Building Capacity in Technology Use through Research in Lesson Study A Partnership Project with KPRDSB, Trent University, the University of Toronto, and the Ontario Ministry of Education

Summary Report

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I. Executive Summary

Background, scope, and place within existing literature

This project emerges from recommendations from various governmental policy documents encouraging school boards to increase the development of professional learning communities for teachers of mathematics especially those with a focus on increasing teacher capacity with information communication technologies. The Math GAINS (Growing Accessible Interactive Networked Supports) project is the supporting network for the delivery of this lesson study project with a specific focus on the use of interactive whiteboards (IWBs) and was co-developed by teachers and consultants at an Ontario district school board and researchers from both Trent University and the University of Toronto. Lesson study, a systematic inquiry into teaching practice carried out by examining lessons, while firmly entrenched in Japan, has not developed widely throughout North America, and, in particular, Canada. Therefore, this study fills a gap highlighted by the Ministry of Education's Report of the Expert Panel (2004) which recognized lesson study as one activity that teachers may consider as they are developing a learning team.

Research on the use of IWBs is derived from mainly European sources, in particular, England and Scotland. Early research on IWB use was primarily focused on teacher testimony, whereas, now, a variety of models have begun to emerge with a focus on interactivity of students and teachers with the IWB. Most teacher-participants in this study were in an early stage of development of a repertoire of moves with the IWBs. Therefore, the findings from this study point to the need for continued support of teacher understanding of the interactive potential of IWBs.

Key Findings

Impact of Lesson Study

Throughout the year-long project, extensive qualitative data directly connected to the enactment of lesson study by teams of teachers and administrators was collected, along with quantitative data on student achievement and attitudes towards mathematics learning. Researchers were able to conclude that there were a significant number of positive outcomes for teachers, including teacher-directed decision making which lead to powerful learning for them, the increase in learning about mathematics teaching, and the expanded opportunities for teacher collaboration to increase and refine their repertoire of teaching strategies. For students, improved attitudes toward learning mathematics, including sustained effort and persistence, and modest conceptual understanding gains were evidenced through the student surveys and achievement tests.

In two of the four participating schools teachers reported that the lesson study project had a ripple effect across the school environment. For these teams, the ripple effect consisted of: better communication among teachers across divisions; a climate of change and risk-taking; and, the opportunity for the school staff to think about their subject area holistically rather than as disconnected pieces of curriculum needing to be covered for the purposes of grade advancement. The lessons had the specific focus of teaching particular core concepts in math that students were having difficulty with, using the support of an IWB. Lesson study also contributed to the establishing of a math community in the classroom through a revision of the role of teacher as learner along with students. In summary, the three major factors determining the successful outcome of lesson study were: consistent and explicit administrative support; the expertise and regular involvement of researchers; and, the team dimension of the project which allowed for the development of intellectually-engaged collegial relationships among participants. Teachers frequently cited their team planning meetings as being an important feature in the successful deployment of lesson study and when asked specifically, teachers pointed to activities and communications in-between the more formal planning meetings as crucial to their learning. As researchers, we recognised these 'in-between activities' as essential building blocks of a successful lesson study cycle and represented the 'real work' and commitment of the teacher teams as they supported one another.

Impact of IWB use

Findings from this project strongly point to a shift in participating teachers' identities as learners, especially in relation to IWB use.The effects on school were two-fold. The increase in number of IWBs helped create an awareness and interest across the school about their use; as well, participating teachers were encouraged by the opportunities provided by their administration to share their teaching strategies with IWBs with colleagues outside their division. Finally, the *Framework for effective math teaching and learning using the IWB* (Appendix 3) is the result of researchers, together with the teacher participants, identifying definite and explicit types of IWB use with a variety of different purposes for mathematics teaching.

Recommendations

Results from this study suggest further research should examine in more detail the "in-between" activities of teachers who are participating in lesson study. Articulating these activities will support teachers in revealing the details of the 'hidden' work associated with lesson study cycles. As well, researchers need to develop more fine-grained tools for measuring student achievement that closely match the content being addressed in the mathematics programs. The researchers also recommend that schools and administrators consider adopting a lesson study approach to in-school professional development, ensuring that the necessary supports are in place in order to carry it out in an effective manner.

II. Report

1. Introduction

In 2004, the Ontario Ministry of Education published the Expert Panel on Student Success in Ontario report, focusing on ways to improve mathematical literacy in grades 7 – 12, particularly for those students who are at risk of leaving high school without mathematical competency. As stated in its preface, "mathematical literacy is necessary both at work and in daily life - it is one of the keys to coping with a changing society" (Leading Math Success,10). Math literacy is defined in the report as "an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-founded mathematical judgements and to engage in mathematics, in ways that meet the needs of that individual's current and future life as a ? concerned and reflective citizen." (OECD, 199, 41) Math educators now understand that the goals of math literacy can be better met if students' thinking can be moved from "an instrumental and procedural understanding of mathematics to a relational and conceptual understanding." (Stigler & Hiebert, 1997)

As the report's authors suggest, this requires a more innovative approach to the way mathematics is taught. One of its recommendations is to encourage school boards to provide more professional learning in the use of manipulatives and information communication technologies to support greater student success in mathematics. The creation of professional learning communities has been identified as a crucial step toward student success in mathematical literacy. By supporting the development of professional learning communities, teachers are able to continually strengthen their knowledge and skills in a supportive and cooperative environment. This lesson study projects grows out of this set of recommendations, focusing attention on the necessity of innovative professional development which "creates [new] arrangements for professional work that supports continued improvement of teachers' knowledge and their pedagogical skills." (RAND Mathematics Study Panel, 2003)

As well, one of the major recommendations of the report involved the integration of new technologies into the classroom. "It is critical for teachers to become adept at integrating information and communication technologies into the classroom" by providing ongoing instruction through regular workshops and "time to observe classrooms where technology is an integral part of the learning process." (Leading Math Success, 57) Therefore, another specific aim of this project was capacity building of teachers' use of interactive whiteboards (IWBs), integration of the technology into their lesson planning, and focused attempts to increase student comfort with and use of the technology.

The Math GAINS (Growing Accessible Interactive Networked Supports) project, whose participants include nine school districts in Ontario, is the supporting network for the delivery of this lesson study project with a specific focus on the use of IWBs.

The project was co-developed by teachers and consultants at an Ontario district school board and researchers from both Trent University and the University of Toronto in order to embed the research within the activity of the professional development program. The study took place from September, 2007 to June, 2008 with four schools in a school board northeast of Toronto. Each school team was comprised of one lead teacher and two additional teacher team members. Administrators at each school were asked to support the project as much as possible. Researchers worked closely with the teachers throughout the process.

The overall goals of the project were to:

1. Engage in lesson study to promote and develop effective use of IWBs in mathematics.

2. Determine the effectiveness of lesson study as a professional learning model.

3. Provide support for instructional leadership of mathematics at four school sites.

4. Build teacher capacity through teacher collaboration.

5. Gather records of practice in classrooms where use of the IWB combined with other innovative math teaching strategies were being implemented.

6. Conduct research on teacher learning, student achievement and the process and outcomes of lesson study. (Math GAINS Agenda for Action, 2007-08)

Therefore, this report aims to:

- Summarize research which foregrounds the use of lesson study as a highly successful professional development model and the increasing value of using technology in mathematics instruction, particularly for those students who are at risk and in need of increased engagement.

- Provide a chronological description of the methods of the project; how data was collected and analysed.

- Offer a description of the school sites and the project participants and their involvement.

- Provide evidence of the factors underlying the successful implementation of lesson study at these school sites.

- Synthesize main results from the year-long project thematically regarding the impact of lesson study on teachers, teacher learning, school culture, and student learning and identities as math learners.

- Provide evidence and explain the impact of the use of IWBs on teacher efficacy and student learning and engagement, and, finally, the enablers and barriers to effective IWB use in schools.

- Offer a "Framework for effective mathematics teaching and learning using the interactive whiteboard" as a resource for various stakeholders.

- Make recommendations for how the results of this project can help facilitate similar projects in other Ontario school boards including how to create favourable conditions for increased IWB use.

It is hoped that a full discussion of this lesson study project can offer a template for supporting teachers in developing best practices for student success in mathematics and, in turn, create generative professional learning environments that will continue to nurture reflective, collaborative pedagogies of practice.

2. Background to Study

The following is a discussion of the research which foregrounds this study.

2.1 Lesson Study – One Continuous Model for Professional Development

Lesson study, as undertaken in this project, is inspired by Japanese Lesson Study, an intensive professional development model that Stigler and Hiebert (1999) describe as a way for teachers to look at their own practice "with new eyes". It has been broadly described as a systematic inquiry into teaching practice, carried out by examining lessons. In Japan, lesson study is an activity that is both sanctioned and supported by the Ministry of Education. (Fernandez, 2002)

As a professional development model, lesson study has garnered the attention of researchers and educators due to the fact that it "is embedded in the classroom and focused on students, it is collaborative and ongoing, and it is based on teachers' own concerns and questions." (Darling-Hammond & McLaughlin, 1995) In this way, lesson study is a teacher-led or teacher-initiated activity that has the potential to increase research-based knowledge that is critical to improving instruction. (Lewis *et al*., 2006) "Teachers engage in lesson study as researchers and scholars of their own classrooms. Their inquiries honour the fascinating and complex nature of teaching." (Stepanek, 2001)

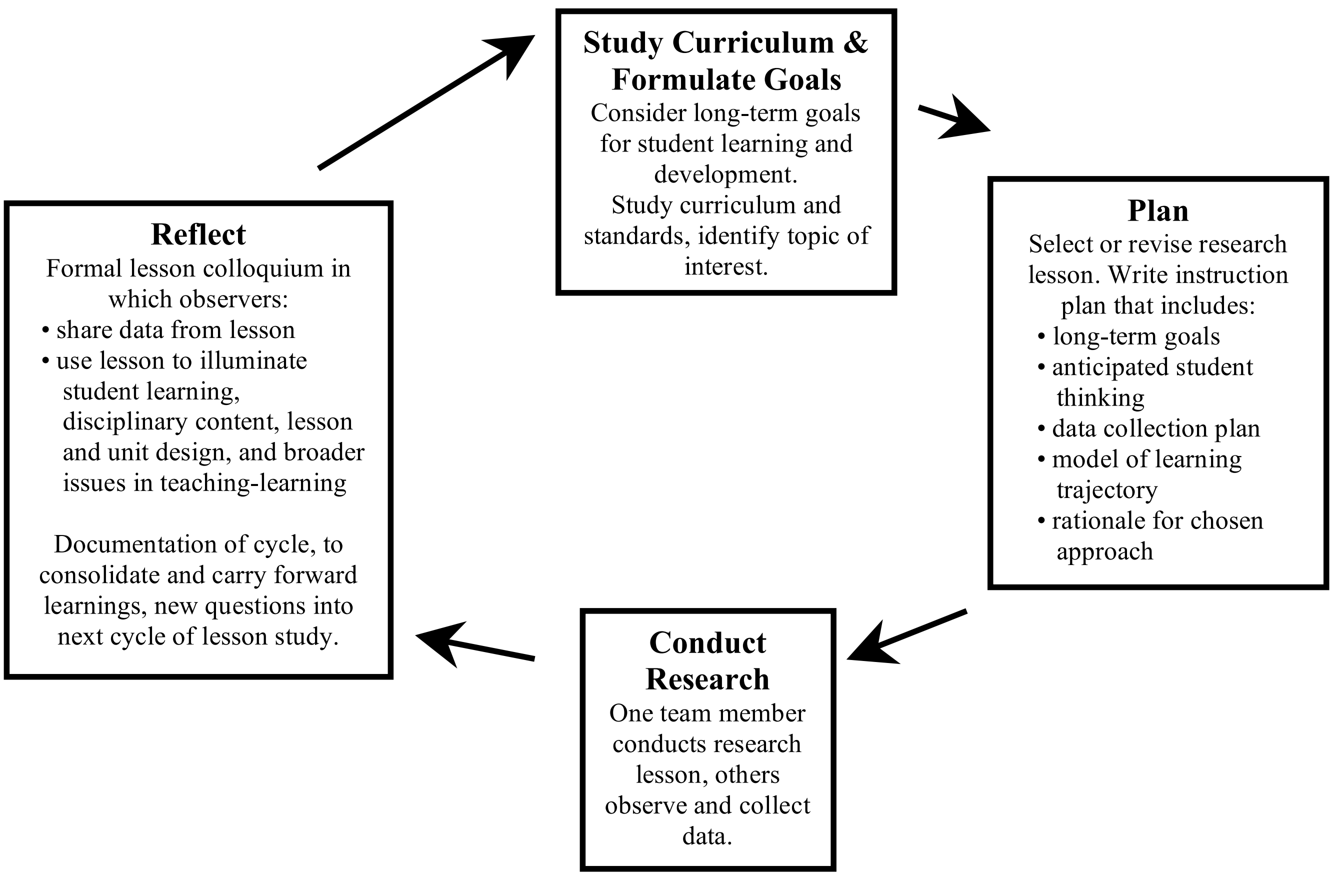
The use of lesson study as an effective professional development tool has spread rapidly in the United States since 1999. (Lewis *et al*., 2006) In Ontario, the Ministry of Education's Report of the Expert Panel (2004) cited lesson study as one activity that teachers may consider as they are developing a learning team, in which they identify challenges, determine possible solutions, discuss classroom strategies, share successes, and identify next steps.

Despite the ongoing activity in lesson study in Japan, and the recent activity in the United States, there are very few examples of researched case studies and related publications in North America. (Fernandez & Yoshida, 2004) Therefore, there is a pressing need for expanding the knowledge base of lesson study beyond the existing case studies. Further, researchers are interested in the specific mechanisms of lesson study that enable teacher professional development to occur. Because lesson study is not carried out in any large-scale systematic way in Canada, there is little opportunity given to teachers to influence national educational policy (Fernandez, 2002) as there is in Japan.

2.2 Critical Components of Lesson Study

The lesson study working group of researchers of the Psychology of Mathematics Educators of North America (PMENA) identified four critical components of lesson study: Goal Setting, where the facilitator may assist in setting goals; Curriculum Planning, with as much support as appropriate; Implementation and Observation, where live watching of the lesson and focused observation are fundamental (including training on how and what to observe); and Debriefing/Reflection on the lesson study process itself. (Bruce, 2007) The components that they cited were derived from the lesson study cycle outlined in a seminal article by Lewis, Perry and Murata (2006), as shown in Figure 1.

Figure 1: The Lesson Study Cycle (Lewis, Perry & Murata, 2006)



In the initial goal setting phase, teacher participants begin by setting a goal for their students that they are aiming to address in their lesson. This is often something that is difficult for the students to learn, or difficult for the teachers to teach. In other words, "the desire to improve is stimulated by seeing what's *not* working." (Lewis *et al*., 2006) Goal setting leads to an exploration for the best instructional strategies that could be used to achieve the goal. (Fernandez, 2002) During this curriculum planning stage, the teacher participants need access to outside sources of knowledge – both print (e.g., textbooks, innovative materials, outside research articles) and human (e.g., outside educators, content specialists, researchers). Once the lesson is planned, teacher teams decide who will implement the lesson. The lesson is taught and observed, and a detailed debriefing session and reflection takes place. This debriefing period drives the continuation of the cycle as the next set of goals is established. These final phases of the cycle –

implementation / reflection / debrief – should feel less like a final performance and more like a catalyst for further study and improvement of practice. (Lewis *et al*., 2006)

Lesson study is a straightforward idea, but a complex process, requiring the commitment of teacher participants over a long period of time and an openness to learn about subject matter and its teaching and learning. (Lewis *et al*., 2006) According to Lynn Liptak, a principal involved in lesson study in the United States, "anybody who goes into lesson study because they want a quick fix is going to be disappointed. This is not quick. This is a long-term strategy." (Richardson, 2001) That being said, teachers such as the one cited below have commented about the rewards of lesson study (Fernandez, 2002):

> In my experience lesson study is the most important thing for me to improve my teaching method or teaching techniques. Many teachers have observed me during my lessons and I have asked them to give me comments and criticize my lessons ... Through these experiences, I believe that my teaching method has improved.

2.3 Ideal Conditions of Lesson Study

According to PMENA lesson study working group, there are five ideal conditions that contribute to success in lesson study: the presence of outside experts; a supportive and present administrator; the development of trust; the ability to experience and discuss 'what makes a good math lesson'; and the identification of an area of mathematics teaching / learning that is problematic. (Field notes, October, 2007) A brief discussion on the first two conditions is outlined here.

An outside expert is considered to be a person who works externally from the group (e.g., a university participant researcher). This outside expert may be a content expert, who asks probing questions and facilitates teacher interaction with one another (e.g., asking "how can we link geometric and algebraic representations in this task?"), assisting with unpacking of the lesson/task, discussing how to support individual students through *planful* differentiated instruction. This type of outside expert is common in Japan and is gaining popularity in North American lesson study projects. Another role of the outside expert is to facilitate the lesson study process. As a teacher participant said "It would be very difficult to transform the way your school does professional development without 'knowledgeable others'". (Jarrett Weeks, 2001) In these cases where the outside expert acts as facilitator, there is, ideally, a gradual release of responsibility to the group as a teacher leader takes over the facilitation role.

The PMENA working group considered the lesson study situation ideal when a lesson study teacher team is supported by an administrator who is involved from the beginning stages and continues to be a presence throughout the lesson study cycle. Researchers have consistently established a positive relationship between effective principal leadership behaviours and student achievement. Without effective leadership, even staffs with many dedicated and skilled teachers are not able to function as an effective school community to ensure high levels of learning. One school administrator describes the role as non-traditional: “You are not leading from in front (where you have the answer and share it). You are not leading from behind (where you facilitate). You are truly leading from within along with everyone else.” (Liptak as cited in Boss, 2001) The administrator is also in a position to be able to use lesson study in order to respond to external mandates so that “lesson study is not one more demand on teachers but the primary means of addressing the many demands they face.” (Lewis *et al*., 2006)

2.4 Recent Math Education Directions in Ontario

Many recent research studies support a standards-based approach to mathematics education as it has been directly linked to improved student performance. (Ross, McDougall, & Hogaboam-Gray, 2002) Over a number of studies from approximately 2000 to present, a group of Ontario researchers (e.g., Ross, Bruce, McDougall, Hogaboam-Grey, LeSage, Benjafar) have developed and refined a description of the chief characteristics of standards-based mathematics teaching including an extensive review of math education research (Ross, McDougall & Hogaboam-Gray, 2002) and National Council of Teachers of Mathematics policy statements. (NCTM 1989; 1991; 2000) These characteristics have undergone significant revisions over time through the various studies and publications. The table below (see Table 1) is a very brief overview of the 10 dimensions of standards-based mathematics teaching. (See also: Bruce, 2006; Ross, McDougall, Hogaboam-Gray & LeSage, 2003; and, McDougall, 2004.)

Table 1: 10 Dimensions of Standards-based Mathematics Teaching

Characteristic	Description
Teacher Beliefs about Mathematics	
1) **Teacher’s conception of mathematics** as a discipline *Refers to how the teacher views mathematics as a body of knowledge and as a way of thinking.*	The teacher’s conception of mathematics is that of a dynamic ever changing field, rather than a fixed body of subject knowledge.
Teacher Beliefs about Student Learning in Mathematics	
2) **Student self confidence** *Concerns the range of strategies the teacher uses to build confidence in their ability to do mathematics.*	The teacher believes that raising student self-confidence in their ability to do mathematics is a central goal.
3) **Opportunity to learn** Concerns the extent to which the teacher provides students with the opportunity to learn higher mathematics.	The teacher believes that all students, not just the most capable, can learn math and should have access to a variety forms of mathematics, including complex mathematical ideas.

