledge of nonstandard measurement to order objects, recognize that objects can be sorted in a variety of ways and think flexibly when dealing with size.
>
> Free exploration challenge: Find three objects that you can order by size.
>
> Prediction: Is there more than one way to order the three objects?
>
> Comparison: pair/share—Can you guess my measurement sorting rule?
>
> Focused exploration/application: Which measurement sorting rule would change my order? Which rule would not change the order? Where would a fourth object fit? How do you know?
>
> Recording: Record your favourite sorting rule in your math journal. What did you notice about measurement and sorting in this activity? Did you notice any patterns?
>
> Extension: How could you measure a water puddle after a rainy day?

Conclusion

The lesson-study approach helped these teachers create shifts in their thinking and teaching, and develop useful knowledge of mathematics teaching. They reported deeper and more meaningful understanding of the following inquiry teaching:

- questioning techniques that guide and enrich student thinking;
- open-ended, thought-provoking questions to motivate students to discuss and understand mathematics at a deeper level;
- student-centred strategies for listening to students and observing their problem-solving behaviours; and
- strategies that allow students to assume ownership of their knowledge and knowledge construction.

With these shifts, students were more involved in mathematics as a way of problem solving, reasoning, communicating and connecting to their world.

The teachers also valued the collaboration during the lesson study; that is, being a part of the group process of planning, observing, debriefing and sharing specific examples from classroom work. As one teacher explained, "It was a powerful experience to hear the student communication that an observer can

record, but which the teacher misses as she focuses on presenting the lesson and maintaining classroom management." In general, their collegial focus on mathematics instruction increased, and they articulated and demonstrated a renewed interest in mathematics. Most important, they learned an approach that they can use for ongoing learning and growth in their teaching. They offer their experience in the article as an example of an approach other teachers could adapt in their quest to inquiry-based teaching.

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