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Abstract: *For more than a decade, researchers, math educators and professional developers from the Galileo Educational Network (Galileo) in the Faculty of Education at the University of Calgary, to which the two of us are associated, have worked to improve the teaching of mathematics. Our focus has always been twofold: to improve teacher knowledge of mathematics and the pedagogy of teaching mathematics. We report on the extensive work we have conducted with teachers with lesson study, classroom mentorships and math fairs.*

Keywords: Lesson study; Math fairs; Math teacher professional development; Galileo Educational Network

Introduction

Initially encouraged by the findings of the Third International Mathematics and Science Study (Institute of Education Sciences, 1995), we started our first Lesson Study. We sought and acquired external funding. We invited mathematicians from the Pacific Institute for the Mathematical Sciences (PIMS) to join our efforts. We extended an invitation to teachers from the schools in which Galileo professional developers were working. Monthly sessions with teachers, mathematicians, mathematics educators and researchers all focused on improving mathematics learning and teaching were followed by job-embedded professional development for teachers. We worked with teachers in the context of their own classrooms providing them with support by teaching alongside them,

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videotaping their instruction for later examination and discussion and providing them timely, effective feedback on their instruction.

Initially, we began with only the findings from Institute of Education Sciences (1995), knowing that something needed to change in order to bring about the stronger mathematical reasoning. Through personal communications in 1999 with James Hiebert, researcher from Institute of Education Sciences (1995) videotape study, we were encouraged to contact Clea Fernandez who was forming a Lesson Study group in the United States. While we built on many of the ideas and approaches from Fernandez and Yoshida (2004), we also modified our approach to Lesson Study to adapt to the needs of our teachers. Like Fernandez and Yoshida, teachers met to collaboratively plan lessons; however, knowing that the majority of our teachers did not have enough mathematical knowledge for teaching we always included at least one, and frequently more than one, PhD mathematician, mathematics educators and researchers in our endeavours to ensure our planning was rooted deeply in the discipline of mathematics. Although our funding allowed us to provide teachers with monies with release time to meet during class hours, we were unable to also fund teachers to obtain teaching release time to observe lessons being taught. That said, we were able to provide teachers with a combination of mathematicians, mathematics educators and/or professional developers to work alongside them in their own classrooms as they tried out new instructional strategies. To provide teachers the opportunity to learn from other teacher's lessons we videotaped the teachers. Videotapes were viewed and discussed during a portion of our group meetings.

Our Lesson Study has never been devoted entirely to lesson planning. We always split our time between planning and learning mathematics for teaching as many teachers in Alberta (and Canada) lack sufficient background and understanding of mathematics (Friesen, 2005). In this way, the teachers in Alberta are not unlike many teachers in the United States.

In Liping Ma's (1999) groundbreaking study she identified a discrepancy in the mathematical knowledge between teachers in the US and China. Teachers from China have less education than their U.S. counterparts, yet they have a better understanding of mathematics for teaching. Unsurprisingly, the quality of mathematics teaching was dependent on the teachers' mathematical understanding. Ma called for a more connected longitudinal concept development form of teaching mathematics.

Ball et al., (2005) observed that of mathematical understanding of many U.S. teachers is "dismally thin" (p. 14). They argue that rather than more advanced undergraduate mathematics classes, teachers would benefit from knowing more mathematics for teaching. Yes teachers need to know the concepts and procedures they teach: fractions, functions, factoring, symmetry, etc. But to extend this knowledge into their classrooms, teachers need a different type of mathematical knowledge for teaching for planning, implementing, evaluating, and assessing student work. Beyond recognizing student errors, teachers need to be able to pin point the misconception that resulted in the misunderstanding. Effective mathematics teachers need to engage these (mis)understandings and move student understanding into the discipline of mathematics (Fuson, Kalchman, & Bransford, 2005). Being able to explain *why* and the *meaning* of mathematical concepts require much more than being able to *do.*

Learning the *why* and the *meaning* of mathematical concepts is extremely difficult when people have been taught mathematics as sequence of rote facts and procedures to be remembered, recalled and regurgitated rather than connected concepts to be understood requiring procedural fluency and adaptive reasoning; developing strategic competence and a productive disposition (Kirkpatrick et al., 2001).