Characteristic	Description
Teacher Practices in the Mathematics Classroom	
4) **Student-student interaction** (mathematical discourse) *Refers to how the teacher guides and encourages student discourse about mathematical ideas.*	The teacher organizes the classroom (physically and structurally) to promote maximum student-student interaction as a key learning mechanism, rather than to discourage it as an off task distraction.
5) **Use of mathematical tools** *Concerns how the teacher uses manipulatives and technology to teach math.*	The teacher engages students in mathematical problems in standards-based classes with the aid of manipulatives and mathematical tools (i.e., calculators, computers and IWBs) to promote optimal student learning. In traditional programs such tools are not made available or use is restricted to teacher presentations of new ideas.
6) **The nature of student tasks** *Includes all work assigned to students to complete. This would include items such as projects, handouts, homework questions, experiments, and investigations.*	The teacher selects and/or designs tasks that are complex, open-ended problems embedded in real-life contexts; many of these problems do not afford a single solution. In contrast, in traditional math, students work on routine applications of basic operations in decontextualized, single solution questions.
7) **Construction of Knowledge** *Refers to how the teacher helps students develop their mathematical understanding.*	The teacher focuses instruction on the construction of mathematical understanding through student discovery and learning in a social context rather than transmission through presentation, practice, feedback and remediation.
8) **Program scope** *Concerns how the teacher implements the mathematics curriculum.*	The teacher includes a broad scope of mathematics concepts (e.g., multiple math strands are addressed) and observes both the teaching and learning of mathematics as a multi-layered activity.
9) **The teacher's role** *Refers to how the teacher presents his/her mathematical knowledge/expertise to students.*	The teacher's role is that of co-learner and co-creator of a mathematical community rather than sole knowledge expert.
10) **Student assessment** *Refers to how the teacher collects and interprets data on the quality of student performance.*	Assessment is authentic (i.e., analogous to tasks undertaken by mathematicians), integrated with everyday events, and taps a wide variety of abilities, in contrast with end-of-week and unit tests of near transfer that characterize assessment in traditional programs.

In this current research project, the teachers and researchers were particularly interested in dimension 5 (use of mathematical tools such as the IWB and manipulatives), dimension 6 (the nature of student tasks), and dimension 9 (the teacher's role).

In terms of recent directions in math education in Ontario, in 2003, the At-Risk Working Group submitted a report to Ontario's Minister of Education. It was called *A Successful Pathway for all Students* and it outlined a series of recommendations including the formation of a series of expert panels on students at risk to further explore its recommendations on literacy and numeracy. Various support materials followed, such as the Targeted Implementation and Planning Supports: Grades 7, 8, and 9 Applied Mathematics (TIPS), course profiles, exemplars, licensed software, and a document called *Leading Math Success – Mathematical Literacy Grades 7 – 12:* The Report of the Expert Panel on Student Success in Ontario (April, 2004). Shortly after the release of this Expert Panel report was the establishment of the Literacy and Numeracy Secretariat in 2004, a branch of the Ontario Ministry of Education aimed at boosting student achievement.

The Report of the Expert Panel indicates that "unless immediate, sustained, and effective action is taken, a sizable portion of the student population will leave school unprepared for the challenges they will face as adults." (2004, 9) It asserts that teachers of mathematics need professional learning opportunities that strengthen their competence in both mathematics content and the methodology for teaching it.

2.5 The Use of Interactive Whiteboards in the Mathematics Classroom

A nationwide initiative to install IWBs in each school in England began in the mid-2000's with an emphasis on technical installation, training, resource development, and teacher pedagogical training. In some ways, this has positioned the UK ahead of other nations in their adoption of IWBs in the classroom. Nonetheless, the introduction of IWBs is not just a phenomenon in the UK. A similar movement is occurring internationally, including in Canada and the United States. (See Schuck & Kearney, 2007.)

The earliest research on IWB use was summarized, by Higgins, Beauchamp and Miller (2007), as primarily being qualitative in nature with an emphasis on teacher testimony, as well as action research based approaches. (See Glover and Miller, 2003 for example.) Benefits of IWB use identified through these early studies included: a) ease of use for whole class teaching (Stephens, 2000) including dynamic visual demonstrations (Kennewell & Beauchamp, 2003); b) classroom management of IWBs; and c) the integrated use of a range of multimedia resources. (Ekhami, 2002)

In subsequent years "As the IWB became established in classrooms, researchers began to examine the process of teacher development associated with both the introduction of the IWB and the development of its use. This focussed on technical as well as pedagogical change, and included the position of pupils in this process of development and their own use of the technology." (Higgins, Beauchamp, Miller, 2007) A variety of models began to emerge with a focus on interactivity of students and teachers with the IWB. (See Davison & Pratt, 2003 for example.)

Most recently, there has been a research interest in teacher pedagogy and technical skills as highly interconnected factors which influence the effectiveness of student learning. The shift to empirical research is recent and mostly uncharted. (See Glover, Miller, Averis, & Door 2007.)

Relatively few peer-reviewed non-industry sponsored research studies have been published on IWB use in classrooms. Of the few that exist, most indicate that the IWB is

both a tool to enhance teaching and a tool to support learning.
This is especially in true for North America where IWB use is not as widespread.

Research indicates that teachers work through a series of stages as they gain understanding and fluency with IWBs. Teachers' initial competence with computers appears fundamental to promoting the use of IWB techniques such as recalling previous screens and integrating the use of various mathematical software easily. Findings also indicate that teachers who were previously unfamiliar with mathematics software such as graphing programs were less apt to use it with the IWB, and tended to use pre-packaged and more teacher-directed IWB lessons. (Miller & Glover, 2006)

According to Higgins *et al.,* the most widely claimed advantage of the IWB across many studies (gathered largely through anecdotal evidence) is that IWBs motivate pupils because learning is more enjoyable and interesting, resulting in improved attention and behaviour. (Higgins, Beauchamp, Miller, 2005) At the same time, there is little quantitative evidence that use of the IWB leads to increases in student achievement. Researchers consider the possibility that motivational aspects of the IWB and the pupils' obvious enjoyment of lessons may have misled the teachers into thinking that more learning was taking place than was actually the case. As a result of the lack of improvement in student achievement, some researchers question the justification of using costly technology when other kinds of projection technology would presumably facilitate the same level of learning. (Higgins *et al*., 2005)

Tied closely to student achievement is the question of teacher practice. It is important to note that several research projects question the effects of IWBs on teaching practice and identify 'best practices' – and yet there are no definitive statements linking the use of the IWB to increases in effective teacher practice. Moss *et al.* states: "Good teaching remains good teaching with or without the technology; the technology may enhance pedagogy but only if teachers and pupils engage with it and understand its potential in such a way that the technology itself is no longer viewed as the ends but as another pedagogic means" (2007, 94). Glover *et al.* (2007) reiterates the importance of focusing on good pedagogy, stating that teachers need training in order to understand the relationship between approaches to interactive learning and conceptual and cognitive development. Another study's observations indicated that 'best practice' of the IWB involved linking the IWB to work being done at students' desks where students can assimilate learning and go back to the IWB for explanations. (Miller & Glover, 2006) Interestingly, the idea of interactivity with the *interactive* whiteboard is examined in one study, as the observed teachers' pedagogical understanding of 'interaction' varied dramatically. Many teachers appeared to understand interactivity as standing for interacting with the board itself - not manipulating mathematical concepts. The researchers note: "Where we observed best practice, departments or individual teachers were aware of this dimension and had consciously set aside time to reflect on the most appropriate use of the technology in this context." (Moss *et al*., 2007) These questions fit under the broader concept of teacher identity – as math teachers and learners (of content and technology). Currently, there is little research available which informs educators about the possible impact IWBs may have on teacher identity. Therefore, this current study which brings IWB technology forward in the broader context of lesson study in mathematics will bear some important findings about developing teacher practices and increased effectiveness of IWB technology use.

3. Methodology

The overall purpose of the study was to conduct a formative investigation of how lesson study might be enacted and to observe its effects on teachers and students for the purpose of improving in-service. Lesson study is cyclical in nature, with the observation and analysis of live classroom lessons being core to the process (Lewis, 2002); groups of teachers, with the support of a research team, collect data on the teaching and learning activity of the lesson and analyse the data collectively which in turn informs the next lesson cycle. The length of this project allowed for two cycles of lesson study, and therefore, two cycles of data collection. The first cycle was defined as a familiarization cycle; the second, as a formalizing cycle, during which teachers teams had increasing levels of knowledge about the lesson study approach, and increased independence in their self-directed professional development process.

3.1 Activity of the Lesson Study Participants

Participants engaged in a year long cycle of lesson study. Each school site selected an area of concern/importance to study – in this case, a core mathematical concept which seemed to specifically challenge their students (and teaching) to the point of stalling student mathematical development. These included the concepts of: fraction as division, understanding linear functions and systems, and angle theories. The teachers worked in school teams to design a lesson sequence with one fully developed feature lesson, tested the lesson and refined the lesson. In one of the four sites, a revised version of the lesson from the first cycle was repeated during the second cycle with older students; in three sites, the teaching team developed a distinct but related lesson that built on student understanding of concepts explored during the first lesson study cycle. School teams had the support of an expert in lesson study who facilitated the lesson study process with the following:

1. Support of teacher teams in the development of a lesson study package, including samples of all materials used for the lesson, observation guides and copies of preceding and subsequent lessons. These packages were used during the public lessons to help observers (other teachers, researchers, and invited guests).

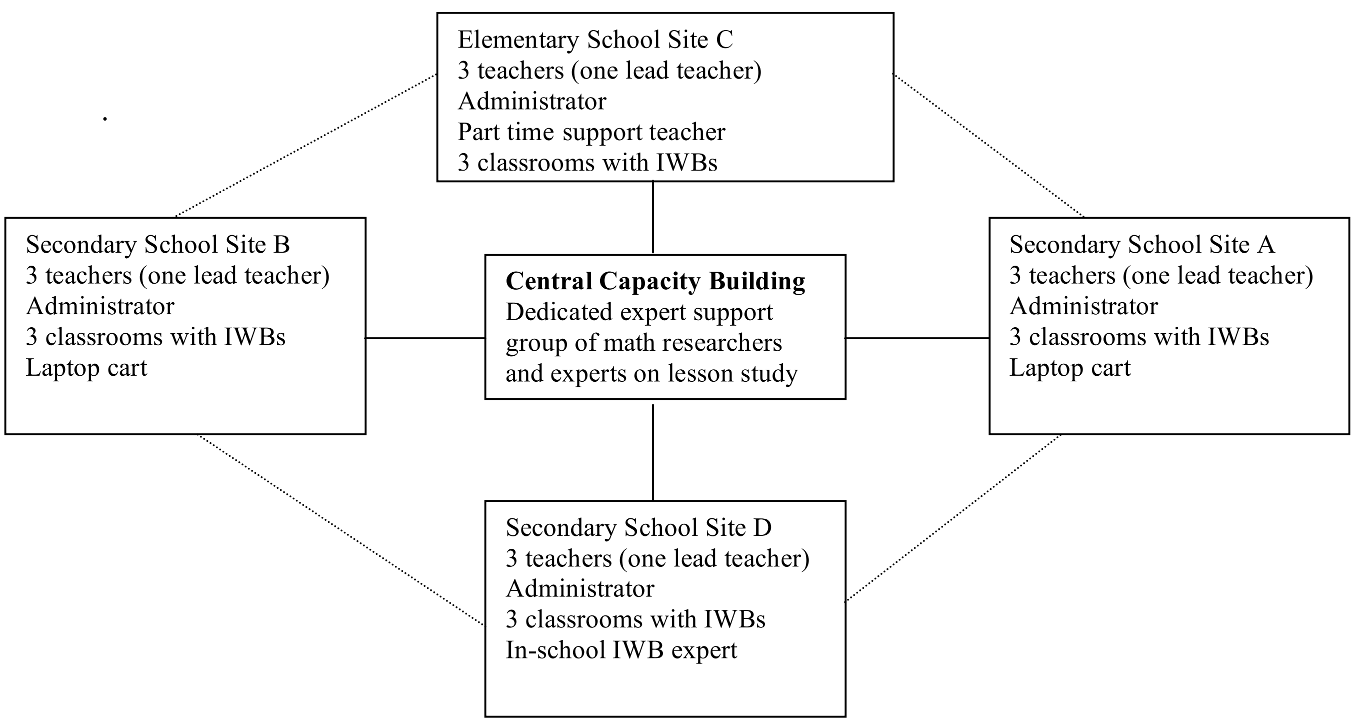
2. Coordination of invitations to guests for the public lessons. "Advisors to lesson study groups are chosen as a result of the fact that they have strong content, pedagogical, or curricular knowledge…and can serve as a vehicle for helping lesson study groups learn from each other." (Fernandez, 2002, 396) The activities of the school teams, though guided by advisors from the research team, were mainly teacher-directed and included all decisions concerning the direction of the lesson study process. (See Figure 1 – Lesson Study Cycle.)

3. Whole-group teacher professional development sessions, which focused both on lesson study activity and IWB training.

4. Facilitation of teacher team meetings as needed. Teachers selected the focus for the lesson development, planned the lesson together, selected the teacher who would be observed teaching the lesson, and, finally, carefully analysed the data gathered from the lesson implementation. Teacher ownership of the learning was fostered by the clear expectation that teachers would make decisions about how to proceed through the lesson study process. For example, teachers decided on the way to proceed when they had completed stage 4 of the lesson study cycle and returned to stage 1 of the lesson study cycle. After analyzing the data from stage 4 of the cycle, teachers were encouraged to either:
(a) Revise the lesson and then all teachers would teach the revised lesson independently;
(b) have one teacher teach the revised lesson as a demonstration for all;
(c) move on to the next cycle with a new focus;
(d) some combination of a,b,c.

The project was guided by an overarching structure of engagement and communication within school teams, across teams and the research group and on regular occasions, as a whole, as demonstrated by the graphic representation in Figure 2 below.

Figure 2: Model of Communication among School Sites



3.2 Month to Month Research Summary

In September, ethical reviews were approved for conducting research with students in junior, intermediate and secondary grades and with teachers. These were obtained from both the university and from the participating school board. During this early stage, control groups for the quantitative testing were identified on the basis of statistical matching. The research team then met with each school team separately to introduce the lesson study project formally at the schools involved, taking care of urgently needed equipment, organizing consent forms for student involvement, and giving out consent forms, pre-tests and surveys for student to complete.

In early October, a whole project planning meeting took place with all four site teams. At that meeting, participants were given a more involved introduction to the structure of lesson study and its benefits, an introduction to IWB technology by two experts, and time for initial goal setting. Crucial at this stage was for the school teams to identify a core concept their students were having difficulty with and which they felt hindered their progress to more advanced math and/or the consolidation of essential math concepts. At that meeting, dates for cycle one of the project were chosen by each school team. This included two planning days and a public lesson date (each with release time) which were attended by the whole school team, the research team, and in some cases, a member of the school administration. These dates were determined with the rhythm of the school semester in mind, so none extended past the middle of December.

Planning days were three hours in length and provided the school teams with the opportunity to refine and develop their lesson plan with the help of the research team. These sessions were marked by a sense of discovery and possibility by the teacher teams as they engaged in in-depth discussions of their practices and why different approaches used had not always met the needs of all students. The days chosen for the implementation of the public lessons were usually full day events and began with anintroductory session in which teacher teams provided an overview of the lesson, including a rationale for their chosen topic and approach, and an explanation of how they planned to use the IWB. An important element of the process at this stage involved having the lesson study facilitator ask the participating teachers to *predict* what they thought would happen in the lesson based on their understanding of the students being taught and their careful scripting of the lesson itself. This scripting process included the development of a lesson study package for each observer. The package contained the agenda for the day, a copy of the lesson plan and copies of other lessons preceding or following the public lesson, copies of any student materials that were to be used during the lesson, and finally, observation guides tailored to address areas of concern and the curiosity of the teacher team. (See Appendix 4 for a sample.) The extensive supportive and cooperative de-briefing of the first public lesson by all participants was essential in planning and developing the approach to the second formalized cycle of the project.

In January, the first cycle culminated with a presentation by School A and School C at the provincial Ministry of Education-sponsored GAINS conference, demonstrating the effectiveness of the lesson study project to date. Attended by administrators and consultants as well as other math educators from around the province, one presentation focused on ways to improve teacher efficacy with IWB technology. The other presentation took the form of a public lesson with students and live camera feeds to rooms of conference participants. Providing this generative professional learning opportunity was key in underscoring how meaningful professional development was in the lives of these teachers.

In early February, a second whole group meeting was convened. At that time, the research team conducted mixed focus group interviews which not only provided data to be analyzed but an opportunity for members of different school groups to listen and learn about the experiences at other sites, another essential piece of the lesson study process. A presentation by an interactive whiteboard teacher expert was offered (that focused on *student* use of the IWB) and school teams were provided time both to share the results of the first cycle with other teams and then plan on their own for cycle two. These whole group days were crucial for the research team as they provided the opportunity to set the agenda for the formalization cycle of the project and to gather data on teacher development on a variety of different levels.

Cycle two began in earnest at the end of February and ran through the middle of May. The teams worked somewhat more independently during this second cycle of lesson study, having gained familiarity with the process throughout the fall.

At the beginning of June, the final whole group meeting occurred, during which focus group interviews were again conducted. Teachers and administrators took part in a number of cross-school sharing exercises designed to help all participants better understand the workings of the lesson study cycle at each particular site and to identify what worked and, finally, to consider implications of the variations of practice within the larger framework. As well, teachers were asked for their input into a Framework for Effective Teaching and Learning using Interactive Whiteboards (Appendix 5) designed to help guide teachers in developing practices which enhance student engagement and use of the whiteboard technology.

3.3 Data Collection

The study employed a mixed methods design in which qualitative and quantitative methods were conducted simultaneously. (Creswell & Plano-Clark, 2007) The quantitative phase involved a quasi-experimental design in which control group schools were matched to treatment schools in a pre-post design. Table 2 displays the design.

Table 2
Design for Investigating the Student Achievement and Motivational Effects of Lesson Study

Treatment	O_1	$X_{Lesson\ Study}$	O_2
Control	O_1		O_2

Sample
Grade 7-10 teachers in four schools were invited to participate in lesson study. Ten teachers agreed to do so. The four treatment schools were matched with statistical neighbours on two criteria: previous student achievement and SES profile. For the prior student achievement score we calculated the average percentage of students reaching the provincial standard (level 3 or level 4) on the EQAO mathematics assessments over the previous three years. For the grade 7 and 8 classrooms we used the grade 6 assessments; for the grade 9 and 10 classrooms we used the grade 9 assessments. We searched the KPR EQAO database for 2-3 schools with the closest EQAO match that were not in the treatment group. We selected from the 2-3 schools that matched on EQAO the best match on SES profile. SES profile was a composite of 14 census variables aggregated using a regression formula developed by Johnson (2005). The result was a matched sample of 10 treatment classes and 10 control classes. However, one pair of classrooms consisted of grade 4 students. This pair was dropped from the sample, leaving nine pairs of classrooms.

There was serious attrition in the project, especially in the control sample. After multiple attempts to retrieve the data, we reluctantly deleted all students who did not complete both the pre- and post- achievement tests. This reduced the sample to six treatment and four control classrooms (*N*=143 and 101 students respectively). Even within these classes there was a treatment class in which only 14 students returned full data and a control class in which only five students participated.

Instruments
Student achievement was measured before and after the lesson study. There were two tests drawn from the PRIME assessment package. Operations and Number each consisted of 14 items. Student responses were scored as incorrect (0), partially correct (1) or correct (2), following the scoring key in the manual.[1] There were two markers. The inter-rater reliability, based on a random sample of 200 items (half from each test) was 93% perfect agreement, Kappa= .88. Bakeman and Gottman (1997) described Kappa scores of .75 or more as excellent. The achievement measures consisted of the average score on the Operations and Number.

