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TEACHING AND LEARNING
RESEARCH EXCHANGE

Technology-Supported Inquiry-Based Learning: Enhancing Teaching and Learning in Secondary Mathematics

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In consultation with Michelle Morley
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Abstract

This research project is a qualitative approach into incorporating inquiry-based learning activities in mathematics instruction. There is evidence in the literature that hands-on, collaborative learning leads to greater success than traditional lecture, drill, and practice math instruction. Furthermore, the renewed Saskatchewan mathematics curricula endorse teaching math through an inquiry-based approach. Despite evidence of the benefits of experiential learning opportunities in math, developing an instructional repertoire of hands-on learning activities that support curriculum and adapting to teaching in such an environment is daunting. In this research, two teachers document their experiences as they change their practice from direct instruction to inquiry-based teaching. The research project is a self-reflection as the teachers explore their beliefs about teaching and learning mathematics, the challenges of changing practice, and the response of students to hands-on, problem-based learning opportunities. The authors record personal experiences along with student responses and outcomes, providing readers with a detailed, personal look at the process of changing classroom practice.

Acknowledgements

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Introduction

Saskatchewan's new math curriculum is intended to be delivered with emphasis on inquiry, collaboration, and problem-solving. The concept of learning through inquiry is not new. Students who discover a mathematical relationship on their own take ownership of the knowledge. Someone once said: If someone takes you for a walk down a path in the forest you may never find the path again, but if you find the path for yourself, you'll never forget it. However, according to several researchers (Jaworski & Gellert, 2003; Lerman, 2005), traditional textbook and teacher-directed approaches still dominate mathematics classroom practices because of a number of sociocultural issues relating to institutional structures, the perceived nature of mathematics, acceptable styles of interaction, and personal attitudes and beliefs. These issues are often neither trivial nor overt in the lives of students and teachers but, instead, embedded within personal and professional ideologies at work in the classroom.

The idea is that learning through discovery or through constructing meaning for oneself creates a deeper, more permanent understanding. It directs students to meaning-making, rather than fact collection and memorization. Learners establish a deeper understanding of concepts, as this type of learning draws on prior knowledge and leads to progression of learning that is more adaptable to new and different situations (Ronis, 2008, p. 2). The National Research Council (1995) reported:

> Math in the workplace is quite different from math in school. It is more concrete and more intuitive, yet at the same time more exciting and more unpredictable. It is rich in data and inextricably linked to technology. To become adults capable of thriving in the new workplace, students must be active learners and collaborative problem solvers. (p. 5)

The objective of the two teacher researchers was to create and to implement a technology-supported, inquiry-based learning environment in a secondary mathematics classroom. Through exploration, the study provided opportunities to understand more about the challenges, barriers, and successes. In addition, the research provided practical insight for other secondary mathematics teachers using a technology-supported, inquiry-based learning environment. Last, the findings provided a baseline for planning professional development opportunities for secondary mathematics teachers.

Literature Review

Broader Understanding of Mathematical Concepts

Ronis (2008) wrote that teaching math in the traditional way presents mathematical concepts as independent and isolated topics. If all we do is teach a skill and then assign practice, we ignore brain research that indicates students develop their understanding through active learning. Students learn extremely well through social interactions. By focusing on drill, practice, and memorization, we jeopardise students' broader understanding of math concepts. Students learn better when they are given opportunities to construct meaning for themselves (Luera, Killu, & O'Hagen, 2003).

Lifelong Learners

The inquiry-based philosophy suggests the learning itself is the goal. Students learn that a quest for knowledge and a struggle for solutions are what learning is about. This develops students into self-directed, lifelong learners, better prepared for life and work in the global environment (Ronis, 2008). Learning through inquiry allows students to develop intellectual autonomy. Teaching students in a traditional classroom setting, with desks in rows, teacher-centred, and using the teacher-controlled lecture method, creates the conception by students that the teacher is the expert and the teacher is responsible for students' learning and knowledge acquisition. Using an inquiry approach helps students learn to construct their own meaning and to take responsibility for building their knowledge base. The teacher is no longer an expert but a facilitator or catalyst of student learning (Damnjanovic, 1999). Our goal as teachers should be to cultivate a lifelong thirst for questioning and independence in learning. We must create thoughtful questions as a habit of thinking (Zion & Sadeh, 2007).

Engagement

Students are more motivated if they are allowed to be curious about open-ended situations (Zion & Sadeh, 2007).