The practice of remember, recall and regurgitate has lead to an identifiable teaching script, “consistent with the belief that school mathematics is a set of procedures” (Stigler & Hiebert, 1999, p.2). This teaching script, referred to as the North American teaching script (Stigler & Hiebert, 1999) involves teachers demonstrating a procedure and students repeatedly practicing the procedure with similar questions. Research has shown that this script is ineffective (Stigler & Hiebert, 2004; Institute of Education Sciences, 1995; Institute of Education Sciences, 1999; Institute of Education Sciences, 2003) leading to what Perkins (1992) calls fragile mathematical knowledge.

Each successive generation of teachers who learned mathematics in just this way have come to believe that mathematics as a discipline is a set of procedures. This belief divorces math learning from the “community of relations” (S. Friesen, Clifford, & Jardine, 2008, p. 118) in which the discipline of mathematics resides. Changing teachers’ practices and beliefs about the nature of mathematics has been our greatest challenge.

That’s A Good Problem

In 1999 a group of mathematicians, math educators and teachers, supported by PIMS, Mt. Royal College and the Galileo Educational Network, started to address the problem of mathematics learning and teaching in K-12 in Alberta. While we knew that policy work was needed, we took a different approach. We started our work at the level of the classroom starting an initiative which we called *That’s A Good Problem*. This initiative provided teachers, students and parents with an opportunity to engage with mathematics, increasing the mathematical understanding and competence of teachers, providing opportunities for deep engagement with mathematics and providing teachers with the opportunity to work with and learn from mathematicians and math educators within the context of their own classrooms.

Schools are invited to send a team of four or five teachers to a half-day professional development day. The focus of this meeting was on: teaching mathematics through math explorations and investigations by working through a number of math explorations and investigations.

Mathematical investigations and problems were created or provided by research mathematicians and math educators. Each of the investigations or problems had particular characteristics in that they:

1. Began with a "story" (i.e., they were situated in a meaningful context)
2. Allowed group work, but encouraged individual effort.
3. Required that students work with mathematical ideas in an active manner.
4. Could be successfully explored at many levels.
5. Permitted innovative solutions by students.
6. Included a rapid evolution from the simple to the profound.
7. Exposed the frontiers of knowledge when exploring ideas.
8. Dealt with fun and important, useful mathematics.
9. Ensured participation requires the communication of original thought.
10. Provided opportunities for interpretation, multiple correct solutions.
(Friesen & Stone, 1996)

The magnitude of the required change for teaching these explorations and investigations was difficult for teachers to envision let alone implement in their classrooms. Two colleagues from a neighbouring university were introducing their math students to good problems through an activity which they called Math Fair. We decided to introduce the teachers we were working with to ideas from Math Fair as a way to introduce good problems into their classroom practice.

Math Fair is a mathematical problem solving fair developed by Dr. Andy Liu and Dr. Ted Lewis, both PhD mathematicians, to bring students closer to the discipline of mathematics (GENA, 2008b; Lewis, 2002). Unlike the familiar science fair, math fair was designed to involve all students in non-competitive, student-led, active problem solving activity. Math Fair problems are rich, good problems which require students find connections and patterns, make conjectures and develop mathematical reasoning. After trying a number of different problems, teams of two children choose and become an expert of one problem. They learn how to give hints and extensions without revealing the solution. At the Math Fair event, students coerce and coach invited adults and peers to solve their problem. A successful Math Fair requires rigorous mathematical work.

We have found that Math Fair is a small enough parcel for teachers to bite into and try out a different teaching script. For us, Math Fair became the crack that helped teachers catch a glimpse of a different way to teach good math problems and launching point to explore math concepts and connections.