The student motivation items were administered before and after the lesson study. *Math self-efficacy* (student survey section 1) consisted of six Likert items measuring expectations about future mathematics performance (from Ross, Hogaboam-Gray, & Rolheiser, 2002; e.g., “as you work through a math problem how sure are you that you

[1] The markers, in consultation with the PRIME test developers, modified the marking scheme. For the NUMBER TEST: Item 4 - 2 points for circling the correct answers; 1 point for circling 2 out of the three; 0 points for circling 1 or any combination with the odd number. Item 5 - 2 points also given if student mentioned that it could be a small town; 1 point for NO without explanation. Item 9 - 2 points for picture with explanation; 1 point for decimal or percentage. Item 14 - 2 points for "how many marbles there were in the beginning" or "how many marbles does Sally have left". For the OPERATIONS TEST: Item 4 - 1 point for using the word "times"; 0 points for leaving out the word "each". Item 6 - 1 point for saying 14x6=84; alternative answer: 16...rubric applies, this is for the interpretation that a van fits the driver and 5 students (total of 6 people). Item 12 - 1 point for drawing the picture correctly (including the 5/6 blocks) but not saying the answer to be 5/6.

can…explain the solution”). There were six response options, anchored by “not sure” and “really sure” for each item. In previous administrations, alpha=.84-.91 (Bruce & Ross, 2008; Ross *et al*., 2002; Ross, Bruce, & Hogaboam-Gray, 2006a; Ross, Bruce, Scoffin, & Sibbald, 2008; Ross, Ford, & Xu, 2006).

Functional Beliefs About Math Learning (student survey section 2) consisted of 11 Likert items measuring beliefs about how to act in math class. Eight of the items were adaptations of grade 7 student comments made in interviews about their attitudes toward participating in mathematical discussions (Jansen, 2006). Students were prompted to indicate how much they agreed with statements like “Don’t be afraid to ask questions.” There were six response options, anchored by strongly disagree and strongly agree. Two of the items (#3 and #7) were reverse coded. The last three items in the section were drawn from Schoenfeld (1985). The same response options were given and all three were reverse coded. In a previous administration (Bruce & Ross, 2008) an exploratory factor analysis of these items failed. In that study, seven of the items (items 4-7, 10, 12-13) constituted a reasonably reliable scale.

Quick/fixed beliefs about mathematics learning (student survey section 3) *consisted* of eight items adapted from Schommer-Aitkins *et al*. (2005). These items measure belief in quick/fixed learning (i.e., that learning occurs quickly or not at all and that intelligence is fixed rather than incremental; e.g., “If I cannot understand something quickly, it usually means I will never understand it”). In our study there were six response options, anchored by “strongly agree” and “strongly disagree” for each item. In Schommer-Aitkins *et al*. (2005), this scale predicted student beliefs in effortful math, useful math, math confidence and understanding math concepts. The scale also predicted achievement in mathematics problem solving. The original ten-item scale was reliable (alpha= .77) in a large middle school sample. We selected for our study all items that loaded in the factor analysis of Schommer-Aitkins *et al*. (2005) at least .40 on this scale (actual range .40-.67) with no cross-loadings (N=8). These items were all worded negatively. We did not recode; i.e., we anticipated that the scale would be a negative predictor. In previous administrations this scale was reliable: alpha=.81-.87 (Bruce & Ross, 2008; Ross *et al*., 2008).

Fear of failure (student survey section 4) consisted of six items (e.g., “I worry a lot about making errors on my math work”) from Turner *et al*. (2003). There were six response options, anchored by “not at all true” and “very true” for each item. This scale measures students’ fear of failing, a powerful inhibitor of mathematical motivation. These items were all worded negatively. We did not recode; i.e., we anticipated that the scale would be a negative predictor. In previous administrations, alpha=.79-.88 (Bruce & Ross, 2008; Ross *et al*., 2006b; 2008; Turner *et al*., 2003).

Effort (student survey section 5) was measured with eight items (e.g., “how hard do you study for your math tests?”). There were six response options, anchored by “not hard at all” and “as hard as I can” for each item. In previous administrations, alpha=.88-.89 (Bruce & Ross, 2008; Ross *et al*., 2006b; 2008).

There were two student demographic questions: gender (male, female) and grade (7-10).

Qualitative data was derived from the four treatment sites only. Data sources were:

1. 6 transcripts of focus group interviews conducted at the end of the familiarization cycle and at the end of the formalization cycle;
2. Transcribed field notes and planning materials from all school and whole group planning days;
3. Video footage and transcripts of all stages of the project including goal setting, curriculum planning, implementation and debriefing;
4. Archives in the form of lesson study packages in various stages of development, including the final packages with completed observation guides;
5. All artefacts generated from professional development activities including:
- Teacher contributions to the development of the Framework for Effective Teaching and learning using the Interactive Whiteboard;
- Records of informal activities related to the formal lesson study cycle;
- Data from rank ordering of the value of professional development elements within the project for teachers and administrators.

3.4 Data Analysis

Quantitative Analysis
We began by removing missing data. We used listwise deletion because the number of cases missing either the pre- or post-tests was greater than 5%. We determined the reliability of the instruments using Cronbach's alpha and established that all variables were normally distributed.

To address the first research question about the effects of lesson study on student achievement, we used t-tests to establish that the treatment and control groups were equivalent at the beginning of the study. We conducted a multivariate analysis of covariance, using GLM in SPSS, in which the outcome variables were the two achievement post-tests, the covariates were the achievement pre-tests, and the independent variable was treatment or control condition.

To address the second research question about the effects of lesson study on student motivation, we again used to t-tests to establish sample equivalence. We conducted univariate and multivariate analyses of covariance to measure the effects of lesson study on each of the five motivation variables. In each run, the outcome variable was one or more of the post-test motivation scores, the covariate was one or more of the pre-test scores on the same variables, and the independent variable was treatment or control condition.

To address the third research question about the moderating effect of student variables on the relationship between lesson study and student outcomes, we split the pre-test motivation scores at the mean, creating high and low scoring groups. We repeated the analysis of covariance, including as an additional independent variable one of the student characteristic measures represented as above or below the mean in the case of the pre-test motivation scores or as male and female or grade 7/8 and 9/10.

Qualitative Analysis

Qualitative analysis of the data has been undertaken inductively, through the use of coding analysis of field notes, transcribed audio interviews and extensive video taping (Bogdan & Biklen, 2003). Analysis was guided by the identification of significant statement or themes "arrived at by reading (or in the case of video, watching and re-watching) and reflecting upon the significant statements in the original transcriptions to get the meaning of the statements in the original context" (Creswell, 1998, 281). In this particular study, 'significant' stands for themes that are common to all the subjects and which emerged from common practices and perspectives shared among the participants (Creswell, 1998), namely attitudes and beliefs about the shared experience of lesson study and the use of IWBs in the teaching and learning of mathematics. For example, questions such as "Which aspects of the lesson study process were most helpful to your individual learning" or "Which aspects of the lesson study process worked well for your students" were asked in both focus group interviews in order to allow for comparisons of responses (consistency, changes).

Three researchers collaboratively identified key themes as attempts were made to get to the essence of the lesson study experience and its structures, and to do so with as little bias or judgement as possible through a consultation process which included coming to consensus and taking anomalies and contradictions into consideration (Thevenaz, 1962). The steps in a phenomenological study – bracketing, horizontalization, finding clustering of meaning, and providing textual description - have also guided the analysis of the data with the goal of reducing rich descriptive data to the essentials of that shared experience (Moustakas, 1994).

4. Project Context

The four schools in a school district northeast of Toronto were chosen for participation in this lesson study project after lead teachers from each of these schools initiated and contributed to the development of a proposal for research and professional development activity in collaboration with local researchers and the Ministry of Education. The district school board has had a long-standing record of engagement in research with academics from local universities demonstrating readiness conditions that facilitate multiple district-level co-generated research studies on an on-going basis. The general culture of the school board is familiar with and welcomes professional development activity that is combined with research and measures of success. The district has an active and organized ethics review committee who vet all studies being proposed and the consultants and administrative staff regularly engage in sophisticated programs which combine research and practice in mathematics education. This district school board's EQAO scores in Grade 9 mathematics – 36% pass rate for applied students and 68% for academic students – are mostly consistent with the provincial scores for the same year which are 36% pass rate for applied students and 71% for academic students. (C.D. Howe Institute for Ontario School Performance Database, 2007).

4.1 School Sites

School A is located in a medium sized town, servicing the children of the town's residents, as well as students from families living in the far suburbs of the GTA. There is a broad spectrum of socio-economic status among families sending their children to the middle schools with relatively high family incomes ($68,000) coupled with a significantly high percentage of parents without a high school degree (27%). Both a middle school and high school are housed in the same location but function with a separate administration. The school population for grades 7-12 is 1050 with 666 students in grades 9-12. There are a total of 63 teachers on staff and it is a fully composite school offering an array of alternative programming. Students in the applied stream passed the EQAO math test 52% of the time while their peers in the academic stream had a pass rate of 62%.

School A's team for this project consisted of the head of the math department who teaches grade 10 as well as two teachers both of whom had taught grade 10 recently or currently. As well, School A had an involved administrator who attended planning meetings and accommodated the needs of the team which included scheduling supply teachers for team planning time.

School B is also located on the shores of Lake Ontario, in a medium-sized town but servicing children from families living on the suburban fringes of the GTA. The school was built in 1960 and houses 624 grade 9 through 12 students, of whom 60% are transported by bus. It is a fully composite school offering French immersion and other innovative programming including culinary arts, construction, and landscape/horticulture courses. In 2007, 65% of Grade 12 students graduated and EQAO math scores for that year were 44% pass rate for applied students and an 81% pass rate for academic students.

The team at School B consisted of a lead teacher who was teaching grade 10 along with two other teachers, one also teaching grade 10 and the other grade 9. The administrator support at School B was less visible during planning sessions.

School C was the only elementary/intermediate school participating in the project. It is located in a small city northeast of Toronto in a neighbourhood with significant socio-economic challenges, including high rates of single parented homes (30%), a family income rate of $54,000, and a relatively high rate of parents without high school degrees (27%). This school offers a full K-8 program and last year had a total of 263 students registered and employed 16 staff members. Provincial pass rates for the Grade 6 EQAO tests in reading and math for the 2006-07 school year were 61% and 59% respectively as compared to the board averages of 55% and 56%. School C's Grade 6 EQAO pass rates for the same school year were significantly lower at 32% in reading and 41% in math.

The configuration of the team at School C was unusual but, in the end, highly effective for this project. It consisted of a team lead who taught grade 7/8, as well as the other grade 7/8 teacher in the school (indicating administrative groundwork to encourage co-planning) and a grade 4 teacher. The administrative support of the team was highly visible at meetings, and that support, the report will later detail, was instrumental in spreading the positive impact of lesson study throughout the school environment.

Finally, School D is a rural high school which up until this year also included grade 8, servicing numerous smaller communities in an area with a largely farming or light industrial economy northeast of Toronto. In 2006-07 there were 500 students registered, with 88 of those students in the grade 8 program. With 38 secondary teachers, four elementary teachers and five EAs, it is a fully composite school which offers innovative courses including sustainable forestry, hospitality, and communications. It has an admirable graduation rate of 85%. However, last year's EQAO scores in math were well below provincial rates for the academic stream. Pass rates for applied students stood at 35% while the pass rate in the academic stream was 38%.

The school team at School D consisted of a lead teacher who was not teaching at all first term, a grade 8 and a grade 9 teacher. Administrative support of the team at School D was not consistent over the course of the project and progress during the second cycle of the lesson study was significantly impacted when the announcement came forward about the removal of grade 8 from the high school and subsequent redundancies, as well as removal of technical equipment.

All teacher participants in this study were highly experienced teachers (with the exception of one teacher who had two years experience) with at least 5-7 years in the field. The teachers' commitment to their own professional development and to the growth of their teaching practices and, in turn, their students' learning was unquestionable, given the amount, much of it personal time, dedicated to the goals of this project.

In the following discussion of the findings from this study, the familiarization cycle which took place from September to November, 2007 is also referred as ‘cycle 1’ while the formalization cycle, which took place from February to May, 2008, is referred to as ‘cycle 2.’ Implemented lessons at the end of each cycle are also referred to as public lessons. And finally, ‘field notes’ refer to both written and transcribed video of planning meetings as well as debriefing sessions after the public lessons. For the sake of confidentiality, teachers and administrators are not named.

5. The Impact of Lesson Study

Results from this year long project indicate that fundamental shifts occurred for teachers and administrators who took part in the lesson study process. These shifts included changes in teachers' professional identities, particularly as math educators but also, as importantly, in seeing themselves as researchers finding ways to solve problems in their practices openly and collectively. These changes towards action-oriented self-images spilled over into the school culture. With the help of active administrative involvement, teachers shared their learning with colleagues and demonstrated that risk-taking and being open to change can be exciting and interesting. This shift also affected students in these teachers' classrooms, again through modelling, that trying new approaches and not always having the right answer was an acceptable, even welcomed, stance. The quantitative results of this study confirm that increased time for professional development and the teacher collaborations that lesson study affords does make a difference. Below is a detailed accounting of the outcomes for teachers, schools and students based on the qualitative data from the study.

5.1 Outcomes for Teachers

Teacher-directed Decision Making Leading to Powerful Learning

One of the teacher-participants put it most succinctly when she stated that "lesson study brings power to the teacher." For her, this power manifested itself in a sense of being able to make *in-the-moment* and planned pedagogical decisions and being respected for these choices (Cycle 2 focus group interview, June, 2007). Teachers reported that their involvement in the project afforded them:

a) increased opportunities to co-plan with their team and to recognize how co-planning could take place cross-divisionally;

b) the opportunity to learn and share collectively about the use of IWBs in their lessons, and;

c) a marked increase in their desire to ask questions about their own practices and experiment with new methods and approaches.
(Cycle 2 focus group interview, June, 2007)

> In terms of observing a public lesson, I found it quite useful, very interesting to actually watch a group of students and not be the one telling them, "Oh, what are you doing there?....I did recognize a lot of the same teaching strategies used by other teachers that I would normally use [as well] but there were some I hadn't even considered. So it was really enlightening. (Cycle 2 focus group interview, June, 2007)

According to participants during interviews, none of this would have been possible without the structure that the lesson study project offered.

During the familiarization cycle, teachers began meeting regularly with the purpose of first establishing what core concept they wanted to focus on (goal setting). A member of one teacher team had an idea about how to use containers and marbles to illustrate substitution and elimination. Once her team started in on this idea, they found out that "it [the core concept of substitution and elimination] applies to so much to what we are doing" (field notes, November, 2007). The group then felt that they were moving too quickly. They needed to return to fundamental concepts of algebra and algebraic expressions before moving to solving linear systems. The group was very excited about their thinking, asking questions about the 'big picture' in terms of the research and what the impacts of this work would be. They had identified a critical area of learning for students and began to tackle this by returning to the mathematical roots/fundamental understandings related to their focus area. At the end of the goal-setting session, the same teacher expressed this sentiment: "Imagine planning all our lessons like this? It would be amazing" (Field notes, November, 2007).

Learning about Mathematics Teaching

Focusing in on a specific goal helped teachers to shift their thinking towards conceptual understanding of the lesson itself rather than their own particular methodologies, freeing participants to think about their teacher identities in new ways, or certainly in ways not normally experienced. For example, the following exchange between two teachers on the same teaching team on the eve of their second lesson cycle aptly illustrates how the process of goal setting helped increase math learning for the lesson study participants.

> Teacher one: It felt really good to consult different places, I was working with the PRIME and from your binder, and I was learning different things from different places. It is rare to have the time to do some learning. Synthesize rather than brush along…and then also having time afterward to reflect. The huge investment of time will feel worth it.
>
> Teacher two: There's so much information out there, it is important to sketch out first and then fine-tune.
>
> Teacher one: I felt so silly when you guys were talking about the concept of the 'core.' But now I really get why that's so important. (Field notes, April, 2008)

As Fernandez (2002) and others make clear, the goal-setting process embedded in lesson study leads to an exploration for the best instructional strategies for the related goals. These instructional strategies clearly require new math learning for some as was experienced by study participants.

Teacher Collaboration Leading to Expanded Teaching Strategies

As part of the lesson study model, the teacher teaching the public lesson is often not chosen until the last moment, again putting greater emphasis on the content of the lesson itself and not on the practices of a specific teacher. A teacher from School A remarked after teaching the familiarization cycle lesson that "One of the major points of lesson study is that the co-planning is so tight, that any one of us could've taught that lesson this morning" (Field notes, November, 2007). This emphasis on collective planning seemed to contribute to personal growth through a pathway new or unknown to most teachers in the Ontario system.

In the first round of focus group interviews, teacher participants described how 'equal and democratic' the planning had become, formalizing relationships and providing a lot more time for collaboration (Focus group interview, June, 2007). Even early on in the process, teachers could detect changes in their thinking as a result of participating in the familiarization cycle: "I think I was sceptical coming in to this project…how is a formal lesson going to change things? But it does because it changes your thinking" (Focus group interview, November, 2007). Teachers immediately felt a difference because collaborating allowed them to wrestle with ideas together and share the workload. There was a sense of collective responsibility:

> I found it really important because as a teacher team we set the goals, we knew the deadlines that we had to work towards, and we did work as a group to actually produce the goods. (Focus group interview, November, 2007)

For each cycle, teacher teams produced at least one, but frequently two or three, iterations of the lesson sequence which they shared with members of the research team for feedback. A teacher from School B acknowledged that he and his team members had different teaching and planning styles but that the opportunity to discuss one lesson and work together creatively – doing something he normally wouldn't do – was really valuable (Focus group interview, November, 2007). This fine-tuning process proved to be an essential mechanism for increasing participant awareness of the potential array of teaching strategies. It also increased their level of confidence that the lessons generated would produce positive outcomes for students. The result – watching or teaching the public lesson – was recognized by teachers as a unique opportunity to observe their own students and their responses to another teacher and different approaches (See Appendix 4. PD ranking survey results, June, 2007).

During the second round of interviews, teacher remarks about the changes in their self-perceptions as teachers became more explicit:

> It all goes back to the fact that the teacher is focused on one thing and re-evaluating their style of teaching, is trying something new, is experimenting with something new – with all the future lessons we are going to be influenced [by this activity]… (Focus group interview, November, 2007)

Teachers identified the value of being open and 'vulnerable' to change and how difficult it was to let go of the personal responsibility they felt for each of their lessons.
"It was really a big sense of freedom when I got that. And I thought, 'you know what? This is our thing *we've* done and it's not just on my shoulders here' …it was a really great moment to be able to get there" (Focus group interview, June, 2007). Participants

indicated that opening themselves and their classrooms up to new ways of thinking was positive. What was needed to make that happen, though, was trust.

> It's that piece for people to let others into their classrooms, into their world of 'this is the way I do it.' Like you said, 'you know, I've been doing this for years and this is the way it works for me.' Well, sometimes it doesn't work. 'Oh, well, I move on and away we go.' And really, I think as a breed, as teachers, that is a really big hurdle for us to let somebody else in…building up that trust is a really hard thing to do. (Focus group interview, June, 2007)

Teachers learned from observing other teachers teaching, and the planning days leading up to the second public lesson allowed them the opportunity to voice this. As one teacher expressed to her fellow team member:

> One thing I learned from your lesson is to wait for the students to respond. I realized I was calling on the same students and now that I wait, the ones who were unsure are gaining more confidence because I am giving them a chance. My goal is have this group have all their hands up all the time. (Focus group interview, November, 2007)

As a result of the co-planning aspect of lesson study, teachers were better able to recognize the conceptual and sequential nature of lesson planning. Long discussions amongst team members took place about carefully identifying the action and development within one lesson and then looking at whether the lesson fit into the sequence of lessons focused on a core concept (field notes, October, 2007). For example, in one instance during a planning meeting in the formalization cycle, the research lead took time to explain the potential problems with recursive thinking processes for linear functions and how limiting they are. "We need to think about teaching students to look for relationships to solve equations or look for patterns; not down a t-table as they are taught to do for years and years. Research is showing that if students don't make the transition to understanding relationships, they may hit a wall by Grade 9 or 10 Algebra" (Field notes, April, 2008). After further discussion and exploration, the teacher experienced a paradigm shift in her own math understanding and future teaching strategies. The team began exploring how geometric growing patterns are related to algebraic expressions of rules. The teachers were then led to a discussion of multiplication procedures as an underlying support for understanding relationships.