Relevant Learning

We continually tell students that they need math in real life, and then teach them math in an artificial manner. We teach concepts in isolated units and, even though we stress the sequence and connectedness of concepts, students tend to focus on emulating the algorithm and mastering the skill. While developing skill and teaching processes are necessary (and we have to be reasonable when we shift to inquiry and not discard this important aspect of mathematics), the concern is that students develop a concept of mathematics that is artificial. Math in the real world is about making observations, applying a mathematical model (abstraction), and expressing the relationship in the language of mathematics (Jensen, Whitehouse, & Coulehan, 2000). Our math classrooms can certainly be artificial environments, when one considers that students spend years answering questions and solving problems to which everyone knows the answers since they are provided in the answer book. To make deep and meaningful learning, students need time to explore, to make observations, to test theories, to build and to construct, to ask questions, to wrestle with unfamiliar and counterintuitive thought, and to think critically. Math classrooms are an artificial environment where learners have all the information they need and are told there is one way to a correct solution. This does little to inspire curiosity or to prepare students for the complexity of real-life problems (Ronis, 2008).

Better Learning

Marzano, Pickering, and Pollock (2001) quantified several instructional methods in terms of effect size, rating practices that had an increased impact on student learning. In this ranking, inquiry and collaboration have a larger effect size than lecture, drill, and practice. Research shows that all students learn better when they are provided with opportunities to construct knowledge through inquiry (Luera et al., 2003).

Diverse Learners

Student populations are increasingly diverse and an inquiry approach to instruction may benefit students whose needs are not met by traditional instruction. Girls learn better in collaborative groups, for instance. A traditional, quiet classroom, as opposed to an environment of discovery, caters more to boys' ways of learning which are less social than girls' (Tindall & Hamil, 2004). Boys seem to favour logic, argumentation, and rigour, and are more comfortable with separate knowing, while girls are more likely to use conjecture and favour connected knowing, where they draw on their own and others' experiences to construct knowledge (Becker, 2003). For these reasons, the rigid, isolating environment of the traditional classroom lends itself more to boys' ways of learning. Science classrooms are often competitive and do not accommodate a variety of learning styles (Tindall & Hamil, 2004). This creates difficulties for girls, who tend to do better in non-competitive environments. They benefit from being able to explore and to make connections between concepts. Girls are often intimidated by whole-class discussions, but may communicate more freely in small groups (Guzzetti & Williams, 1996).

Due to increased population and efforts to engage and to retain Aboriginal students, there are a growing number of First Nations students whose learning needs must be considered and met. Mainstream curriculum fails to meet the needs of these learners (Saunders & Hill, 2007). First Nations students benefit from collaborative learning, as they are inclined to respond better to small group interactions where they can make connections to life experiences and explore relationships (Doige, 2003). Aboriginal learners benefit from being active, hands-on learners and true participants in curriculum. Curriculum should incorporate holistic learning, where all aspects of a topic, including connections, patterns, and processes, can be explored (Saunders & Hill, 2007).

Barriers to Changing Practice

Changing to an inquiry approach in the classroom can be worrisome to teachers because it requires them to relinquish control. The classroom becomes a noisier, more active environment, which some teachers find intimidating. The lesson material may not always lead students in the intended direction; as students explore uncertainties, there may be greater ambiguity in the attained understanding (Latta, Buck, Leslie-Pelecky, & Carpenter, 2007). Huber and Moore (2001) indicated that teachers often rely on textbook and worksheet activities as a survival strategy, and may confuse an orderly classroom with a positive learning environment.

Other teachers feel they don't have the time to use inquiry instruction as they feel pressured to cover content (Hammer, 1997), and that pressure too is exacerbated if the teacher is faced with high stakes testing (Tretter & Jones, 2003). Other possible barriers to inquiry instruction, suggested by Jackson and Boboc (2008), are lack of materials and facilities needed for inquiry activities, safety issues, inequitable division of work in group settings, difficulty getting and maintaining students' attention, and providing makeup work for students who missed an inquiry activity.

Dewey (1964) said that knowledge is not information, but a mode of intelligent practice, a habitual disposition of mind (as cited in Latta et al., 2007). We are trying, then, to change students' practice and habits of learning. This is a huge shift in understanding teaching and learning. The challenge to teachers is breaking with tradition and changing our approach to instruction.

Research Questions

Will the inquiry-based math classroom affect what students believe about teaching and learning math, and how will their responses to this method of learning ultimately affect our own beliefs about the same? How are prior deficiencies in math related to students' willingness to engage in inquiry-based learning? What are the greatest challenges of teaching math this way? How does a shift to inquiry-based math instruction affect our practice in terms of preparation, instruction, and assessment?