Our mentorship for Math Fair still follows the same format as when we first began with *That's A Good Problem* which has since formed the basis of our current version of Lesson Study. In our first meeting, teachers who are interested, come together to solve good problems and learn what is required to host a successful Math Fair. We provide teachers with information and images of past successful Math Fairs. Once the logistics of Math Fair have been discussed we explore a few Math Fair problems together. We place the teachers in the exact space we hope their children encounter.

Math Fair problems require mathematical thinking and reasoning. We do not provide solutions to the problems. Many teachers find this aspect of good problems somewhat unnerving as most are unfamiliar with having to justify a mathematical solution to a problem. This is often uncharted territory for teachers. However, we encourage teachers to come forward and present their solutions. We teach into the space that their solutions open for us. In this way, we demonstrate for the teachers the ways in which robust, problem solving activity unfolds.

Our next step in Math Fair is to go into the teachers' classrooms where a mathematician and a math educator or professional developer presents problems to the students. Students are enticed to jump into the problems. For most students, this way of approaching problems is unfamiliar. Used to being carefully led through a procedure which leads to a correct solution, the students exhibit many of the same behaviours of their teachers. They want the assurance that there indeed is a unique solution and in time, we will reveal the answer. However, committed to immersing the students in robust mathematical thought and reasoning, that is not dependent on flipping to the back of the book and identifying the correct answer, we persist by traversing the mathematical territory with them showing them where they have already travelled and identifying possible next landmarks. We provide many words of encouragement and leave hints about how their might get the problem to yield more of its secrets. Students experience a range of emotions when tackling difficult mathematical work from frustration to elation. When a student has found a solution we ask them to explore alternate solutions or provide them with an extension to keep them working on the problem and exposing the elastic nature of good problems. The rich elasticity of the Math Fair problems provides a course of action for differentiated learning.

Once most of the students have found a solution to the problem we get them to bring their understandings forward to the class. Together we explore the innovative solutions students have discovered. Then we follow with a discussion about the mathematics we have been investigating.

We then leave the teachers for a few weeks or months depending on their time frame to work on the problems with their student. Teachers are encouraged to explore with their students to find the paths. We always remain in contact by phone or email for students and teachers alike.

Our next visit to the classroom occurs once students have chosen their problem to present at the Math Fair. We introduce students to a formative assessment instrument, a bulls-eye rubric that we have developed, tested and modified (GENA, 2008a), to use as they are working on their problem. The top half of the bulls-eye is based on Kilpatrick et al.,'s (2001) five intertwining strands of mathematical proficiency: adaptive reasoning, procedural fluency, conceptual understanding, productive disposition and strategic competence. The lower part of the rubric is dedicated to the students' hints and extensions, coaching ability and their display. For a successful Math Fair, students need to be proficient, at the centre of the bulls-eye, in all areas of the rubric.

Teachers are often surprised at students' ability to engage with the math investigations. Students are often surprised that they have the ability to assist an adult solve their math problem.

> I enjoyed the math fair because it was fun solving the difficult problems. My mom thought they [people] were confused on jumping chips and my mom got frustrated

> and skipped jumping chips. I felt good because we helped them [parents] instead of them helping us. Math can be fun, exciting and interesting. I would like to have a math fair because we can do better in math and want to do math. We did this because we wanted to see how our parents solve the problems, because they solve them in a more advanced way. – Joel
>
> The math fair was a success because we all worked together. I enjoyed making a problem and working in a group. It was hard for my parents to figure out the problem. Helping my parents was good because then it would be easier to make them finish the problem. We should have a Math Fair every year so other people and our parents can learn more math and to give us different ways to do math. It also shows us math is fun and to improve math. Math can be exciting and we can be better problem solvers. – Emmett
>
> I feel math is fun again. I went with my uncle and he thought it was really nice. I felt really smart helping my uncle. At first he didn't get it then I told him to read it again. I would want a math fair every year because we can see how smart our parents are. – Sarah
>
> I think the Math Fair was fun because I have all the games to myself. I enjoyed when I made the hint cards and made the heads and tails for our game. My mom was confused of my game and when she finished playing she went to Randy's house. When I helped my mom she got better luck of playing. I like the Math Fair because our brain gets smarter and our parents too. Doing different ways to do math is fun. I want to do a Math Fair each year because we will be better at math. Math can be exciting and I can be better at math. – Chi