Teachers involved in the project also noted an increased flexibility in their teaching moves as a result of the lesson study process. After teaching the public lesson in the second cycle, the implementing teacher from the team commented:

> I really wanted [students] to see that the same pattern can look different and they weren't getting a chance to do that yet. So I made that decision to have them walk around and look at the times five rule, and really kind of celebrate the fact that there are so many different ways to show that same rule…and I think that was neat for me too. (Field notes, May, 2008)

Observers of this public lesson supported the teacher in this move, indicating that it was a key moment for students to expand their understanding of what a growing pattern might look like geometrically (Field notes, May, 2008).

As evidence of teacher-participant enthusiasm for the project in terms of their own learning, nearly all expressed interest in continuing their involvement in a lesson study professional development program and are hoping that the project is extended for a second year.

5.2 Outcomes for Schools and School Culture

The Ripple Effect

In two of the four schools, teachers reported that the lesson study project had a ripple effect across the school environment. For these teams, the ripple effect consisted of: better communication among teachers across divisions; a climate of change and risk-taking; and, the opportunity for the school staff to think about their subject area holistically rather than as disconnected pieces of curriculum needing to be covered for the purposes of grade advancement (Field notes, survey data and focus group interviews, November & June, 2008). Understanding the conceptual links both within and between disciplines is considered important to addressing specific challenges currently facing teachers, especially those helping students making the transition between intermediate and secondary school.

One participant began his comments in the first focus group with a slightly ironic and playful comment about this very issue:

> This project has generated interest in the math department and people are asking - is this something we can use in our own classroom?….People don't usually ask questions about the math department…[they think it's] so boring, but now people are interested. (Cycle 1 focus group interview, November, 2007)

At one school site, the teacher team presented a public lesson twice at staff meetings (at the team's school and at the neighbouring intermediate school) and, in the words of one of the presenters, "their eyes just opened and they had tons of questions so it was awesome" (Cycle 1 focus group interview, November, 2007). Participants from other school teams where support for the project was not nearly as visible still reported an increase in collegiality:

> The collegial atmosphere is so improved at our school – it was good before but it is even better now….it has improved the team atmosphere; we're not just talking about lesson study as it applies to us but to other courses, a whole team compliment, bouncing ideas, we tend to do that more. (Cycle 1 focus group interview, November, 2007)

Even at the mid-point of the project, participants were aware of the changes taking place in the way they interacted with their colleagues – not only those on the school team but also those outside it. This was particularly strong for the team where there were participants from two divisions spanning 4 grades.

> We work with people all day, but as teachers we rarely get the chance to work *with* teachers…like you're a little island but now we have bridges between those islands…it gives us something to talk about, connect with on planning days ….the best thing about this project is the collegiality. (Focus group interview, November, 2007)

Teachers who conceive of themselves as learners and researchers are far more likely to have a positive image of themselves as educators and are more comfortable collaborating (Beck and Kosnik, 2001). This positive self-image can be translated into a re-invigorated approach to professional development across the whole school if it is embraced and supported by the administration.

At two of the four school sites, principals attended and participated in the public lessons and provided specific feedback about student learning in the classroom. In one instance, the principal became directly involved in helping students with a problem while the other principal's experience of observing the lesson affirmed for her that precise planning is so critical (field notes, May, 2008). She saw that the teachers on the team understood the 'essential learnings' that underpinned the lesson and understood how that sense of purpose positively influenced the flow and activity of the lesson itself.

As one teacher pointed out after the second public lesson, "The more you have of a staff on board with [lesson study], the far better end result you get. And this is not the culmination either, of just the three of us – it's the school principal, it's all the staff" (Field notes, May, 2008). Lesson study has the potential to re-invigorate teacher practices, not just those on the team, but across the school, when there is an explicit show of support by the administration.

In two schools, administrative support was less physically evident. In these schools, administrators were not observed participating in the team planning stages, nor in the public lesson activity or debriefing activities. This does not suggest that the administrators were unsupportive but researchers were unable to determine the level of support provided as in both cases, the administrators declined interviews. (June, 2008) These two school teams seemed to have greater difficulty establishing planning times together, organizing materials for public lessons, and inviting observers (Field notes November & December 2007, April & May, 2008).

5.3 Outcomes for Students

It is challenging to connect the benefits of the lesson study process to students and their learning because of the limited duration of the project and because the teachers focused on a variety of different mathematics topics based on student need and long range planning. Nonetheless, positive effects for students were identified in both the quantitative and qualitative data sources.

Qualitative student evidence:

First of all, the observation aspects of lesson study (that is, having experts in the room and being video-taped) made students feel like they were part of something special. Any intervention can have a positive impact on student learning and the additional impact of learning while all, including the teacher, are being observed is substantial. Observation of public lessons by the team of researchers, observers and discussants afforded specific attention to be paid to student learning. The observation guides developed by the teams and used during the public lessons provided guidance on how to observe:

- student independence and comfort level in asking for assistance;
- student engagement in the lesson content from the beginning to the end of the lesson;
- student use of and engagement with technology from the beginning to the end of the lesson.

These guides were then collected by the teacher teams and utilized in the planning of the next cycle. (See Appendix 6 for a sample observation guide.)

Core Concept Learning

One of the key dimensions of standards-based mathematics teaching is 'the nature of student tasks' (effective tasks are complex and include open-ended problems, real contexts with multiple solutions, and multiple solution strategies). Lesson study provided a vehicle for participants to pay close attention to the tasks they were assigning students. The lessons had the specific focus of teaching particular core concepts in math that students were having difficulty with, using the support of an IWB.

In the case of School B, the teacher team agreed that the focus of their first lesson would be the solving of equations. The rationale provided by the teachers was that students struggle with the conceptual understanding of what they are doing when they are asked to solve an equation. And understanding the concepts behind solving equations is fundamental to the math they are doing. The team began to develop a method for representing the equations visually. After much exploration, the team eventually found a method to visually represent the equation that works for substitution and elimination. The teachers wanted to give students a model that they could use consistently. They asked about middle-skilled students – what do they do? "If we give them a tool that they can hang on to, they can always go back to the visual." This approach contrasted to the traditional way of their teaching equations, which involved explaining single-step equations and then multi-step equations, and finally using brackets and fractional equations. With this new method the teacher developed an approach where students could seamlessly work through the above on the first day and then work with the teacher and other students to organize their thinking more symbolically (Field notes, November, 2007).

In the case of school C, Grade 4 students were engaged in solving linear equations through the use of manipulatives and geometric pattern making. Although the concepts explored were well above the Grade 4 curriculum, the teacher team was determined to find ways to "make it meaningful" to young students. The Grade 7 and 8 teachers also focused on linear functions but in more sophisticated contexts.

Establishing a Math Community of Support: Revising the role of teacher WITH the students

Teacher-participants concurred that they were modelling risk-taking in their teaching and the use of the IWBs (Cycle 2 focus group interview, June, 2008). Teachers involved in this project were engaged in learning to use the IWB as an effective tool during their lessons and in doing so often made mistakes, and in some cases, called upon students with more technological knowledge to assist. These sorts of experiences for students – seeing adults make mistakes, ask for help, and continue to learn – appeared to be important to supporting student understanding of themselves as math learners. The role of the teacher, one of the 10 dimensions of effective math teaching, was clearly being revised in the lesson study context. As one teacher expressed during the first focus group interview, "the kids who are really struggling with math saw my vulnerability too and I think that was a neat opportunity for them to know that I don't know everything" (Focus group interview, June, 2008).

Teachers also reported that students were well aware of teachers collaborating in the school and were then able to see more than one math teacher as a source of help and support. Because the lesson study process encouraged observation by the teachers on the team, a number of participants were pleased by the fact that they now knew more of the students in the school.

> I think the new thing for me is that because I observed a grade 8 class and a grade nine class, I now know a lot more students in the school that I wouldn't have known….I'm really looking forward to working with those kids and…now they come up to me in the hall and talk and say, oh, Mr. S isn't around, could I get some help from you? That's been really good building [that relationship] with the students. (Focus group interview, November, 2007)

Field notes from school visits corroborate this teacher statement as researchers observed students communicating comfortably with multiple math teachers in the schools (Field notes & Focus group interview, April - June, 2008).

Students saw teachers as learners and this contributed to a shift in perception affecting the larger school culture. One teacher in the first focus group interview summed it up well when she said, "having their teachers focused on math and improving math – it has to be a good thing – as opposed to not being engaged at all – having us being aware of [our] growth and wanting to change and be better [teachers]." (Focus group interview, June, 2008) When there was an obvious commitment by teachers and administrators to address the needs of students – and risk-taking involved on the part of those adults – students began to see school and the environment of learning in new ways. Researchers observed student excitement and engagement at each public lesson at each school (Field notes, November & December 2007, April & May, 2008) and part of this excitement included comments about the teachers working together to learn about teaching. This was particularly accentuated in the case of one group of students who participated in the provincial GAINS conference during a public lesson that one of their teachers presented (February, 2008). Students were well aware that the teachers were engaged in a professional development program and that the goal was to increase student understanding of challenging mathematics concepts with the support of the IWB.

5.4 Student Attitudes toward Learning Mathematics and Student Achievement Effects

Credibility of the Instruments

Table 3 displays the descriptive statistics of the achievement variables on the pre- and post-tests. Both achievement scales were reliable on both occasions (the criterion is alpha=.70). All measures were normally distributed (skewness < .78 and kurtosis < .85). There were no outliers and no missing data (after students who did not complete either the pre- or post-test had been removed from the data base).

Table 3

Means, Standard Deviations, and Cronbach's Alpha of Student Achievement Variables

Variable	N cases	N items	Mean	SD	Alpha
Operations 1	244	14	1.15	0.44	.81
Operations 2	244	14	1.22	0.46	.83
Number 1	244	14	1.34	0.42	.80
Number 2	244	14	1.45	0.38	.75

Achievement Effects of Lesson Study

Table 4 displays the pre-and post-test means and standard deviations for the treatment and control groups. Rows 1 and 3 of the table show the t-tests comparisons demonstrating that the groups were equivalent prior to the lesson study. The table also shows that both groups improved from pre- to post- on both tests.

Table 4

Means and Standard Deviations by Group and Test

Variable	Treatment (N=143)		Control (N=101)		Comparison
	Mean	SD	Mean	SD	
Operations 1	1.13	.44	1.19	.45	$t(242)=-1.03, p=.304$
Operations 2	1.22	.45	1.22	.49	
Number 1	1.34	.46	1.34	.37	$t(242)=.002, p=.999$
Number 2	1.45	.36	1.43	.41	

We addressed the first research question by conducting a multivariate analysis of variance in which the outcome variables were Operations 2 and Number 2, the covariates were Operations 1 and Number 1, and the independent variable was lesson study (treatment or control). The assumption of homogeneity of covariances was met (*Box's M*=2.34, *p*=.510) but the assumption of homogeneity of variance was not quite met for the Number test [*F*(1,242)=3.97, *p*=.047). The model explained 56% and 57% of the variance in the two outcome variables. Both covariates were statistically significant [Wilks' Lamda *F*(2,239)= 38.72 and 53.906 respectively, *p*<.001]. There was no statistically significant effect for lesson study [*F*(2, 239)=.517, *p*=.597]. The univariate effects (not reported) showed the same pattern: strong covariate efforts accounting for most of the explained variance with no significant difference between the treatment and control groups. However, when we began to include additional controls, as discussed below in research question 3, the picture began to change.

Motivation Effects of Lesson Study

Table 5 shows the means and standard deviations for the motivation variables. All were normally distributed (skewness <.85 and kurtosis <1.1). The math self-efficacy scale was revised to increase its reliability. Table 4 shows the items that were included in the final version of the scale, which was the same for pre- and post-administrations. The reliabilities were acceptable except for the beliefs about mathematics learning which was slightly below the alpha=.70 criterion on both administrations.

Table 6 shows the means and standard deviations for treatment and control groups on the pre- and post- motivational measures. The t-test comparisons report in the table shows that there were no statistically significant differences between the treatment and control groups on any of the motivational variables prior to lesson study.

Table 5
Means, Standard Deviations, and Cronbach's Alpha of Student Survey Instruments

Scales	N	Items	Mean	SD	Alpha	Comment
Math Self-Efficacy O_1	250	6	4.24	1.00	0.89	Items 4, 5, 6, 7, 10, 12, 13
Math Self-Efficacy O_2	250	6	4.20	1.00	0.90	Items 4, 5, 6, 7, 10, 12, 13
Beliefs about Math O_1	250	7	4.13	0.75	0.58	
Beliefs about Math O_2	250	7	4.18	0.81	0.67	
Quick/fixed Learning O_1	250	8	2.37	0.89	0.79	
Quick/fixed Learning O_2	250	8	2.36	0.90	0.81	
Fear of Failure O_1	250	6	3.07	1.10	0.83	
Fear of Failure O_2	250	6	3.02	1.12	0.82	
Effort O_1	250	8	3.97	1.00	0.89	
Effort O_2	250	8	3.84	0.98	0.88	

Table 6
Means and Standard Deviations by Motivational Variables, Test Occasion, and Experimental Condition

Motivation Variable	Treatment (N=142)		Control (N=108)		Comparison
	Mean	SD	Mean	SD	
Math Self-Efficacy O_1	4.22	1.06	4.26	.94	*t*(248)=-.308, *p*=.759
Math Self-Efficacy O_2	4.23	1.01	1.16	.99	
Beliefs about Math O_1	4.14	.81	4.11	.66	*t*(248)=.319, *p*=.750
Beliefs about Math O_2	4.23	.86	4.11	.72	
Quick/fixed Learning O_1	2.41	.94	2.31	.83	*t*(248)=.920, *p*=.359
Quick/fixed Learning O_2	2.26	.87	2.49	.93	
Fear of Failure O_1	3.10	1.16	3.03	1.03	*t*(248)=.516, *p*=.606
Fear of Failure O_2	3.09	1.10	2.94	1.14	
Effort O_1	3.97	1.00	3.96	1.01	*t*(248)=.123, *p*=.903
Effort O_2	3.94	.92	3.71	1.04	

To investigate the effects of lesson study on student motivation (our second research question) we conducted two rounds of analysis of covariance. In the first round we conducted univariate tests: the outcome variable was the post-test score for one of the motivational variables, the covariate was the pre-test score on the same variable, and the independent variable was lesson study (treatment or control). In the second round we conducted a multivariate analysis of covariance which included all the variables. The results were identical. However, we will report the multivariate results because it is less susceptible to Type I error arising from conducting repeated measures on similar outcome variables.

In the multivariate analysis, the covariances were equal (Box's M=17.556, p=.309). The multivariate results showed a strong statistically significant effect for each of the five covariates (lambdas not reported). The most important finding was that lesson study had an overall effect on the motivation variables [Wilks' Lambda F(5,239)=3.043, p=.011].

When we examined the univariate results we found that when the effects of the covariates were in place, there was an independent effect of lesson study on functional student beliefs about mathematics [*F*(1, 243)=8.333, *p*=.004] and their self-reported effort [*F*(1,243)=5.467, *p*=.020]. Examination of the means in Table 5 indicated that students' functional beliefs about mathematics learning improved in the treatment group from pre- to post- but in the control group functional beliefs were unchanged throughout the duration of the project. We also found that students' self-reported effort remained constant from pre- to post- in the treatment group while declining in the control group. The effects of lesson study on students' motivation were statistically significant, albeit small. Lesson study explained 3% of the variance in dysfunctional beliefs about mathematics and 2% of self-reported effort.

Moderators of Lesson Study Effects on Student Achievement

Our third research question asked whether various student characteristics (grade, gender, and motivational variables) might moderate the effects of lesson study. We began by considering grade, which we collapsed into grade 7/8 and grade 9/10. We found there was a statistically significant interaction between grade and experimental condition [Wilks' Lambda $F(2,216)=9.60$, $p<.001$]. However, there were no significant main effects for either treatment [$F(2,216)=1.77$, $p=.173$] or grade [$F(2,216)=.35$, $p=.703$]. Both pre-test scores were significant predictors of post-test performance [$F(2,216)=36.29$, $p<.001$ for Operations 1 and $F(2,216)=63.05$, $p<.001$ for Number 1].

Table 7 displays the univariate results. The model explained 55% of the variance in post-test Number and 56% of the variance in Operations. The table produced results comparable to the global analysis: significant effects for the covariates (pre-test achievement) but no overall effect for lesson study. The table also shows that there was a grade-treatment interaction but it was statistically significant for Number but not Operation. Inspection of the means in Table 7 indicated that lesson study contributed to higher achievement in Number in the grade 7/8 classrooms: student achievement increased in the treatment classrooms but not in the control. Tables 6 and 7 also show there was no significant group * grade interaction in grades 9/10.

In the global analysis, lesson study had no effect on student achievement. The subgroup results suggest a more optimistic interpretation: lesson study had a positive effect on student achievement that was limited by the type of outcome measured (Number, a more conceptual test than Operations, which was a more algorithmic test) and by grade (positive effects in grade 7/8 but not in grades 9/10). However, these results should be treated with caution because the cases were distributed unevenly across the cells of Table 9 and because students are clustered in classrooms: the grade assignment of one student is not independent of the grade assignment of other students.

Table 7
Univariate Results of MANOVA of Achievement Effects

Source	Dependent Variable	SS	df	MSS	F	Sig.
Corrected Model	Operations	25.71	5	5.14	54.08	<.001
	Number 2	18.37	5	3.67	69.04	<.001
Intercept	Operations 2	0.10	1	0.10	1.01	.316
	Number 2	2.36	1	2.36	44.30	<.001
group	Operations 2	0.06	1	0.06	0.59	.444
	Number 2	0.19	1	0.19	3.50	.063
Operations 1	Operations 2	6.25	1	6.25	65.70	<.001
	Number 2	1.30	1	1.30	24.35	<.001
Number 1	Operations 2	3.21	1	3.21	33.78	<.001
	Number 2	6.34	1	6.34	119.12	<.001
grade	Operations 2	0.01	1	0.01	0.12	.729
	Number 2	0.04	1	0.04	0.70	.405
group * grade	Operations 2	0.25	1	0.25	2.63	.106
	Number 2	1.02	1	1.02	19.15	<.001
Error	Operations 2	20.63	217	0.10		
	Number 2	11.55	217	0.05		
Total	Operations 2	392.58	223			
	Number 2	513.12	223			
Corrected Total	Operations 2	46.34	222			
	Number 2	29.92	222			
Number	R Squared = .555 (Adjusted R Squared = .545)					
Operations	R Squared = .614 (Adjusted R Squared = .605)					

Table 8
Means and Standard Deviations for Achievement by Experimental Condition and Grade

Test	Grade 7/8		Grade 9/10	
	Treatment (N=74)	Control (N=21)	Treatment (N=58)	Control (N=70)
Operations 1	.98 (.44)	1.35 (.40)	1.38 (.32)	1.19 (.44)
Operations 2	1.11 (.46)	1.26 (.47)	1.39 (.37)	1.26 (.48)
Number 1	1.21 (.49)	1.39 (.35)	1.56 (.27)	1.36 (.33)
Number 2	1.40 (.39)	1.37 (.38)	1.56 (.28)	1.50 (.38)

We repeated the multivariate analysis exploring for gender effects. There were no gender * group interactions [$F(2,218)=.795$, $p=.453$]. There were no significant main effects for gender [$F(2,218)=.774$, $p=.462$] or group [$F(2,218)=.304$, $p=.739$]. There were significant effects for pre-test achievement [$F(2,218)=31.366$, $p<.001$ for Operations and $F(2,218)=56.853$, $p<.001$ for Number]. Gender did not moderate the effects of lesson study on achievement.