Rationale

Though we wanted to explore inquiry-based instruction, the short time frame of the project prohibited collection of any meaningful data on changes in student achievement. We therefore focused the study on self-reflection—seeking to understand how the teaching and learning process changes when we shift from a traditional, teacher-led classroom to an inquiry-based, collaborative learning environment.

Researchers

Arlene Prestie is a middle years teacher from Preeceville School. In addition to her role as teacher, she was asked to join a team that helped guide teachers in the Good Spirit School Division as they implemented the new math curricula which focuses on the constructivist approach to teaching mathematics. Arlene has helped facilitate many teacher workshops, including the division's Summer Math Institute.

Cindy Smith is a secondary math teacher at Yorkton Regional High School. She has been involved in math projects through the Good Spirit School Division's Leadership Academy, including incorporating technology into math instruction. She recently completed a Master's Degree in Administration and used research opportunities to explore educational theory regarding inquiry-based instruction.

Setting

Our study was conducted in one rural and one urban school in the Good Spirit School Division in Saskatchewan. Arlene teaches at Preeceville School, a K-12 school with an enrolment of just under 300 students. Her work in mathematics for this research focused on a class of 26 Grade 9 students, but included a class of Grade 7 and 8 students. Cindy teaches at Yorkton Regional High School, which has an enrolment of approximately 750 students. She focused her study on 55 Grade 10 students in two classes, but included a Math A30 class. The study was implemented over one course, which for Arlene was one school year, but for Cindy, one semester.

Methodology

Our research questions were addressed through a qualitative, self-reflective study for the course of one school year.

Data Collection

Data included journal entries kept on a blog site dedicated to the research project, anecdotal records kept on students' responses, student journals, observations, interviews, video recordings, and photographs. The quantitative data, which is not included in the study but did influence our reflections, included unit exams, Canadian Achievement Tests (CAT-4) results, and the performance of these students in their subsequent math class.

The Research Process

Role of the Teacher and the Student

Arlene:

I had strong traditional roots in how math should be taught; by the end of the research period, I hoped to have evidence to support the belief that the successes of teaching in a technology-enhanced, inquiry-based classroom outweighed the challenges of the same. In my mind, success would be measured by the students' improved understanding as well as their willingness or preference to learn this way over the traditional, more direct approach.

A teacher assumes an authoritative role as she begins her career. It is a situation of great responsibility and trust to deliver the provincial curricula, and a common view of mathematics teaching is teachers have the knowledge and need to pass it on to their students. Teachers are being challenged to question what they once thought was good instruction. I prided myself on my students' accomplishments for many years. However, after some time, I began to question my teaching practices. Any research I found reported on our own dismal results when compared to other countries in the world and other provinces, so I looked to professional research and literature for answers.

When I initially entertained the notion of teaching math through inquiry, it was very uncomfortable for me. I've always felt most comfortable when I've held the reins, with full control of my students' learning. Letting go of some of that control was the first major challenge, and will be for all teachers who were taught through traditional methods. I had to learn that teaching math isn't just telling students what I know and then expecting them to learn it.

The teacher-centred classroom is all that I have ever known, all that the parents have ever known, and quite possibly all that my students have ever known. Changing my teaching practice to that of inquiry would do one of two things: annoy and frustrate, or intrigue and challenge. I was not sure, but I knew that change was inevitable, given the implementation of the new curricula.

The resistance I felt in giving up my control was, and still is in part, due to the fact that I am the one who in the end must be accountable for my students' learning. After all, what if they didn't achieve the outcomes? What if they weren't cooperative? What if I wasn't doing the job of facilitator correctly? In the end, I wanted to know if the inquiry-based math classroom was the best learning environment for all of my students.

In order to understand my students' preconceptions about their learning environment, I posed these journal questions: What is a good math teacher? What does it mean to learn math? The majority of my students explained that in order to learn math, there must be a good teacher. A good teacher, in their opinion, was one who explained everything thoroughly and showed them how to do the procedures before expecting them to practice. The teacher, in their eyes, was solely responsible for their learning. If a student did not grasp the concepts the first time, the teacher would provide more direct instruction. I was surprised by their responses, given that I had started implementing the new Mathematics 8 curriculum the previous year, and had given them what I believed were many rich, inquiry-based experiences. I was certain they would have seen the value of learning through problem-solving, and having opportunities to construct their own understanding.