After teachers have hosted a Math Fair, we follow up with another group session with the teachers where we discuss their learning from the Math Fair experience. Teachers are often encouraged by the positive energy and mathematical insights generated in Math Fair. Math Fair provides images of what working with math differently may look and feel like.

For some teachers that is as far as they are willing to travel. For them, Math Fair becomes a one of event, an add-on to their 'real work' of teaching students mathematical procedures. Their beliefs and practices of mathematics remain unmoved, their teaching script unchanged despite the changes in learning they have observed in their students. For others Math Fair gave them a glimmer of possibilities and provides an opening for change. These teachers are ready to transition their mathematical experiences from Math Fair into student learning and our Galileo Lesson Study. We have found that a combination of Math Fair, Lesson Study and strong classroom mentorship is effective in helping teachers develop stronger instructional practices for teaching mathematics.

Beyond That's A Good Problem: Galileo's Lesson Study

Our Galileo Lesson Study addresses both knowledge of mathematics and knowledge of mathematics for teaching. Our research has shown that mentorship is absolutely integral to supporting teachers in their efforts to improve their practice. When teachers were ready, we mentored teachers within the context of their own classrooms. We worked with the teachers to design lessons, teach alongside them at times and provide them with timely, specific feedback on their instruction. We specifically looked for student understanding and helped teachers coach their students through problems encouraging them to dig deeper into mathematics and to assist them to teach into the various solutions students presented to the class. We found that we needed to scaffold the teachers learning in this way to have them take on rich, rigorous mathematical problems and stay true to the mathematical reasoning and problem solving needed for mathematical proficiency. Our research indicates that we were making headway with teachers shifting their teaching script.

Unfortunately, a few years ago we lost our funding. While we were able to continue with Math Fairs, as schools were able to afford the small price tag for our externally subsidized Math Fairs, and we were able to provide monthly Lesson Study meetings after school hours, along with PhD mathematicians from Mount Royal College and the University of Calgary but were no longer able to provide the accompanied mentorship in the teachers' classrooms. Our research has shown that the classroom mentorship was a necessary component of our Lesson Study. Lesson Study, without the classroom mentorship was starting to yield less robust mathematical instruction. In an effort to address this matter we began working with video exemplars from a variety of sources.

A Problem With Transfer of Professional Learning: A Case Study of Area of a Triangle

During one Lesson Study we watched the video "Can you find the area?" (Takahashi, 2002b). In Takahashi's lesson, students used geoboards and dot paper of the same unit size. Students used elastics to create the exact right-angled isosceles triangle shape Dr. Takahashi requested on the geoboard. They then recreated the exact shape on the dot paper. Before moving on, Dr. Takahashi invited two students with different sized triangles to bring their work forward. Together, the class learned which was the accurate size. With an exact geometric right-angle isosceles triangle, students were then asked to find the area. A right-angle isosceles triangle lends itself to accurate counting of the squares and half squares, although, Dr. Takahashi gave his students the opportunity to make that discovery themselves. With successive exercises, the shapes of the triangles evolved and Dr. Takahashi lead the students to discover the pattern of the area between all the different triangle shapes.

The video exemplar inspired a group of teachers to plan and implement a lesson for their Grade 4/5 students to find the area of the triangle. For the most part, the teachers in this group were new to Lesson Study. They had not hosted a Math Fair. However, one member had been part our Lesson Study group for several years. The teachers planned together in their own school and invited us to video record when they began to teach the lesson.