Finally, we repeated the multivariate analysis searching for motivational moderators. We began by bifurcating each of the motivation variables (self-efficacy, dysfunctional beliefs about math, math as quick/fixed learning, fear of failure and effort) at their mean scores. In each analysis (not reported) the outcome variables were the post-test achievement scores (Operations 2 and Number 2), the covariates were the pre-test scores on the same variables (Operations 1 and Number 1), the first independent variable was group (treatment or control), and the second independent variable was one of the five pre-test motivation scores, variables. The results were the same on all the runs. There was no significant treatment * motivation interaction and no main effects for treatment or for any of the motivation variables. As in previous analyses, the pre-test achievement scores were the only significant predictors of post-test achievement. Students' motivational beliefs at the outset of the study did not moderate the non-relationship between lesson study and student achievement.

In summary, the only moderator of the relationship between lesson study and student achievement was grade. Lesson study had an effect on grade 7/8 students' performance on the conceptual test, Number, but not on the procedural test, Operations. This is a reasonable finding given that the framework for lesson study established by the university change agents emphasized a conceptual rather than algorithmic approach to mathematics education. There were no significant effects on the achievement of grade 9/10 students. This finding should be treated with caution because of the unequal distribution of cases across grades. It may be that the finding is explained by the particular individuals teaching the classes in which the lesson study impact was observed.

Moderators of Lesson Study Effects on Student Motivation
In this section we examine possible moderators of the impact of lesson study on functional beliefs about mathematics learning and on self-reported effort. We focused on these outcomes because the global analysis found statistically significant impacts of lesson study on these variables but not on the other motivational measures in the study. As with the achievement analysis, we examined grade, gender, and motivational variables. For all but one of these potential moderators the results replicated the findings from the global analysis: there were main effects as expected for the treatment and the covariates but with one exception there were no interactions.

We found one statistically significant moderator of the impact of lesson study on student motivation variables. In the multivariate analysis the outcome variables were post-test scores on functional beliefs about mathematics learning and self-reported effort. The independent variables were group (treatment or control) and high or low dysfunctional beliefs about math learning, i.e., beliefs that learning in math occurs quickly or not at all and that math ability is fixed. The covariates, as in previous analysis, were the pre-test scores on the two motivational outcome variables.

In the multivariate test there was a significant interaction for group * dysfunctional beliefs [$F(2,212)=4.89$, $p=.008$]. There were also main effects for group [$F(2,212)=3.65$, $p=.028$], the pre-test covariates [$F(2,212)=34.05$, $p<.001$ for functional beliefs; $F(2,212)=50.59$, $p<.001$ for effort], and for dysfunctional beliefs [$F(2,212)=3.85$, $p=.023$].

The univariate tests largely reproduced these results for both outcome variables. However, the group * dysfunctional beliefs interaction was significant for the functional beliefs outcome [$F(1,213)=3.97$, $p=.002$] but not for the effort outcome [$F(1,213)=.09$, $p=.767$]. Table 9 was constructed to interpret the interaction. The table reports the pre- and post-test means and standard deviations for the treatment and control groups. The table divides the experimental conditions in terms of their pre-test scores on dysfunctional beliefs. The table shows that students who entered the study with relatively low scores on the dysfunctional belief scale developed more positive beliefs about math learning over the duration of the study if they were in lesson study classrooms. But if these students were in control classrooms their beliefs about math learning became less positive during the study. When we focused on the students who had relatively high scores on the dysfunctional beliefs scale, we found that their scores on the functional beliefs scale were more likely to improve if they were in the control group than if they were in the treatment.

Table 9

Means and Standard Deviations for Functional Beliefs by Experimental Condition and Dysfunctional Beliefs

Experimental Condition	Test Occasion	Pre-test Dysfunctional Beliefs Score			
		N	Low	N	High
Treatment	Pre	69	4.43 (.76)	62	3.83 (.72)
	Post	69	4.54 (.77)	62	3.84 (.82)
Control	Pre	54	4.29 (.65)	34	3.80 (.59)
	Post	54	4.12 (.73)	34	4.01 (.58)

This finding should be treated with caution. First, the students were not equally distributed across the four groups. Second, the size of the effect is small, accounting for 4% of the variance in the outcome variable. Third, we lack a compelling theory to make sense of the moderator. Our speculation is that teachers actively promoted functional beliefs about mathematics learning, such as the benefits of exchanging mathematical ideas in student discussion groups. This advice fell on fertile ground when students were not encumbered by pre-existing dysfunctional beliefs. But students who had high scores on the dysfunctional beliefs pre-test may not have been able to benefit from teachers' input unless their dysfunctional beliefs were explicitly addressed. Since there was no main effect of lesson study on dysfunctional beliefs we suspect that treatment teachers did not address them.

5.5 Challenges to Successful Implementation of Lesson Study

Through the implementation of this lesson study project, researchers identified some clear challenges to successful implementation. These barriers can be easily addressed during the initial stages of the project but it is clear that it becomes more difficult for the team to recover if those deficiencies aren't addressed by the end of the familiarization cycle.

Limited Administrative Support

In some cases, teachers identified a lack of administrative support as a substantial barrier to the successful implementation of lesson study. This lack of support translated into a perception among the school staff that the extra time and energy teachers on the team were devoting to lesson study did not matter to the school as a whole. Insufficient administrative support was often described by teachers as:

a) A lack of technical support, specifically, in the case of this project, facilitating the installation of IWBs;

b) A lack of continuity where teacher positions were not secured for a second year so that the team could remain together for at least a two-year period to consolidate their learning from the initial lesson study activity;

c) Difficult timetable schedules that hindered collaboration.

In short, a lack of administrative support was communicated through an unwillingness to embrace the project as an integral part of school activity.

Team Planning Time

All teacher teams indicated that time for planning together raised some challenges. (Cycle 2 focus group interview, June, 2008) In one case, the teacher team spent well over 30 minutes developing the introductory 7 minutes of a lesson. (Field notes, April, 2008) The teachers in this case commented on the significant amount of time the planning was taking, yet they also indicated that it was extremely valuable and helped to set up the students for key learning activities later in the lesson and subsequent learning.

One team of teachers did not want to miss teaching time, so arranged with their principal to have planning time at the same time in term 2. These teachers met frequently during their shared planning time to focus on lesson study activity while not requiring release time. (Field notes, January, 2008) For other school teams, the lack of shared planning time and other commitments constrained the ability of teachers to meet together. Researchers observed that those teams in which there were teachers who expressed an unwillingness or were simply unable to meet regularly with their team, as part of the informal processes of the lesson study cycle, were less enthusiastic about the lesson study process. This was most clearly observable in the forms of: 1) limited teacher-initiated communication with the research team; and, 2) actions which signalled conflicted messages about commitment to the lesson study process (such as leaving meetings early or arriving late, minimal contributions during meetings). Lesson study is, of course, a detailed-oriented approach to professional development and this was received by teachers with a range of levels of enthusiasm, even though all teachers were voluntary participants in the study.

Perceptions of Students and Opportunity to Learn

One of the 10 dimensions of standards-based mathematics teaching is providing students with the "opportunity to learn" where "the teacher believes that all students, not just the most capable, can learn math and should have access to a variety forms of mathematics, including complex mathematical ideas." Lesson study continually revealed teacher perceptions of 'which students can learn what'. In one case, a team member persistently brought a deficit model to bear when assessing her students' math abilities, especially in relation to their familiarity with technology and in the perceptions of themselves as successful math learners. This led to lesson development that was significantly below grade-level expectations and limited opportunity to investigate complex ideas. (Field notes, January, 2008) In another case, the teacher brought high expectations of student abilities to the planning meetings and as a result, developed lessons that were significantly above grade-level expectations (Field notes, April, 2008). In both cases, observers reported during the debriefing sessions that students met the expectations of the lesson successfully (Field notes, May, 2008).

This 'opportunity to learn' also extends to the learning opportunity offered to the teacher-participants of this study. In the end, our findings suggest that some teams were better positioned to take full advantage of the opportunity to learn offered to them through this project. School teams who were hindered in their progress were those that experienced greater difficulty meeting together on a regular basis with the research team or who found themselves made uneasy by the expertise offered by the research team or by the discussants during the public lesson debrief sessions (Field notes, April, 2008). It was also observable that participating teachers who were unable to persistently locate specific goals and then continually refine them as part of the lesson study process were at a disadvantage. School teams who benefitted most from the lesson study process were more successful at asking themselves what core concept students have difficulty with and how they could successfully address this need. This type of question is qualitatively different than typical questions of how to motivate students to better like math.

5.6 Summary

Results from this study confirm that the numerous and varied outcomes for all participants far outweigh the potential barriers to the implementation of lesson study. While it is easy to see the direct benefits offered to the teacher participants, results from the qualitative data strongly underscore the numerous benefits for their students and the school as a whole. The effect of seeing a group of teachers open themselves up to the risk along with the rich possibilities of being observed (often a first since teachers college) was motivating for teachers and students. Lesson study in this project seemed to have a transformative power – not only for developing specific teaching practices in a particular curricular area but also to change the school culture into an environment where teacher learning was explicit and ongoing along with student learning. The quantitative results indicate that although there were no statistically significant increases in student achievement, the students demonstrated positive increases in their beliefs about learning mathematics. Previous research has indicated that increased student efficacy in turn leads to increased student achievement over time. Given that the study was one year in length and that the assessment measures were substantially broader in scope than teaching foci for the lesson study, there is clearly more work to be done in this area.

6. Overall Factors Which Contribute to the Successful Implementation of Lesson Study

The results of this project help to make a strong case for the expansion and development of lesson study as an effective professional development model for teachers. Specifically, lesson study allowed for a supportive analysis and development of teacher-generated teaching methods, and a shift in the perceptions teachers held of themselves as learners and as a teacher-researchers. In the qualitative analyses, teachers participating in this study reported a tremendous growth in their confidence, their trust in their own teaching and in the teaching practices of their colleagues, as well as a greater sense of community and purpose within the school and with the larger educational community (Focus group interviews November & June, 2007-08). A more nuanced and deeper appreciation of the challenges other teachers in the same discipline face, especially cross-divisionally, was also revealed (Focus Group Interview, May, 2008). During the course of this project, it became clear that there are a number of factors which clearly contributed to these positive outcomes, including explicit administrative support, research support, and the support of colleagues. This section of the report describes the findings related to the above factors.

6.1 Administrative Support

> If people are interested in [lesson study] you need to have ….the support of the administration. I cannot say enough about how our principal has been so great at letting us do what we have to do and totally trusting that we were on target…it was a really nice feeling. (Focus Group Interview, November, 2007)

Support by the administration was cited frequently by teachers involved in the project as an essential feature in determining the successful outcome of lesson study in focus group interviews. As well, teacher-participants rated the planning days with their teams and members of the research team as being one of the 'most helpful' aspects of the lesson study process (PD ranking results, June, 2008). These days would not have been possible for the teacher teams without explicit support of their administration. Lesson study, if executed fully with both a familiarization and formalization cycle, involves significant periods of planning time for the school teams. This time is taken up by goal setting, meticulous planning of the lesson as a group, developing the lesson study package, meeting regularly with the research team, setting up the public lesson itself, debriefing and starting the cycle again.

Administrative support for this project also came in the form of advocacy for the purchase and installation of IWBs for each participating teacher. This included finding additional funds to purchase IWBs beyond those provided by the research project funds. Finally, teachers in the project valued the simple, but what they saw to be necessary, regular contact and communication with school administration as key to their success. When asked which aspect of the project had been most supportive of their own learning, teachers consistently responded that the release time provided was essential. Administrators supported the organization of supply teachers and worked closely with their staff to offer participating teachers as much additional time as possible for their involvement. For some, this support meant collaboration and sharing beyond the project. As one teacher remarked, "It's the collaboration with all the staff." In one school, the administrator arranged an adjustment of the school schedule so that supply teachers did not have to be called in when the teachers wanted to meet together. The lesson study project, in the words of another participant, helped to create a sense of community, "a togetherness of teachers...but not just those involved…it really affects everyone" (Cycle 1 Focus Group Interview, November, 2008). We found that administrative support was crucial not only on the micro-level (so that each participant felt supported) but also on the macro-level where, because of providing a platform of sharing information among the staff, improvements in teaching practices across divisions were systemically achieved.

6.2 Research Support

The next factor identified by participants as essential to the successful implementation of lesson study was support offered by the research community. For this project, teacher teams met face to face at least four times with members of the research team. As well, researchers with math expertise in the area specific to the math goal identified by the school team were available for advice at meetings, via email and telephone. In addition, researchers provided articles and web links to teachers for specific topics the teachers had identified. Teachers stated that this support was vitally important to the design of their public lesson and for guiding and supporting their thinking processes as they developed these lessons. It is important to emphasize that the role of such advisors is not to "take over the work of a group, which is meant to always remain teacher-led and responsive to the needs of the particular children served by the teachers in the group." (Fernandez, 2002, 396) When discussing changes in their individual learning as a result of lesson study, one teacher noted how much they had personally benefitted from having been sent materials about "teaching something basic in a new way, like dividing fractions" (Focus Group Interview, November, 2008). Others noted how the research team provided opportunities for reflection and to put aside their scepticism about how lesson study was going to change their thinking. Access to a math expert was noted on more than one occasion during the focus group interviews as an important feature of the project.

> Researcher support was incredible because they just know things I don't know and led us off in a direction that we hadn't initially been heading towards. And it was like, oh, this makes so much more sense….[it was] so positive and powerful. I found it really, really helpful. (Focus group interview, November, 2008)

This was especially noted in the important final stage of development of the public lesson when conversations with members of the research team helped teachers to anticipate some of the pitfalls in their planning and, in turn, helped teachers make adjustments to the lesson. In one case, a teacher changed the lesson sequence as a result of last-minute discussions with members of the research team (Field notes, May, 2008). During the course of this project, researchers were seen as complementary members of the school teams and the importance of communicating that sense of team-work and shared expertise with the school teams by the researchers cannot be underestimated. The support offered by researchers needed to occur on a regular and consistent basis and, as much as possible, in a face-to-face context at the home school.

6.3 Collegial Support

Cited most frequently and recognized as an essential part of the success of this lesson study project was the collegial support teachers offered one another. This support depended on the level of commitment of each individual to the project and the degree to which they were prepared to reveal their own teaching practices. For many, it would be the first time since teachers' college that they would be observed teaching; opening the doors to scrutiny was a huge first step for many of the teacher participants. One teacher described it this way:

> I feel like we're sharing more and purposely bouncing things off each other instead of before you might just pass one another in the hallways and it was just 'hi, how are you?' And now it's, 'hey, how did that go and I need help on this part with the IWB.' (Focus Group Interview, November, 2007)

This signalled a fundamental shift in the way teachers saw themselves and their collegial relationships – as supportive rather than competitive or judgemental. Teachers reported getting to know each other where they hadn't had the opportunity to do so previously (Focus Group Interview, November, 2008). The use of IWBs helped to structure this collegial support by providing practical ways to share knowledge:

> What's neat is that we can put these lessons on the server so its knowledge that's in there and something you've done becomes shared knowledge. You're not in a dark room thinking, 'ok, what do I do?' Now you have access to something. (Focus group interview, November, 2007)

Team Leadership and Trust

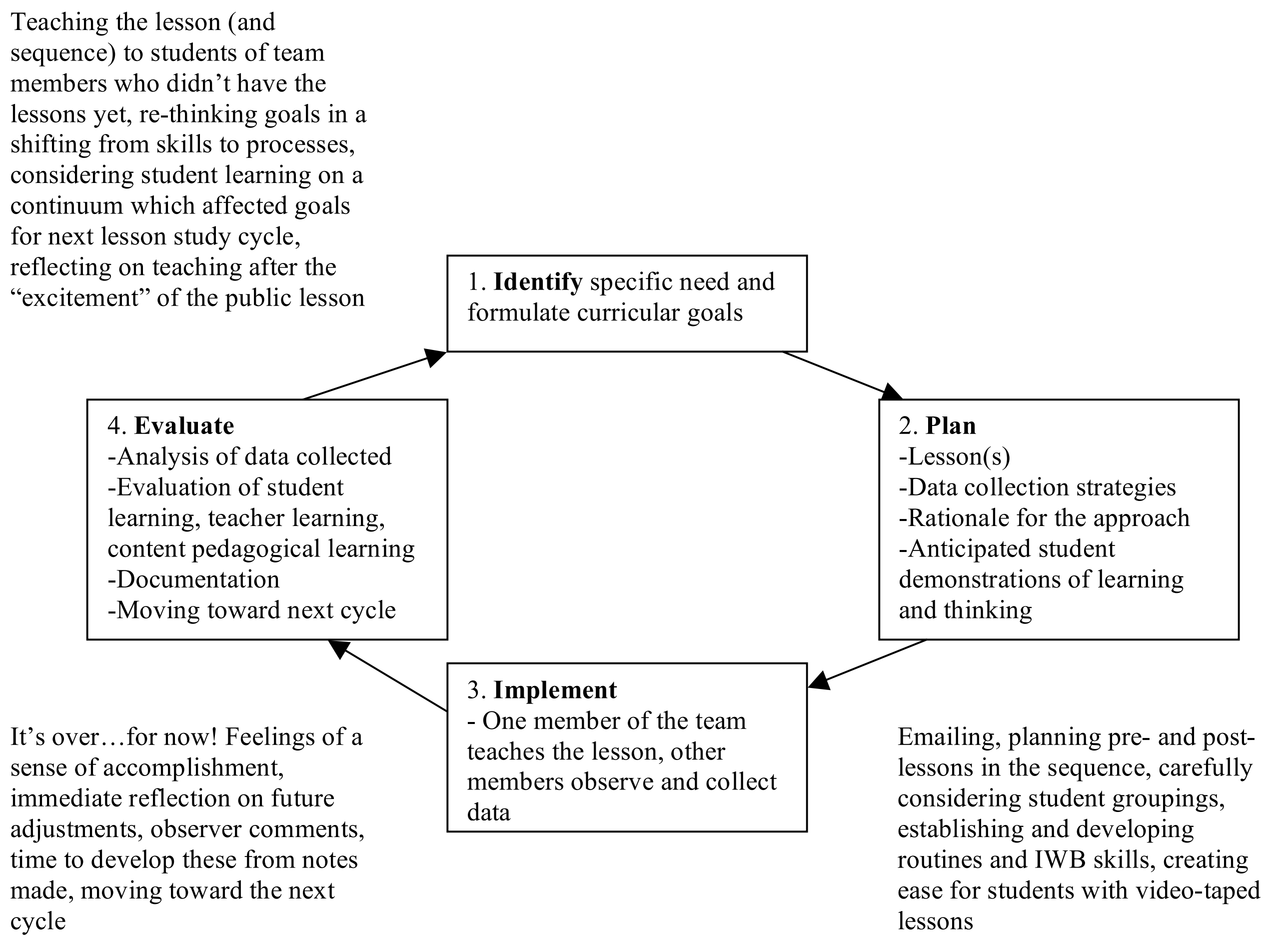
It was essential for team leads (those experienced teachers, often, but not always, department heads) to set a positive tone in order to facilitate effective team building and sharing – the first step being collective goal setting. As one teacher noted, "it was really valuable to sit down as a group and discuss what we were going to focus on…because we didn't have any real restrictions on what we were going to teach" (Focus group interview, June, 2008). As part of this process, the lead teacher needed to create the circumstances for collective decision-making among team members from the outset.

All participants at one time or another during the focus group interviews (November, 2007 & June, 2008) brought up the importance of trust and how establishing that sense of mutual trust was a determining factor in the positive outcome of the project. This collegial support was also facilitated by having a mix of teachers on the team - those with differing years of teaching experience and levels of technical expertise. The fact that teacher teams were all using a standards-based Ontario curriculum as their guide and had, in advance, agreed to investigating one math concept meant that they could plan by building on their collective past experiences with the single lesson (Fernandez, 2002). The fact that so many of the teacher-participants were struck by the rarity of such collaborative opportunities compared to their previous years of experience (ranking survey results, June 2008) suggests that that lesson study can offer a pathway for a paradigm shift in the ways in which teachers interact and support one another in developing effective practices.