We found that the mathematical nuances of Dr. Takahashi's teaching were missed entirely by our teachers. Dr. Takahashi bound the exploration strongly by the rules and discipline of geometry. He chose exact triangles in a specific sequence all the while enforcing precision accuracy. Each of his students discovered the generality for the area of a triangle. Dr. Takahashi's accompanying Lesson Plan (2002a) provided the goals for what he wanted the students to learn. The Lesson did not spell out the specifics that were demonstrated in the video. The teachers borrowed heavily from the Takahashi's Lesson Plan (Takahashi, 2002a) adding only the outcomes from the Program of Studies for Mathematics (Alberta Education, 1997).

What we witnessed when we came to video was constructivist practice interpreted at its worst. The lesson was very unstructured. In the class prior to our arrival students were instructed to draw and cut out a triangle, any triangle on plain white paper. Without the use of rulers and unbounded by the nature of geometry, students created sloppy, uneven shapes all less that 3 centimetres in height or length. When we arrived the sloppy triangles were pinned to a board at the front of the room. Students were instructed to remove their triangles and using any tools they wanted, find the area of the triangle. Towards the latter part of the class students came together to discuss their findings. The teachers listened, never interrupted, never corrected mistakes and never directed the students understanding into the discipline. Student activity was isolated from the discipline that would have held activity in place. When most of the class did not arrive at a generalization for the area of the triangle, the teachers were quick to blame the students.

Like their students, the teachers were on their own to try an unfamiliar practice with unclear and poorly understood tools for guidance. In Alberta, teachers are used to both this type of professional learning and also its accompanying failure to provide real instructional improvement. Brought together to discuss and plan new practices, they are left to their own to figure out how to implement the new practices in their own classrooms. It is not yet common practice to provide teachers with professional learning opportunities within the context of their own classrooms. In our previous research we had documented teachers' learning gains when provided with a combination of offsite group learning and situated contextual professional learning. Stretched to volunteer our time for monthly group meetings and amateur video and editing, we have had no choice but to restrict our Lesson Study to providing an opportunity for teachers to learn mathematics and to design lessons for their respective classrooms. Our research has shown that while teachers still continue to learn mathematics and design lessons; without the added support within their classrooms most teachers are not able to transfer their learnings into the context of their own classrooms.

Does A Math Fair Help Teachers Transfer Learning: A Case Study With Fractions

We wanted to know whether a teacher who had hosted a Math Fair would be more successful in trying out new instructional mathematics practices.

When we walked into the classroom, the energy level in the classroom on that first day was electric. Sandy's room was overflowing with books, manipulatives, and students work. Students were grouped around hexagonal tables and their voices were buzzing. Some were seated; some were walking around talking to students at other tables; some were trying to get Sandy's attention. Sandy appeared completely at ease within this vibrant environment; the students appeared keen and excited as they tackled the problem Egyptian Fractions, which appeared on a SMART Board™[2] at the front of the classroom.

> **Egyptian Fractions**[3]
>
> The Egyptians only used fractions with a numerator of 1. Take the fraction 80/100 and keep subtracting the largest possible Egyptian fraction till you get to zero. Three Egyptian fractions are enough:
>
> 80/100 = 1/2 + 1/4 + 1/20
>
> Do the same for 85/100, 90/100, 95/100, and if you are particularly fond of Egyptians, 99/100

As the students started to work on this problem some misconceptions about fractions became increasingly apparent. It was clear that a number of students were trying to recall a procedure that Sandy had previously introduced to them using the first example of 80/100. Similar to Hiebert's (2005) observation of North American classrooms, Sandy had demonstrated a procedure for breaking the larger fraction into smaller fractions. Brian[4] worked through the problem as shown in Figure 1. He had accurately broken the fraction into two smaller fractions: 85/100 = 75/100 + 10/100. He worked procedurally to break the smaller fractions into smaller fractions; however, as shown in Figure 1, Brian's over dependency on procedural knowledge soon started to

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[2] An interactive whiteboard.
[3] Galileo Educational Network, http://www.galileo.org/math/puzzles/EgyptianFractions.html
[4] All students' names are pseudonyms

show some significant conceptual misunderstandings. Brian did not write the denominator in the next iteration of breaking the fraction into smaller fractions.

$\frac{75}{100}$	$\frac{10}{100}$
$25 + 50$	$5 + 5$
$\downarrow \quad \downarrow$	$\downarrow \quad \downarrow$
$\frac{1}{4} + \frac{1}{2}$	$\frac{1}{2} + \frac{1}{2}$

Figure 1: Brian's Solution

Krista: "How did you get the two 1/2 fractions?"

Brian: " I just divided the 5 by 10 to get 1/2."

Brian's error provided an excellent opportunity to confront him with what he could not see and did not understand. When Krista asked him if "1/2 + 1/2 equalled 10/100", he silently shook his head. "I must have made a mistake". He gazed back at his work. Knowing he was wrong, but not knowing what was wrong, left him unsure of what to do next. He had no further strategies to draw upon.

There are two ways that people attempt to solve problems: (1) *direct translation strategy* and (2) *problem model strategy*. The direct translation strategy for solving a mathematical problem uses a procedure of picking numbers from the problem and performing arithmetic operations on them. This 'short-cut' procedural approach emphasizes calculation. A problem model strategy emphasizes finding the relationships among the variables in the problem. This procedure begins with the person trying to understand the situation described and establishing a solution based on their representation of the situation (Mayer & Hegarty, 1996).

The *direct translation strategy* is a common method for less successful problem solvers. North American children are more likely to engage in short-cut procedural approaches to solving problems and instruction is more likely to emphasize computing correct numerical answers rather than understanding the problem (Friesen, 2005; Stigler & Hiebert, 1999). Procedural problem solving is the most common in North American classrooms (Hiebert, 2005).

While *direct translation strategy* makes minimal demands on memory and does not require extensive knowledge of problem types, it frequently leads to erroneous answers. Similarly, *direct translation strategy* is not productive for solving non-routine problems (Mayer & Hegarty, 1996). Routine problems are problems that learners know how to solve based on past experience. Non-routine problems are problems that the learner does not immediately know how to solve (Kilpatrick, Swafford, & Findell, 2001). Brian's error in the example above demonstrates his *direct translation strategy* for solving the problem. Brian was trying to follow the procedure demonstrated by his teacher. As we continued to move about the classroom, we found that most of the students tried to follow Sandy's procedure for solving the problem.

The solution to the Egyptian Fraction problem requires the subtraction of "the largest possible Egyptian fraction till you get to zero." (GENA, 2008b, ¶ Egyptian Fractions) For 85/100, the second largest fraction is not 1/4, but 1/3. None of the students in the class had come upon this realization. All were working with 1/4 as the second largest fraction. The students realized that 1/4 was not working but they were unsure what fraction they might try instead. Krista suggested that they try 1/3. As the students set about the problem again, many struggled with how to proceed. Sandy's problem solution procedure would not work as easily.

One group of four girls worked with coloured wooden blocks to solve their problem. They engaged in a heated discussion about how to divide the hundred's block into 1/3. After much consternation and debate, they finally agreed that the hundreds block could not be divided into thirds. Fully convinced they announced that the problem could not be solved. Krista rebutted their claim and assured them that indeed, the problem did have a solution. After all, the Egyptians had figured out how to solve it.

Knowing how to create a common denominator with fractions 85/100 and 1/3 eluded the students. It didn't take long before other misconceptions about fractions were illuminated. These students had memorized a set of procedures but had no conceptual understanding of the problem and limited procedural fluency with fractions.

Seeing that the children were struggling with the problem, Sandy would pull children aside to a table at the back of the classroom for assistance. By the end of the Egyptian Fraction class time, Sandy was surprised to see how many of her students were struggling with the concept of fractions. Many teachers would have been quite distraught with this finding, but not Sandy. She saw this problem as an opportunity to learn something about her students. In reflecting on the students' experience, Sandy said, "I've learned an tremendous amount about their understanding of fractions from this problem."