The In-Between Activities in the Lesson Study Cycle

Teachers frequently cited their team planning meetings as being an important feature in the successful deployment of lesson study. As researchers, we were interested in how that enhanced or contradicted the model of the lesson study cycle (Figure 1) offered by Lewis, Perry & Murata (2006). During the final consolidation day in June, researchers asked teachers to list the tasks that took place during the familiarization and formalization cycles of the process with specific attention to how their time was spent. The following figure (Figure 3) builds on Figure 1 with the teacher-participants' insights post-project into what specifically took place between each phase of the cycle informally and in-between the more formal planning meetings with members of the research team or school team meetings. These informal or "in-between activities" are a significant addition to our understanding of what takes place for teacher-participants as they move through the cycle. As researchers, we recognised these 'in-between activities' as essential building blocks of a successful lesson study cycle and as representing the 'real work' and commitment of the teacher teams as they supported one another.

Figure 3: Informal/Formal Activities during Lesson Study Cycle



7. Impact of IBW Use

Each school site was supplied with one IWB to support the project. Then principals in 3 of the 4 schools negotiated through central resources and school budgets to acquire addition IWBs. By the middle of November, all 12 teachers had IWBs in their classrooms. Unfortunately, one teacher's IWB was removed from his classroom mid-way through the project. This teacher booked the library IWB into his room so that he could continue to use one regularly. Participants were provided with modest training on IWB use through the project (two half-day sessions). Teacher team members relied on one another and those with the most experience with IWBs to support their ongoing learning.

In addition to the already noted methods of data collection, a videographer also went to each school and interviewed the teachers on video regarding their use of the IWB. The following categories were identified through analysis of these video interview transcripts, transcribed focus group interviews and videotaped lessons as the ways IWBs impacted how teachers constructed their identities as teachers of, in this case, math content, but more significantly, how they constructed their identities as learners of technology in relation to their students, many of whom had more technological expertise than they. As researchers, we understand identity for both teachers and students as a process of negotiated experience, which is ongoing and part of a multi-dimensional community (Wenger, E. 1998). Teachers and administrators recognized that the use of IWBs in their classrooms also had the potential to affect the whole school through modelling and demonstration of new teaching methods.

7.1 On Teacher Learning

For 10 of the 12 of teacher participants, their knowledge and use of IWBs in their classrooms was nil to limited, and thus this project allowed for the opportunity for participants to gain that experience and expertise through ongoing IWB access and professional development which supported their learning. Analysis of qualitative data showed that all participants had a strong sense of themselves as learners in relation to IWB use. In the broader context, the presence of IWBs in participating schools positively impacted the community (teachers, students, and the broader school community) response to the potential of IWBs as effective tools for learning.

Teacher Identity as Learners

Teacher learning, often framed in terms of on-going or continuous learning by participants, was frequently recognized as one of the benefits of participation.

> I think it's positive when a teacher is forced a little bit out of their comfort zone because it keeps things fresh. It keeps you [the teacher] thinking and learning and being challenged. (IWB interview, May, 2008)

Through the support of experienced teachers and IWB experts, there was a marked increase in confidence using IWBs among participating teachers. For example, by the end of the first focus group interview, teachers were able to agree that they were recognizing the following about IWB use:

- There are many different and distinct uses of IWBs during a single lesson;
- There are varying levels of effectiveness for those uses in relation to student learning;
- IWBs are timesavers during class but their effective use requires more preparation time.

By the end of the project, teachers added the following:

- IWBs are not a magic bullet but a tool with tremendous capabilities but also limitations;
- The ways which students can use IWBs during a lesson differ from conventional teacher use and that needs to be better understood and explored;
- Effective use and application of IWB technology requires sufficient time for 'play' in order to develop working expertise.

These two lists illustrate significant growth in teacher learning through the course of the project and indicate a desire among participants to continue that learning. One teacher expressed how valuable it was for him to have a growth experience using IWB technology: "I really learned a lot having someone else show me" (Focus Group Interview, November, 2008). Another teacher concurred that she had had "a lot of personal learning around math and technology and that makes me a better teacher and that's my job…to make myself better, so that I can help the kids better." (Focus Group Interview, June, 2008) Nearly all participants at one time or another expressed the sentiment that they still had much to learn in terms of effective IWB use, proof of seeing themselves as learners and as being *capable*, still, of further learning.

By the end of the project, teachers were also able to begin to identify specific ways that student learning was enhanced due to IWB use:

> When I show a video clip – it just grabs their [the student's] attention. They relate to the whole blending of technologies, so why not use that? I can bring up the internet, bring in DVDs, other software that they couldn't have seen otherwise. (IWB interview, May, 2008)

The same teacher expressed her learning over the course of the project in terms of recognizing the reality of the presence of technology in her students' everyday lives:

> It's so much in tune with what their world is. It's the way that we need to gear teaching to do the students that we have, the best service that we can. We really need to starting using more technologies like this [IWB] because that is what their world is going to be. And we aren't preparing them as well as we could if we don't have those resources for them to use. (IWB interview, May 6)

By the end of the project, teachers recognized that IWBs had tremendous potential but they also better understood the limitations of IWBs as a learning tool; in other words, they are not a "magic bullet." They began asking themselves about the finer points of using IWBs, using them not as 'glorified chalkboards,' but seeing how they had to carefully plan the ways which students actually used IWBs in the lesson sequence and, as importantly, better anticipate the challenges presented by endeavouring to "really increase the student use."

Enhancing Awareness of Teacher Moves with IWB use

Participating teachers considered the ways in which the IWB influenced the moves they made during a given lesson sequence. For instance, a participating teacher spoke to how effective use of technology can deliver an increased number of teachable moments:

> It's a great way to do more of the on-the spot teachable moments that have to do with technology – because a moment has a lot of potential and if you are so rigid and so geared to 'this is my lesson and this is the handout. Go sit down. Go do the handout…' you're missing all the kinds of questions that come up by exploring many different things at one time. (IWB interview, May 2008)

During the formalization cycle of the project, participants engaged in purposeful planning that had clear goals but flexible sequencing and directions:

> With IWBs, there are the lesson plans, laid out, each day, what you're doing. You can modify it, you can change it but at least there's a strategy for you to grasp onto and see what you're expected to cover. (IWB interview, May 2008)

One teacher found it remarkable to observe how students' modes of communication had shifted as a result of interacting with IWBs, individually, in pairs, in small or whole groups.

> I like the interaction that it brings into the classroom, the willingness of the students to participate. I call it a tool. They probably call it a toy. But if they're engaged, they can call it what they like. They are more interactive when answering questions. They are wanting to help me by telling me what to do and sometimes they'll come up and work by themselves and I will step away or we will work together and the rest of the class will give suggestions. And I'm finding, particularly in math, the communication has changed because they know that if they are going to contribute I expect them to use proper mathematical language. (IWB interview, May 2008)

For others, IWBs opened up myriad possibilities about where to take their math lessons to help students understand the practical value of abstract mathematical concepts.

> The IWB has been helping me easily integrate media and news and pull that into the math lesson – they can see the importance of math in life – real people use real math to solve real problems. (IWB interview, May 2008)

From the data, we have concluded that learning how to effectively integrate IWBs into a lesson sequence can support growth in the repertoire of teacher moves. Participating teachers became increasingly aware of the enormous potential to transform their practices as result of IWB use and acknowledged that a commitment to continuous learning was essential to their growth as teachers.

7.2 On Student Learning

Student learning is generally enhanced by a new intervention but particularly when that intervention has a technological dimension. It is obvious, then, that the introduction of IWBs into teacher classrooms did have an immediate effect on student engagement. Therefore, as researchers we wondered about the specific manifestations of student engagement and how it could be deepened and enhanced through effective use of IWBs by teachers.

Teachers in this study reported that student learning was improved through appropriate use and application of IWB technology but they also learned that those students' conceptions of themselves as learners, particularly as math learners, could be shifted and re-formed.

> It's definitely interaction [that] is the major thing. For the kinaesthetic learner it is so much easier to implement. We can use the virtual manipulatives online – when you think about algetiles, they are right there. The students want to come up, they want to touch it. They are much more text savvy than us, and they want to be up there doing it. It's so easy to bring the real world into math now. (IWB interview, May, 2008)

Repeatedly, teachers acknowledged that IWBs increased student interest, not just among academic students but for those applied and essential students who so needed validation as capable math learners. As one teacher reported after the familiarization cycle, "students are now fighting to get work done so they can access the IWB." and two Other teachers reported that "students who don't raise their hands now have positive participation" and "with IWBs they are so much more involved, curious" (Focus Group Interview, November, 2008). There is no shortage, throughout the length of the project, of similar comments about the direct correlation between use of IWBs and student interest; what persisted among participants was the idea that IWBs could be used and understood as a bridging mechanism in many different ways.

For example, an observer in the second lesson cycle at one school site noted that the IWB served as a bridging tool that encouraged students to use manipulatives and then move to the IWB as a different representation of the same idea.

> The manipulatives really opened up the conversation between the pairs. And

> then the work being done on the IWB transferred the talk that was happening at the tables to the front – they all faced forward – then the talk continued and then it was silent as they were all furiously working….the IWB was that bridge to the abstract and [allowed] the conversation to continue. (IWB interview, May, 2008).

Effective use of manipulatives combined with IWB use was prevalent in 3 of the 4 school sites. Teachers, who had long ago shelved the manipulatives, were re-introducing them in their classes as a bridge to the virtual manipulatives of the IWB.

This bridging also occurred when students could easily access previously learned concepts through IWB technology.

> Findings ways of getting the students up there using it [is my biggest challenge]. It's a captivating tool and students find it pretty cool. Any time you can get them up there doing something on it that really grabs their attention. (IWB interview, May, 2008)

Teachers frequently commented on how these features allowed for quick consolidation, both inside and outside class (e.g., posted homework, online review), for students struggling with basic concepts. The IWB's bridging capability - between old and new concepts and between abstract and concrete 'materials' - is illustrated in this anecdote confirmed by those present and shared by a teacher in the first focus group interview.

> One thing we've found is that Gr. 8s have so much trouble solving equations. The stronger kids grasp the basic concepts needed but the middle-range kids need some sort of template to guide them each time. We're using manipulatives and the IWB to help so we can get them started. (Cycle 1 Focus group Interview, November, 2007)

IWBs also provided a bridge between different ability levels in the classroom. Perfectly designed for rapid movement between various websites, previous lessons, worksheets and new concepts, IWBs allowed for flexibility unavailable in a conventional chalk and blackboard classroom. Many teachers cited their ability to change, adjust and respond to different levels of learning in the classrooms more readily as a result of IWB use.

Finally, IWBs allowed for interaction, again a form of bridging between students of different levels, which teachers suggested wouldn't take place otherwise. Across the board, an increase in student interaction was reported and even just midway into the project, teachers were noting there had already been a big change from their traditional approaches and, instead, "they [the students] are up there and doing it." As one teacher expressed it, "kids get a lot from explaining [concepts] to their peers" so when they are up at the IWB, it's just 'a bit richer.' (IWB interview, May 2008)

Teachers in this study viewed IWBs as an organizing tool, allowing, in turn, for some greater flexibility, translating into an increased ability to positively impact student learning. Other studies have noted that IWB use can impact positively by creating an even ‘digital’ playing field and, thereby, decrease the social divide among students. This creates a new environment, turning the classroom into a ‘place for interaction,’ not only among students of differing levels of skill but among students and teachers as they develop and grow their IWB competency together (ICT Impact Report, 2006).

Even the few teachers with more experience using IWBs expressed similar concerns about using them effectively in order to truly enhance student learning. As one teacher put it:

> It’s not an overhead, it’s a tool. And using it as a tool is the challenging part. And continuing to look at lessons and figure out ‘how is it important here?’ And not using it all the time. If we are truly differentiating for our students then we can’t use the same tool every time. It shouldn’t be on one hundred percent of the time. (IWB Interview, May, 2008)

During a typical exchange between a facilitator and a teacher in the debrief after the second public lesson, the teacher recognized how the use (or in this case, the lack of IWB use) impacted the sequence of the lesson and, as a result, student learning.

> In the action part of the lesson, there was no IWB use. And one of your goals was to have students using it. So what if one pair was working on the whiteboard instead of using tiles at their desk?

Or in another exchange during the debrief of the first lesson cycle, the facilitator and teachers discussed IWB use in relation to the use of manipulatives and how students could benefit from the teacher’s understanding of more effective IWB use.

> Observer: How was IWB integrated into the lesson? There were non-dynamic uses including the introduction and consolidation tasks. Dynamic uses included dragging the tiles, infinite cloning, etc. But I have something I’m calling ‘competing tools.’ This happened when a student was at the IWB and then had the competing visual of the manipulatives – an increasing majority of students kept looking at the manipulatives rather than the IWB. So the question is should the manipulatives be taken away?
>
> Observer: They weren’t prepared to give up on the manipulatives and watch the IWB until the solution they were working on was solved.
>
> Researcher: So perhaps more time is needed for all students to complete the task with the manipulatives. And then the next issue is when students are using the IWB, could they go up in pairs so that one could manipulate the board and the other does a talk aloud – this is so hard but so crucial. What can we do to encourage that talk aloud at the IWB? (Debrief field notes, January 2008)

Finally, teachers saw that IWB use afforded students the opportunity to consolidate their understanding through multiple applications, including catching up on tasks when they were not present in the class.

> A student who is away can see it [on the IWB]. You can record what a student is doing [on the IWB]. The real world applications [are] so visible and hands-on at the same time. There's just, so many reasons to use it. (IWB interview, May, 2008)

7.3 On Schools

Schools benefitted from the increase in number of IWBs placed in classrooms during this year-long project. Expertise with IWB technology varied within each school team and those variations yielded increased collaboration and, ultimately, increased confidence among novices, mirroring, in effect, the ripple effect of lesson study on the school culture as discussed in Section 6.2. Those schools which took the step of sharing new IWB practices during faculty meetings, for example, clearly increased the perceptions among teachers of the potential positive impact of IWBs on classroom practices, particularly in combination with manipulatives. As noted in the lesson study discussion, there was a marked increase in confidence levels of the participating teachers as a result of the opportunity to share IWB practices with their colleagues. This resulted in a shift toward a more collaborative and healthy risk-taking environment in schools where learning was embraced.

The theme of sharing, whether within the school team, the division or with colleagues in different curricular areas persisted throughout the interviews conducted during the project. One participant remarked, "I like how the secondary teachers are talking more and more….and I'd like to implement that at the intermediate level" (Focus group interview, November, 2007). At the end of the project, teacher participants seemed more sensitized to the challenges faced by their colleagues, particularly in the case of secondary teachers learning about math instruction at the intermediate level.

7.4 Enablers for effective IWB use in schools

Once again, enabling factors for increased and effective IWB use in schools mirror those needed to support the widespread use of lesson study as an effective professional development tool. There needs to be a consistent and long term financial commitment to the purchase of IWBs for use in classrooms by school administrators and school boards. Secondly, once in place, teachers need explicit and regular support in developing effective IWB practices in the form of expert advice and time to 'play' with the technology. Otherwise, school administrators run the risk of buying expensive technology that is used only as a 'glorified chalkboard' rather than the highly interactive tool. Research (Glover *et al*., 2007, among others) has already identified the lack of confidence and motivation about using IWB technology among teachers, as well the absence of an ‘effective infrastructure’ to support the proliferation of IWB use, as significant barriers to development.

At the start of the project, one teacher with IWB expertise was asked how to get started and she responded: “Put it in your room and use it. I dove in feet first. Just start. It’s key that it is accessible.” (Cycle 1 focus group interview, November, 2007) It was imperative for participants with less IWB expertise to similarly dive in and get started but, also be fully supported along the way. For some participants, this long term support manifested as time to “download, to play, to learn, like learning Flash” (Cycle 1 focus group interview, November, 2007). Sufficient time provided to teachers through the advocacy of their administration enabled them to take hold of the technology and really learn about the capabilities of IWBs, especially important given how quickly the technology itself is changing. Teachers also noted that learning how to use IWB technology is a process which requires long term support, beyond the end of this particular project.

> You can’t expect to do it in a year. It’s a process: you do the first bit and then someone else builds on it and refines it. And you depend on other people’s expertise, finding someone who is an absolute whiz, who can really support you…that’s how you manage. (Focus group interview, June 2008)

This long term support is spearheaded by effective and sustained administrative support and interest. Teams who had more prep time felt they had the best opportunity to take full advantage of the opportunity to take the time to learn about IWBs.

> We were very fortunate that way…the administration really supported us in this project. I think that was a real plus because without their support, who knows what might have happened? (Focus group interview, June, 2008)

Lesson study provided a structure and vehicle by which learning expectations were set with participants and researchers supported the teams in meeting their goals. Explicit use of the lesson study cycle further refined the activity.

The results of this study suggest that the development of teaching practices using IWBs is best facilitated within the context of a professional development model like lesson study, which provides for a formalized structure of supports for teachers to grow as learners.

7.5 Challenges to effective IWB use in schools

Participants highlighted a number of challenges – at the school level and in terms of their own daily use – to the effective integration of IWBs into their regular teaching. Repeatedly, teachers pointed to the issue of time and time management as being a significant barrier to developing their technological expertise and, further, how best to make full use of the IWB for student learning. For example, one participant expressed her concerns about the commitment of her time outside the regular school day preparing lessons integrating IWBs. She said, "We have two experts at the school who rescue us but I have to spend a lot of extra time at home and after school trying to figure things out" (Cycle 2 focus group interview, June, 2008). While participating teachers were provided extra planning time as a result of the project funding, many concurred that they too were spending extra personal time preparing their lessons with the IWBs.

> For a first time teacher on the interactive whiteboard, it is time consuming to create the lessons, you have to realize. But I think you can say short term pain for long term gain. (IWB interview, May, 2008)

In some cases, teachers framed this discussion in a positive way, noting that they felt excited and motivated as learners, but, more frequently, frustration was expressed about the lack of time available for them to 'play' with the technology and develop their expertise.

> There are so many parts of the [software] program that I still have yet to try and that just comes down to time. (IWB interview, May, 2008)

The effective use of IWB technology also required working technology and technological assistance when the technology was not working. Teachers required consistent access to the IWB in working order.

> The technology was a huge challenge for us. The thing is you do your research at home and then you get to school and try to access it and you can't – it's either blocked or you can't download it. (Focus group interview, June, 2008)

Therefore, ready access to technical expertise for teachers developing IWB proficiency was key to insuring successful integration of the IWB into mathematics lessons.

7.6 Framework for effective math teaching and learning using the IWB

In this study, the researchers observed teacher activity closely, not only in terms of the implementation of lesson study, but also in terms of IWB use. These close observations during public lessons and meetings throughout the academic year revealed to all participants and researchers that there were definite and explicit types of IWB use with a variety of different purposes. In this way, the research is deeply grounded in teacher practice. At the same time, the teachers and researchers brought various theories to their work in the project in terms of what constitutes good mathematics learning, rich mathematics tasks and effective uses of the IWB.

Development and content of the Framework for Effective Math Teaching and Learning using the Interactive Whiteboard

The development of the IWB framework began with researchers observing IWB use in general and then theorizing about how the teachers might use the IWBs as teachers

began their practice of incorporating the IWB as a tool in the math classroom. The researchers developed a
framework to describe IWB use in the math classroom based on their observations. This framework consisted of six stages that the researchers believed to be sequential. That is, as the teachers began to feel more comfortable using the IWBs, their types of use would change and progress from the first type of use through to the sixth type of use. The types of use identified were:

1. Non-dynamic demonstration (the screen acting as an overhead or static screen for visual support with limited interactivity);

2. Dynamic demonstration (the screen working as a computer screen with interactivity which was demonstrated by the teacher);

3. Student practice (to repeat what the teacher had demonstrated);

4. Student investigation (to investigate mathematical ideas with the use of the IWB);

5. Facilitating discourse (the teacher using the IWB with students to facilitate math communication);

6. Consolidation (using IWB to consolidate ideas brought forth by students).

The researchers imagined the teachers moving from #1 to #6 over time as their comfort with the IWB increased and their engagement with the lesson study profession development continued (Field notes, November 30 2007). This continuum approach concurs with the work of Glover, Miller, Averis & Door (2007) who found that the teachers in 50 video episodes fell into a three point continuum from: (1) a teacher-directed, non-dynamic approach to IWB use; to (2) a teacher-directed but interactive approach with the use of dynamic/interactive demonstrations which engaged students and led the teachers to wanting to further explore the potential of the IWB as a teaching tool; to (3) a student-directed highly interactive and dynamic approach which exploited the interactive capacity of the IWB. These teachers also demonstrated considerable enhanced understanding of how children learn, how technology supports student learning and how to differentiate instruction.