In this investigation, Sandy was working in what Donovan and Bransford (2005) term an effective learning environment. In the *learner-centered lens* students' misconceptions and misunderstandings about fractions became apparent. This enabled

Sandy to know where instruction was needed to move into the *knowledge-centered lens*. Within the *assessment-centered lens*, student thinking and learning became visible. This provided a guide for both Sandy and her students in learning and instruction. The questioning, the dialog, the respect and the risk taking were all indicative of the *community-centered lens.* An incredible space for exploration of fractions had been opened up. However, confronted with the realities of teaching a densely-packed curriculum in an examination year[5], Sandy faced a dilemma. Should she devote more time to this problem and fractions in general or should she carry on with other content that was also pressing at this time of the year. Sandy made the decision to move on.

> "Unfortunately, we don't have any more time than this class to devote to fractions. It is near the end of the year and we still have so much to cover."

Fractions and proportional thinking are foundational concepts in mathematics. The Egyptian Fractions Problem helped to expose these Grade 6 students' superficial understanding and misunderstanding of fractions. This is particularly worrisome as these students will carry their fragile knowledge of fractions into next year's study of proportions. But fostering deeper understandings takes time and effective instruction; time to play, to ponder, to think, to forward and justify solutions and instruction attuned to the students' emerging understanding and tethered strongly to the discipline of mathematics.

When Sandy demonstrated an algorithm for her students, typical of the North American teaching script she stripped fractions from their mathematical "community of relations" (S. Friesen et al., 2008, p. 118) into fragments and isolated rote facts and

[5] All Grade 6 students in Alberta write standardized provincial examinations in Mathematics, Science, Social Studies and Language Arts.

procedures. When the problem strayed from the algorithm, Sandy's students' fragile mathematical knowledge came forward. At the end of the year, Sandy's teaching focus was pressured and influenced by the high stakes provincial exam. She felt pressured to move on to 'cover' the curriculum.

While Sandy was unable to fully transfer her learning from Lesson Study into her practice, her experience with Math Fairs allowed her to make further progress in improving her instructional practices than a teacher who was involved in Lesson Study alone. We should also note, that Sandy was able to reflect on her practice in ways that the teachers involved in Lesson Study alone were not able to do. In time, with continued reflection, Sandy might be able to further improve her instructional practices, more attuned to her students' understanding and tethered more deeply to the discipline of mathematics.

Endbit

Changing and improving mathematics instruction is a multifaceted complex endeavour in North America. While significant money has been expended on teacher learning to improve teachers' understanding and practice of mathematics, in order to improve the quality of student learning, little progress has been made (Mizell, 2007; Sawchuk, 2008; Smith, Desimone, & Ueno, 2005).

Loss of funding has provided us with the opportunity to study the effectiveness of (i) Math Fairs when combined with monthly Lesson Study professional learning opportunities without classroom mentorship and (ii) monthly Lesson Study professional learning without Math Fairs or classroom mentorship. Our research has shown that, in

Alberta, our combination of Math Fairs, Lesson Study and classroom mentorship was very effective in bringing about the changes and improvement to teachers' understanding and practice of mathematics. Math Fair interrupts the everydayness of teaching mathematics and provides teachers with insight into how mathematics might be taught differently. Their students' excitement and intellectual engagement observed in Math Fair encourages teachers to explore a different practice at Lesson Study. After Math Fair at Lesson Study, teachers are willing to explore mathematics and develop lessons that lead to rich mathematical inquiries. Mentorship in classrooms with Galileo's mathematics educators helps teachers shape the lessons into effective changes in practice. We acknowledge that the changes to teaching practice are not instantaneous. However, we have seen how a combination of Math Fair, Lesson Study and classroom mentorship lead to a profound progression into teaching mathematics in connected relational nature.

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