However, our research team quickly realized that our theoretical framework was not working, even though it was grounded in observations of classroom teachers using the IWBs in their rooms. What the researchers found when we tried to apply the framework was that teachers were not static in their use of the IWB but in fact, they moved through the six types of use within a given lesson. Immediate context became very important in determining how to use the IWB. That is, the IWB was used in multiple ways based on needs and purposes of the teaching and learning moment. This became particularly apparent during a lesson observation where researchers tried to apply the framework to the demonstration lesson activity. In this case, the teacher used the IWB in almost all six ways within the one lesson (Field notes, November, 2007). Because of this and additional lesson observations where the framework was applied, the framework moved away from a continuum approach that described teachers in general and began to re-shape itself to describe the types of IWB use in the context of specific mathematics lessons. The framework was no longer a continuum of use but a description of possible types of use. It should be noted that the researchers were professionally excited by this revision because it moved the framework away from a deficit model, where one end of the continuum represented "better" or more sophisticated teaching than the other, to a description of types of use for various purposes: a descriptive model which better reflected IWB use on a practical, lesson-by-lesson basis.

The framework underwent one additional major revision as it was being prepared for web-based dissemination. In this case, the descriptions in the framework were linked directly to video samples, lesson plans and Notebook™ (an IWB software package) files that provided explicit examples of IWB use. This version of the framework is being launched as part of a website called TMERC (Trent Mathematics Education Research Collaborative) at www.tmerc.ca.

The framework, currently in its 9th iteration, continues to undergo revisions but is marked now as a solid description of what the teachers and researchers have learned about IWB use to date. To see the full framework, please see Appendix 5.

Possible uses of the Framework

As researchers we believe that the framework may prove useful in a number of different ways.

1. The framework can be examined by teachers who want to familiarize themselves with how IWBs might be used in the mathematics classroom. Viewers will be able to look at the framework, view video footage of teachers using the IWB and peruse the accompanying lessons and files for each video vignette.

2. The framework can be used by experienced IWB teachers who wish to extend the ways in which they are using the IWB for mathematics. In this case, teachers could identify which ways they are currently using the IWB, identify ways in which they would like to add to their repertoire of strategies and test out examples and samples provided.

3. The framework can be used by observers of lessons that include IWB use to provide a 'way of noticing' what is occurring in the lesson.

4. The framework can be used as tool for refining certain types of use – for example, by timing the ways in which the IWB is being used in a series of lessons and then increasing those uses which are least developed in the teachers' natural repertoire. For example, we noticed through the observations, that it was much more challenging for teachers to orchestrate student investigations and particularly student math talk using the IWB. Through the lesson observations, it was noted that participants of the study spent less time on these two more challenging aspects of IWB use compared to

the other four types of use (non-dynamic and dynamic demonstrations, student practice and consolidation).

5. The framework might be useful to administrators in schools and other educational research bodies interested in understanding how IWBs are being used as a tool in the mathematics classroom context.

7.7 Summary

A rich set of themes related to IWB use emerged from this study. Participating teachers detected a shift in their own identities as learners and researchers as a result of being supported in the development of their IWB skills. As well, the integration of IWBs into their practices helped to broaden the spectrum of teacher moves in any one lesson (enhanced, of course, by the fact that they observed their colleagues' lessons as well). Participants were in agreement about the impact IWBs had on increasing the varieties of collaborative practices, between individuals within the same division, cross-divisionally, and, more broadly, with the larger school staff. Finally, teachers were able to identify the ways in which IWBs affected student learning, not just in terms of student engagement, but across various levels of student ability and different kinds of 'teachable moments.' The *Framework for effective math teaching and learning using the IWB* is the result of researchers, together with the teacher participants, identifying definite and explicit types of IWB use with a variety of different purposes.

8. Overall Summary and Conclusions

This one year research project on lesson study using IWBs was a beginning point in many ways. This was the first time lesson study had been formally introduced to the teacher participants and the district school board. This was also the first time the teachers (all but 2) used IWBs in their mathematics classrooms. Further, this was a first attempt at using a mixed methods research design to assess the effectiveness of lesson study for indirect student outcomes. The researchers learned a great deal along with the teachers in the project – about lesson study, about IWB use, and about research design strategies for lesson study projects.

We found lesson study, as enacted in this project, had limited effects on achievement. There were statistically significant improvements for students in lesson study classrooms but the achievement benefits of lesson study were limited by type of objective measured and by grade. We found that students scored better on a conceptual test if they were in lesson study classrooms than if they were in the control condition. Our explanation for this finding is that the central purpose of the in-service was to promote conceptual approaches to mathematics education. This purpose was reflected in the improvement on a test measuring conceptual dimensions of mathematics, without loss (or benefit) to algorithmic performance.

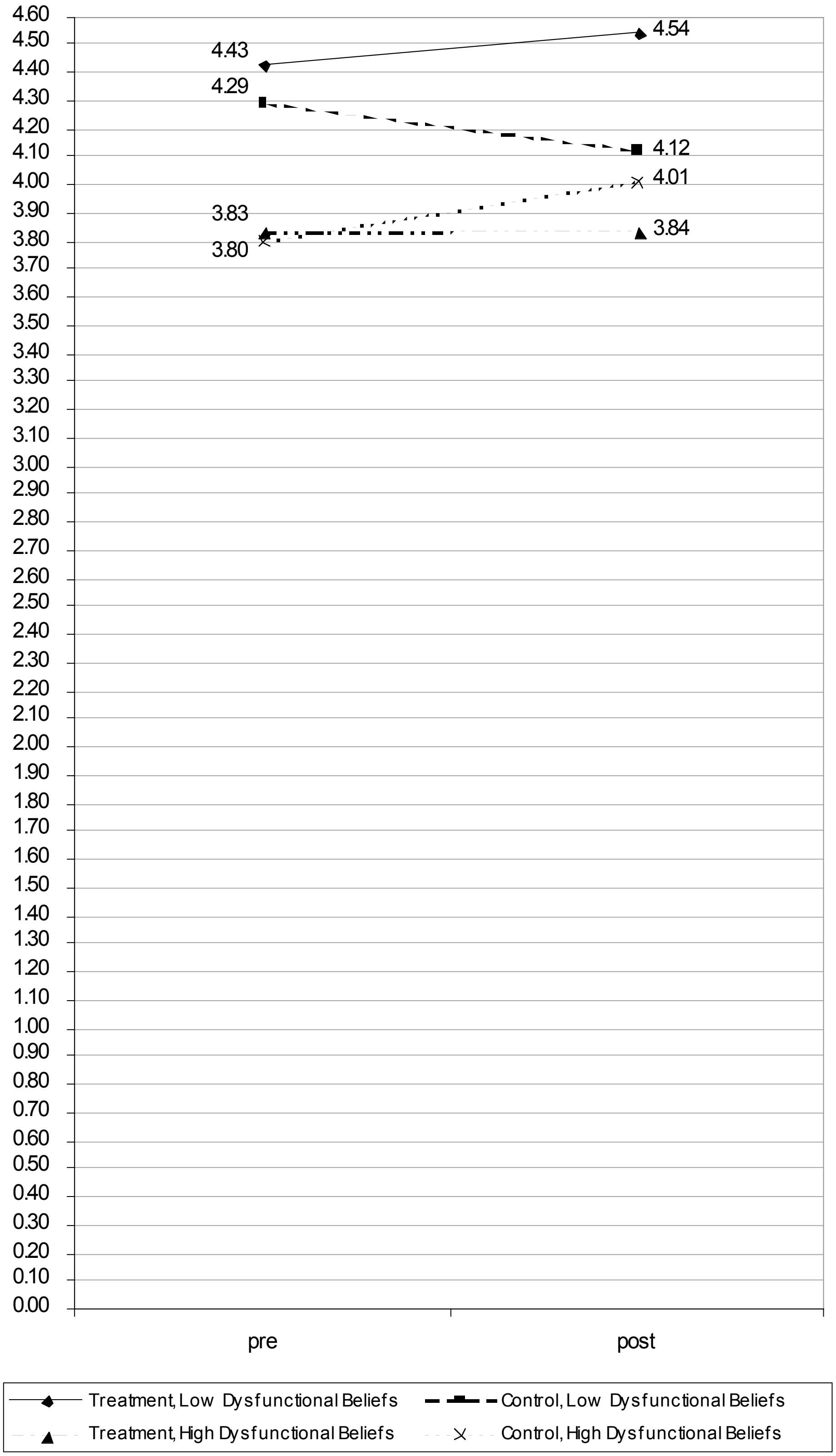


Figure 4 Functional Beliefs about Math Learning

But we found achievement benefits only for grade 7/8 students. We speculate that lesson study might have been a better fit with grade 7/8 because the collaborative culture of the school is stronger in elementary than secondary, in part because of the larger size of secondary schools. In addition, the tests that were used addressed grade 6 expectations. Although previous administrations indicate that substantial proportions of students beyond grade 6 have not mastered these expectations (Ross *et al*., 2006b), the higher the grade level the less relevant these measures might be. The finding that lesson study affected performance in grades 7/8 but not grade 9/10 might be due to the better fit of the tests with the learning needs of grade 7/8 students.

The student achievement findings may underestimate the impact of lesson study. We did not have a set of items that focused on the content of the lesson study in each of the schools. We used a general test, from the PRIME program, that addresses core expectations of the Ontario mathematics curriculum. It is possible that none of the items fit the instructional focus of the lesson study. This feature contributed to the credibility of the design in terms of fairness to the control group but it suggests that the achievement benefits of lesson study were indirect. Lesson study may have influenced the knowledge, belief and practices of teachers that were applied beyond the context of the specific lesson they worked on.

We also investigated the effects of lesson study on student motivation. We found a statistically significant effect. Students in lesson study classrooms, in comparison to students in the control condition, showed improvements in functional beliefs about math learning and in self-reported effort in math class. Given the short duration of the lessons that were the focus of the intervention, it is likely that these student effects were indirect. A reasonable interpretation is that lesson study affected the knowledge, beliefs and practices of teachers. These teacher changes included attention to student motivation, persuading students that active involvement in math discussion groups and greater effort contribute to higher student achievement. A key priority for further research on the impact of lesson study on student achievement and motivation is to develop a theoretical framework linking lesson study elements to teacher changes and to student outcomes. Such models can then be empirically tested.

We also searched for moderators of the relationship between lesson study and student outcomes. Given the small number of classrooms participating in the study we limited the search to student characteristics. We found only two moderators. Grade was a significant moderator of student achievement effects, as discussed above. In addition, students with relatively weak dysfunctional beliefs about math learning were more likely than students with strong dysfunctional beliefs to show improvements in functional beliefs, if they were in the lesson study condition. We speculate that lesson study teachers attempted to strengthen beliefs that contribute to math learning (such as participating actively in group discussions) but did not address dysfunctional beliefs (such as the math ability is fixed). Holding strong dysfunctional beliefs may have been a barrier to responding to input on functional beliefs. The implication for further implementations of lesson study is that teachers should explicitly attend to dysfunctional as well as functional beliefs. In addition, future research should search for teacher moderators, a quest that requires a larger sample of teachers.

To summarize, four major learnings from the study are highlighted below.

a) Although the study can be characterized as a "pilot study" for a number of reasons already outlined, the findings have been rich and instructive, contributing to the literature on lesson study and IWB use. One of the major recommendations of Leading Math Success was to integrate new technologies into the classroom with teacher support through regular workshops and time to observe classrooms. This project built teacher capacity by: a) providing classrooms with IWB technology; b) providing teachers with professional development on the use of IWBs; c) providing time for teachers to observe one another using technology during mathematics lessons; and d) providing the structure of lesson study to focus on high quality instruction. Participants indicated a strong wish to continue with lesson study using IWBs in the following school year. In fact, at one of the sites, the teacher team independently applied for and received a research grant so that they can continue their work without interruption. Teachers at the three other sites have also indicated interest in continuing even though there are teacher transfers and major school changes (such as the Grade 8 students and teachers moving back to the elementary school in the case of School D).

b) Researchers have called for further studies that expand the knowledge base of lesson study beyond the existing case studies and related publications in North America (Yoshida & Hiebert, 1999; Fernandez & Yoshida, 2004). This study adds to the theoretical discussion (and the implications for practice) of the use of lesson study as a professional development model. In particular, participants of this study were able to articulate the types of activities they engaged in which have been less clearly identified in the literature to date. We have called these "in-between stages activities" which feature some of the detailed actions and feelings teachers experience beyond (and between) the key four stages of lesson study. Participants summarized their experiences in Figure 3.

c) Using a mixed methods research design to examine effects of lesson study and IWB use is unusual. There are very few examples to draw from in terms of models, and as researchers, this makes it challenging to borrow from helpful models. Nonetheless, our student survey data indicated that students' beliefs about learning math were more positive in the classrooms involved in lesson study with IWBs than in control group classrooms. The most important finding was that lesson study had an overall effect on student motivation and in particular on student beliefs about mathematics and their self-reported effort. Students in the lesson study group reduced their beliefs that people are either good at math or not. In other words, these students began to believe that math is something that can be learned by anyone. They also changed their beliefs about getting answers immediately – the students in the lesson study classrooms began to believe that if they persisted with a problem, they could find an appropriate solution. Further, we found that students' self-reported effort in math class remained constant in the lesson study group but declined in the control group. These findings are important because they go beyond individual teacher reports of student motivation, persistence and effort to a relatively large student population that demonstrated statistically significant positive increases in attitudes toward learning mathematics.

d) The framework for effective teaching and learning in mathematics using IWBs is a new contribution to the literature and theoretical frames for several key reasons. 1.) The framework operates from a position of examining the variety of types of IWB use for a variety of different purposes, rather than working from a deficit model position. The researchers distinctly moved away from a continuum approach in the framework as it did not reflect teacher activity, nor did it reflect the various ways IWBs can be and are being used. 2.) The framework is practical and offers teachers, and other educators, ways to think about IWB use in mathematics classrooms with the support of video examples, Notebook ™ files, and lesson samples (lesson sequences and feature lessons). It is anticipated that the framework can be built on and revised over time as we learn more about the potential of IWBs in the mathematics classroom.

This study had several limitations. First, it was essentially a pilot year study that requires refinement should it continue. For example, the quantitative measures for student achievement require closer matches to the content teachers are focusing on. Second, the project had considerable problems with scheduling for teachers and the more advanced notice all parties have of this type of work, the better. Third, the project was at the mercy of IWB technology working properly and being fully accessible. This is an ideal condition. In reality, not all teachers have access to IWBs and when they do, the IWBs are not fully functioning at all times. These are typical problems that require time and energy to be resolved on an on-going basis. Finally, the study involved only 12 teachers at 4 sites and their respective students. This is not a low number for a qualitative study, however, it is low for a mixed methods study. Once again, this leads the researchers to further questions about how to design a best-fit model for researching lesson study which they hope to explore over the next several years.

9. Recommendations

9.1 Further research activity

Further research would be helpful on several fronts:
a) To examine in more detail (through observations, video analysis, etc.) the "in-between" activities of teachers who are participating in lesson study. Articulating these activities will support teachers in revealing the details of the 'hidden' work associated with lesson study cycles.

b) To develop more fine-grained tools for measuring student achievement that closely match the content being addressed in the mathematics programs. This is particularly challenging when the teachers are self-selecting their focus for the key concepts that will be 'tackled' and when there are multiple grades involved in the studies. One might suggest that the issue of student achievement is irrelevant but others argue that it is a fundamental goal of all classrooms, schools, and districts to find effective ways to support student achievement. There are perhaps other ways of measuring student achievement which should also be explored in the case of lesson study.

c) To continue the research begun in the one year study in order to build on the work that the teachers and researchers have already established as fruitful. This requires the will of the local district school board and teachers in schools to continue with lesson study as a positive form of teacher professional development. One strategy would be to invite the schools involved from this pilot year to continue with lesson study while also inviting some neighbouring schools to join them. The cross-divisional nature of the professional development could be strengthened as it expanded.

9.2 School actions

The researchers recommend that schools and administrators consider adopting a lesson study approach to in-school professional development, ensuring that the necessary supports are in place in order to carry it out in an effective manner. Administrative support must be explicit and ongoing and requires advanced preparation so that teachers have planning times together and sufficient blocks of time to enact the elements of the cycle without becoming overburdened. Teacher teams participating in this study fared better when administrators took an active role in the lesson study process by observing the public lesson and when they felt they had the time to make use of the findings from every iteration of the public lesson.

Support for purchasing of IWBs is also recommended so that teachers are provided with access to this innovative technology. Teachers who do have IWBs require technical support and professional development opportunities for updating their own technical expertise.

9.2 Policy-maker actions

Whenever possible, funding agencies and policy making bodies should fund and support professional development programs like lesson study which fosters the development of successful teaching. Lesson study offers an accessible and easily reproducible model for the building of professional development teams within schools and their communities.

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III. Appendices

Appendix 1

Lesson Study Implementation #1

Grade 7 and 8 Representing Patterns

Lesson Study Project

Y Public School
December 14, 2007
8:30 – 11:30

Lesson Study Implementation
Y Public School
December 14, 2007

Agenda

8:30 – 9:15 Overview (Music Room)
- Introductions
- Background to the Lesson
- Introduction to Lesson Study
- Role of Observers

9:30 – 10:30 Lesson: Balancing Linear Equations
- teacher: H (Room 10)

10:45 – 11:30 Debriefing (Music Room)

Contents

Background

Patterning and algebra skills are essential for any student in a day and age wherein discovering and utilizing relationships is key. The ability to represent such concepts in a variety of ways becomes critical when students begin to tackle the more complex relationships they will encounter, for example, in high school math, science, and geography. According to Van De Walle and Lovin (2006), a recent shift in algebra curriculum has begun to stress the importance of an ability to represent patterns and relationships in symbolic, numeric, and graphic ways. This aids in a student's ability to visualize and communicate about the patterns they encounter.

This lesson sequence addresses some of the "big ideas" outlined in Van De Walle and Lovin's chapter on algebraic reasoning. (2006, p. 265) By giving students an opportunity to play around with physical materials that make patterns, and by stressing the fact that all patterns can be represented in a variety of ways (algebra, model, graph, table/chart), we are addressing big idea #1 and #2 (2006, p. 265), which state that:

> Logical patterns exist and are a regular occurrence in mathematics. They can be recognized, extended, and generalized with both words and symbols. The same pattern can be found in many different forms. Patterns are found in physical and geometric situations as well as in numbers.
>
> A variety of representations such as diagrams number lines, charts, and graphs can be used to illustrate mathematical situations and relationships. These representations help in conceptualizing ideas and in solving problems.

Historically, teaching of algebraic reasoning has been restricted to equation building and solving. The result was that algebra was restricted to students with above-average abilities, excluding those with limited readiness. (Spielhagen, 2006, p. 34) The 'traditional' teaching method of "follow the steps" did not require students to fundamentally understand what the parts of an equation represent. By changing our North American curricular standards, policy-makers are hoping to create a framework that will build all students' algebraic reasoning skills. One way the Ontario Curriculum is doing so is by encouraging teaching strategies that address students' different learning styles. By valuing graphical representations of patterns, student who may be visual learners are given an opportunity to grasp onto something they can see, which allows them to them connect with a more abstract representation, such as an algebraic expression. By creating pathways that encourage a wider section of the student body to access algebraic thinking, mathematics educators and researchers believe many more students can attain mathematics literacy. (Spielhagen, 2006, p 38)

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Overall Goal for the Lesson

Our goal for this lesson is to create a learning opportunity that can be experienced by the wide range of abilities present in our students. By exposing them to the different possible representations of a pattern, it is hoped that each student can be brought to a new level of algebraic understanding.

Lesson Sequence

Patterning & Algebra
8m60 – model linear relationships using talbes of values, graphs, and equations through investigation using a variety of tools

	Day 1	Day 2	Day 3
Title	Build a Model	How many seats?	Fundraising Party
Goal	- review of how to move from growing pattern to algebraic equation	- represent a pattern in various ways - describe one representation and explain strengths	- move from being able to use concrete (square tiles) to abstract (money amounts)
Description	- students work with coloured square tiles and position numbers 1, 2, and 3 to grow a pattern / build a model - students identify the algebraic equation by following the sequence: #of tiles = position + _______ OR # of tiles = position + _____ x ______ - end with graphing of the patterns	4 groups of 4 students Beginning: revisit some graphed samples from yesterday Middle: students are working on a problem that involves #'s of tables and chairs at a grade 7/ 8 celebration – tables are trapezoidal, must be long banks of tables *How many tables will you need to seat x people?* - building the model - transferring model to a table - developing an algebraic equation / rule - graphing the model End: jigsaw task where students meet in an expert group;	Impact Math p63 Beginning: - scenario / cover page is presented; discussion around "minimum total charge of $400" Middle: End:

Lesson Study: Day 1 in 3 Day Lesson Sequence

Math Learning Goals

- Activate students' prior knowledge (patterning/algebra terminology; how to build and describe models of patterns)
- Have students build growing patterns with hands-on materials
- "Play" with the materials so they are more familiar with them for Day 2's Lesson

Question: ***"How do we build and describe a variety of growing linear patterns using correct terminology?"***

Materials*: a variety of materials/manipulative with which to build patterns, SMARTBOARD, vocabulary cards made in advance*

Minds On… Whole Class → Connecting/Activating Prior Knowledge (10 min)

Show some patterns on the SMART Board (SB) that reflect actual manipulatives that students are familiar with.

Ask students to think about the patterns on their own, in terms of what they are made with, their characteristics, how they are growing.

Then ask students to consider the various proper math terms (patterning/algebra related) as you put them up on the chalkboard. Students can then volunteer their ideas to the class. If a student uses a word when talking about a pattern, they take it down off the board and hold onto it. At an appropriate time, all those with cards can write their word on the SB. This will be our "word wall" in progress.

Action!

1a. Distribute materials to students (one set of material for every pair) who will be working with their "elbow partner". Instruct them to build any pattern they would like with the materials they have available, suggesting they build their pattern to the third or fourth term. Ensure that students have a piece of scrap paper handy to record a few things during the lesson.

1 b. Partners work together to write a descriptor that connects the term number (position number) to the term value (total value). At this point, no direction will be given with respect to "descriptors." This will mean that many students will use words, while others may use algebra.

2 a. Teacher: **"Now, I would like you to consider the pattern you just created and the description you came up with. Is your description one that could be written algebraically?"** After appropriate wait time, teacher will then instruct students to create a new pattern with manipulatives, one that they know will be able to be written in an algebraic expression.

2b. Students will use scrap paper to record the algebraic statement that connects the term number to the term value.

3a. Teacher: **"Now that you have explored patterns that can be described using words or algebra, I want you to think about building patterns from a new angle. I would like you and your partner to build a pattern that has a part that doesn't change, and a part that does. May I suggest you use some kind of visual difference between the two parts?"**

3b. Instruct students to write a descriptor that connects the term number to the term value, paying close attention to how the part that changes and the part that does not are addressed in the descriptors

Consolidate ... Debrief Whole Class → Discussion/Sharing (20 minutes)

Ask students to volunteer to put some of their patterns and related descriptors on the SB, eliciting from them their thinking behind the creation of the pattern and the descriptions. A SB file will be ready, hosting a variety of "manipulatives" that match what the students have.

From these examples, the teacher will lead a discussion on the idea of a constant and the concept of a variable, stressing the use of these terms.
The teacher will assist students in creating new descriptors, in particular algebraic expression, that contain a constant and a variable. These will be saved for the Minds On of Day 2.

Lesson Study: Day 2 in 3-Day Lesson Sequence (PUBLIC LESSON)

Math Learning Goals

- Gr. 7: represent linear growing patterns using a variety of tools (concrete materials, paper and pencil) and strategies (table of values, graph, words)
- Gr. 8: model linear relationships using table of values, graphs, and equations through investigations using a variety of tools
- *Mathematical processes:* Problem Solving, Representing, Selecting tools and computational strategies, Communication

Question: ***"What are the benefits of representing a pattern in multiple ways?"***

Materials: SB file of student work from Day 1, SB file with pictures ready, bag of materials for each group of 4, hand-out (for each individual, tailored to their expert group)

Minds On!!

Whole Class → Connecting/Activating Prior Knowledge (10 min)
Use the SB to review vocabulary list created yesterday by students; have everyone read a word aloud, listening closely so that no word is read more than once.

Use the SB to call up students' patterns from yesterday, however, with the descriptors hidden. Teacher: **"With your elbow partner, spend the next 30 seconds discussing the pattern, and be prepared to report back to the class with a clear way to describe it."** Teacher leads a discussion where students describe the pattern, reinforcing the use of mathematical language whenever possible.

Begin to extend their thinking by asking the class **"We see statements with words, and algebraic expressions used to describe these patterns, but what are other strategies we could use to describe patterns?"**

Action!

Whole Class → Setting the Stage for Today's Exploration (35 min)
1. Set the stage for today's "action" by talking briefly about patterns in the "real world." Confirm with the students that knowing different ways to represent patterns is extremely helpful, because different scenarios may be better modelled using one method over the other. For example, to explain a pattern at the bank, it would not be very practical for the banker to take out a box of tiles to show you what is happening as your money gains interest!

2. Introduce the following problem: **"For the upcoming Festival of Trees here at Highland Heights, we were thinking of having a tea room using tables from the library. We were wondering how many people could be accommodated with the tables, if they were arranged in long rows. Here is a picture of the tables we were thinking of using, and how they would be put together."** Teacher shows pictures of trapezoidal pictures on SB. **"What do you notice about where people can sit, and how two tables are put together?"** Elicit from them facts such as the tables set one on each end, two on the long side, and one

on the short side. Also, point out the fact that when tables are added on, one seating position is lost where they meet. **"Now, you are going to work in group situations to solve some problems that arise from this table scenario."**

<u>Groups of 4 → Exploration</u>

3a. Students are assigned to groups of 4 ("Expert" groups, numbered). They are given manipulatives and are asked to first build a model of what would happen seating-wise for 1 table, 2 tables, … up to 4 tables. They need to show all 4 terms.

3b. When group has completed all four terms and has checked with the teacher, they will receive individual handouts on which to draw the pattern they created with manipulatives and to complete pattern in one other way (determined in advance by the kind of sheet they were given by teacher). The other methods are: by graph, table, statement, algebra (representing the 4 expert groups).

3c. Teacher leads a brief group chat to stress that after working together for a little while, each member of a group will be meeting up with others. Teacher: **"On your hand-out, another type of representation is given to you. You and your group members will need to become experts on your representation because shortly, you will be meeting up with other students to share. As you work on this other format, make sure each member of your current group can effectively explain your representation."** Students then work with their group member to complete second representation.

4a. Group of 4 are created using Jigsaw method (based on shapes cards handed out). These groups are made up of one person from each of the 4 remaining representations: graph, table, statement, and algebra. Each student is given 30 seconds to show how their group represented the pattern with the manipulatives.

4b. Group members then share their individual representations (graph, table, statement, or algebra) explaining how it connects to the model. As these explanations are given, the others copy onto their own sheet.

Consolidate / Debrief

Group/Whole Class (15 minutes)

1. While students are still in groups, ask two questions: "**How many tables are needed to seat 65 tables? How many people can sit at 50 tables?"** Instruct students to use all representations (except a physical model) to answer the two problems and to be prepared to share any one of their solutions with the class.

2. Whole class: Have students return to their seats. Invite individuals to demonstrate each of the representations on the SB (pages will be preset with gridpaper, table, etc.). These representations will be saved for Day 3.

Homework
Reflect in a journal entry which representation was the best one to use to answer the questions? Which one do you most prefer to use and why?

Lesson Study: Day 3 in 3-Day Lesson Sequence

Math Learning Goals

- Review multiple representations
- Give students an opportunity to apply learning to scenarios that involve larger numbers, where modelling with manipulatives is not possible
- Expose students further to "real-life" situations that involve problem solving with patterns

Question: ***"How do we use what we've learned to make effective decisions?"***

Materials: SB file of student work from Day 2, hand-out for each student

Minds On!! (10 min)

Whole Class → Discussion

1. Use the SB to review multiple representations of trapezoid tables problem.

2. Teacher gets feedback from last class' homework by asking students to share their ideas re: what representations they choose as their most preferred and why.

Action! (40 min)
Whole Class → New Scenario

1. Teacher introduces a new problem.

Jennifer, Steve, and their committee are planning a fundraising event to raise money for charity. They want to rent a hall and provide food and entertainment. Everyone in attendance will pay an admission fee to cover cost and the profit will be contributed to a local charity. To minimize the cost of the hall, Jennifer and Steve call three different places to obtain quotes. The maximum number of guests will be 70… (more details to be provided, posted on SB and on hand-out)

The scenario will be posted on the SB, and together, the students and teacher will highlight key information. Teacher will give the following overview: "**Now that you have learned about different methods of representing patterns, it's time to see what you can do on your own with respect to using these methods to solve problems."**

2. Teacher will distribute one hand-out to each student (depending on ability level, as the scenarios will be tailored to three ranges of ability)

Individual → Independent work
Teacher will circulate as students work on their individual work.

HOMEWORK: Complete hand-outs.

Consolidate / Debrief (Next Class)

Group/Whole Class (20 minutes)

1. Have students reflect in a journal entry which representation was the best one to use to answer the key questions on the hand-out.

2. Take up the three different scenarios, and as a class, decide which place offers the best deal for the charity event.

Appendix 2

X HS
Lesson Study Observation Guide

Thank you for joining us as observers for this lesson study!
Reminders:
- Each observer is given a focus. Please stick to your focus. Observers may choose to pay close attention to one or two questions within that area of focus.
- Be prepared to share your observations at the debriefing session after lunch.
- Keep your observations free of judgment. Record only what you see and hear.
- Think about recording questions you have that may be discussed at the debriefing.

Table One: SMARTboard
Observers:

Focus	Observations
• what is the teacher doing with the SMARTboard?	
• what do the students do with the SMARTboard?	
• how do students interact at the SMARTboard vs. at their desks? (focus on one specific group of students)	
• how does the SMARTboard affect the lesson?	

Table 2: Student Performance

Observers:

** choose a pair / set of students to observe and explain why you chose this pair / set to observe

Focus	Observations
• how do these students demonstrate understanding?	
• what problem solving strategies can you see / hear?	
• what is the difference in demonstration of understanding between their work at the desk vs. the work at the SMARTboard?	
• what is the teacher doing to encourage students to demonstrate their understanding?	

Table 3: Communication
Observers:
** choose a pair / set of students to observe and explain why you chose this pair / set to observe

Focus	Observations
• what language is the teacher using to describe objects / unknowns in the equations?	
• what language are the students using to describe objects / unknowns in the equations?	
• in what ways are the students communicating their understanding of the mathematics?	
• in what ways are the students communicating their lack of understanding of the mathematics?	
• record the interactions between students (S-S), and between student and teacher (S-T)	

Appendix 3 – see www.tmerc.ca

Framework for Effective Mathematics Teaching and Learning Using the Interactive Whiteboard

Grounded in Research Observations of Multiple Classrooms KPRDSB

General Descriptor	**Example 1** **(entry level)**	**Example 2** **(more complex)**
Non-Dynamic Demonstration **Providing instruction or information to the class using the IWB as a static screen or series of static screens** [Use of IWB mirrors use of an overhead, chalkboard or chart paper for displaying notes and ideas]	Clip: "non dynamic demonstration 1" Length of original clip: 35 s Source: PH Lesson #2, May 7, 2008 (Tape 1) Description: K outlines agenda for class. **Lesson Plan** **Notebook File** *Context*: Grade 10 applied level Ontario classroom, introduction to a lesson on solving linear systems by reviewing agenda on the IWB.	Clip: "Implementation03IntrotoLesson" Length of original clip: 2m43s Source: HH Lesson #1, Dec. 14, 2007 (CSC DVD, Tape 1) Description: H introduces lesson to class, presents the table/chair problem with photos. **Lesson Plan** **Notebook File** *Context:* Grade 7/8 Ontario classroom; Introduction to a lesson on linear functions. The teacher shows a photograph of one trapezoid table with 5 chairs from the school library.

General Descriptor	Example (simple)	Example (complex)
Dynamic Demonstration **Demonstrating to the class using IWB where the user manipulates words/images/ objects on the board**	Clip: “dynamic demonstration 1” Length of original clip: 1m19s Source: HH #2, May 14, 2008 (Tape 2) Description: L with pattern samples, talking to class and showing how to move the samples **Lesson Plan** **Notebook File** *Context:* Grade 4 Ontario classroom; The teacher posts pattern examples that students recorded on the IWB during the previous lesson. Students discuss their thinking and the teacher moves the pattern examples into one of three categories (growing, shrinking, repeating).	Clip: “dynamic demonstration 2” Length of original clip: 4m07s Source: Live lesson study – rough assembly, Feb. 12, 2008 (from CSC) Description: K with her class at the GAINS symposium in Toronto **Lesson Plan** **Notebook File** *Context:* Grade 9 applied Ontario classroom; The teacher shows the virtual manipulatives that students will be using in the lesson on the IWB (uses the infinite clone feature for dragging and dropping). The students are also given a set of containers and interlocking cubes in yellow and blue that mirror the virtual manipulatives.

General Descriptor	Example 1 (entry level)	Example 2 (more complex)
Student Practice **Students use the IWB to replicate teacher demonstration or model**	Clip: "student practice 1" Length of original clip: 8m03s Source: H Tape 4, Dec. 11, 2007 Description: H's class **Lesson Plan** **Notebook File** *Context:* Grade 7/8 Ontario classroom; The teacher goes to a virtual manipulative website on tangrams. The teacher demonstrates how to use the site (to build figures using tangram pieces). Students are then invited to solve similar problems with tangrams while soliciting suggestions from their peers.	Clip: Student Practice 2 Length of original clip: 4min Source: H Tape 9, Date: Description: H's. Teacher demonstrates virtual tools for practicing angle measurement, then a small group practices at the IWB **Lesson Plan** **Notebook File** *Context:* Grade 7/8 Ontario classroom; The teacher demonstrates how to measure angles on the IWB using a virtual protractor. A small group then practices on their own at the IWB as part of a station activity, while other groups work on similar concepts at other stations.

General Descriptor	Example 1	Example 2
Investigation **Students use the IWB for solving a problem /investigating a situation / exploring a concept**	Clip: "Implementation05GraphonSB" Length of original clip: 56s Source: H #1, Dec. 14, 2007 (CSC DVD, Tape 1) Description: B graphing alone on IWB **Lesson Plan** **Notebook File** *Context:* Grade 7/8 Ontario classroom; The student creates a graph to re-present his linear equation in a different form.	Clip: TriangleLesson Length of original clip: 1m30s Source: H, June 16 Description: N's group investigates properties of triangles using virtual manipulatives on IWB (lesson co-taught by C and H) **Lesson Plan** **Notebook File** *Context:* Grade 7/8 Ontario classroom; a small group works together at the IWB, using virtual manipulatives to investigate the properties of triangles.

General Descriptor	Example 1	Example 2
Math Talk **Facilitating student math talk and idea building with *student* use of the IWB to illustrate ideas** [May also involve making immediate instructional decisions to further student learning with support from the IWB.]	Clip: " Math Talk 2" Length of original clip: 1:25 Source: CSC Rough Assembly – Feb. 12 (GAINS symposium in Toronto) Description: K **Lesson Plan** **Notebook File** *Context:* Grade 9 Ontario students; The teacher directs students to demonstrate their solution strategy to the class using the IWB. One student manipulates the board while the other student explains their process.	Clip: Consolidation 1 Length of original clip: 7m16s Source: H. Triangle Lesson (June 16, 2008, co-taught by CB and HH) Description: groups in H's class present the findings of their investigations. 1st group 0 to 1:51 when C says "thank you for that." 2nd group from 5:26-6:26 (K: "Now *this* triangle….funky number." **Lesson Plan** **Notebook File** *Context:* Grade 7/8 Ontario classroom; The class has just completed an investigation that explored triangles by means of preparing a debate. Opposing groups use IWB tools (e.g., IWB protractor, websites, rulers, rotation feature, back and forward navigation through pages) to summarize how certain shapes presented may or may not fit the definition of a "triangle". The teacher invites students to summarize their findings on the IWB.

General Descriptor	Example 1	Example 2
Consolidation **Using IWB to support the synthesis of ideas brought forth in the lesson**	Clip: "Math Talk 1" Length of original clip: 1m01s Source: H Public Lesson #2, May 14, 2008 (Tape 3) Description: L has students talking about what they learned, word wall approach **Lesson Plan** **Notebook File** *Context:* Grade 4 Ontario classroom; The teacher facilitates a student discussion on what they learned during the patterning lesson with the help of key words posted on the IWB.	Clip: "Implementation06Consolidation" Length of original clip: 40s Source: H Lesson #1, Dec. 14, 2007 Description: H **Lesson Plan** **Notebook File** *Context:* Grade 7/8 Ontario classroom; The teacher saves student IWB work and then displays four examples of student representations of a given linear function (growing pattern) on the IWB in order to review student ideas and consolidate mathematical understandings of linear functions. Students discuss how the representations work together to show the same idea in different ways.

APPENDIX 4. Professional Development Ranking by Participating Teachers
PROMPT: Rank order the below components of the lesson study PD program from most helpful to least helpful.

SURVEY RESULTS	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
Whole group PD Sessions (October and Feb)	6	6	7	6/7	4	5	7	6	2	3	7	7
Planning time on release days with teaching team	3	2	2	2	5	3	2	5	5	5	1	1
Observing a public lesson	5	3	5	3	3	7	5	4	6	7	4	5
Debriefing a public lesson	4	4	6	5	2	6	6	1	7	6	5	4
Researcher support on planning days	2	5	4	4	6	4	3	7	4	4	6	6
Investigating use of interactive whiteboard in math	7	7	3	6/7	1	1	1	2	1	1	3	3
Talking with my teacher team and setting goals	1	1	1	1	7	2	4	3	3	2	2	2

FREQUENCY DISTRIBUTION							
Whole group PD Sessions (October and Feb)	0	1	1	1	1	3	5
Planning time on release days with teaching team	2	4	2	0	4	0	0
Observing a public lesson	0	0	3	2	4	1	2
Debriefing a public lesson	1	1	0	3	2	4	1
Researcher support on planning days	0	1	1	5	1	3	1
Investigating use of interactive whiteboard in math	5	1	3	0	0	0	3
Talking with my teacher team and setting goals	4	4	2	1	0	0	1
RANKING:	**1**	**2**	**3**	**4**	**5**	**6**	**7**

Rankings indicate that:

-*Talking with my teacher team and setting goals* as well as *investigating use of the interactive whiteboard* were the most highly valued by teacher participants

-The *whole group PD sessions* were less valued by teacher participants

- In focus group interviews following the ranking activity, teachers overwhelmingly indicated that it was very difficult to rank order aspects of the overall PD program because all of the components were very important and interconnected: "Well, like L, I was forced into this. I didn't want to put number seven down as whole group PD sessions, but I had to rank them. You forced me to do that. So, I had to indicate debriefing the public lesson as the bottom of my list, not because it's not important."