In my opinion, it is a matter of threatening their comfort. For many years previously, my students probably depended upon the fact that the teacher would show them exactly what to do, and if they didn't get it the first time, the teacher would show them again. In an inquiry-based math classroom, students are forced to venture into the unknown, trying to solve problems and to make sense of math concepts they haven't been taught. Teaching through problem-solving forces students to struggle and they find this uncomfortable. When substitute teachers are teaching in my absence, they usually deliver the lesson lecture-style because that is what they know how to do. Many students reported that they prefer this style of teaching. I wondered if this was just part of the transition, but it raises yet another question. As students move through the grades, learning through inquiry, will they eventually feel more comfortable with the process and view learning through inquiry as the norm?

The idea of teaching math through inquiry is certainly not a new concept. I have been told by a former curriculum writer with the Saskatchewan Ministry of Education that it is how our previous curricula were supposed to be taught, though teachers, including me, did not teach math as intended. Yet, I had to first clarify what teaching in an inquiry-based classroom actually meant. Initially, I believed that an inquiry lesson was having the students participate in hands-on activities. However, simply having students work in groups and use some manipulatives and technology does not mean they are engaged in inquiry. I believe that effective math teachers already inspire students to think and to question, so perhaps the switch to inquiry teaching wasn't the huge leap many perceived.

Journal Entry – October 2009:

> When I first experienced the new math curriculum and its *inquiry-based, constructivist* approach, I was a bit intimidated. No, I think I was actually alarmed because I believed that the new math demanded a totally different teacher and classroom, and I had been doing everything wrong as far as teaching math was concerned. I believe that many teachers in our division felt the same when introduced to the new curricula. However, though some things have changed, like the acceptable classroom environment, for example, good math teachers always used at least a partial inquiry-based approach.
>
> In my brief experience, I've found that there are two key parts to my lessons for which I did not allow time in the past: giving students an opportunity to explore and providing discussion time after the inquiry so they can share their conclusions and make connections. The exploration gives them the chance to make sense of the new ideas and to build on what they already know. Sharing strategies and thinking builds their confidence and helps eliminate the fear factor of mathematics. What hasn't changed? I am still the teacher. Sometimes direct instruction is necessary. I still need to help students make connections, especially the weaker students. Also, I strongly believe students still need to practice the new procedures and skills, but it must be meaningful practice. I'd been hearing conflicting opinions on homework and practice. I've found that when I do not give homework, students seem to lose focus; when I assign a problem or two for homework, students tend to take the class more seriously. In the end, they still need to be proficient at certain procedures (e.g., solving an equation) in order to progress as mathematicians.

Cindy:

With all the evidence of the benefits of learning through inquiry, it is still daunting to change practice. My perception of a skilled math teacher has always been someone who conducts a quiet and attentive classroom, explains clearly, and models the skills logically and clearly on the chalkboard. This describes my high school experience and like most math teachers, my love of math taught this way is likely what led me to become a math teacher. Appreciating this type of learning environment makes it even more difficult to make the leap to changing practice. What was wrong with the way I learned math? Ronis (2008) explained how we learn becomes the basis for how we teach. Undoubtedly, many teachers would have been educated in such an environment, and therefore assume that it is inherently right, which makes it difficult to see the need for change (Saunders & Hill, 2007). We need to be open to the idea that direct instruction is not the most powerful instructional method.

It is difficult to risk relinquishing control in the classroom. In the day-to-day life of a high school, it often becomes a matter of doing the best you can and surviving the hectic pace. We become secure in a quiet and orderly classroom. Wong (1998) cautioned that an overreliance on textbooks causes teachers to become complacent, and to confuse survival with teaching (as cited in Huber & Moore, 2001). A shift to mastery teaching demands that we don't mistake the establishment of a quiet, controlled classroom environment with effective teaching (Huber & Moore, 2001). To begin my research into inquiry-based instruction, I replaced the desks in my room with tables that seat four or five students. The initial reaction of the students was expected: first, wondering what happened in the classroom, then lots of visiting and socializing. I was very clear that talking needed to be on task, and that the idea was to create more powerful learning by discussing mathematical concepts collaboratively using appropriate language. I was very open with the students about what I was trying to do, and that it was based in research. As the semester went on, most students adapted to the new classroom environment. I was pleasantly surprised at how my classes developed a rhythm: I talk, now you talk with each other, now you choose a spokesperson and communicate your ideas and decisions to the class. I did have some groups and individuals who did not demonstrate the maturity needed to handle the learning environment. The question remains if these students would have picked up the concepts in a direct instruction environment.

Other teachers in my school were sceptical about the arrangement of my classroom and the approach to teaching. I was asked if these students would be prepared well enough for the next class, and I had substitute teachers who were not comfortable managing the students at tables and moved the classes to rooms with desks in rows.

The rearrangement of the room was the first step in changing the way I teach.

A Change in Practice

One of my teaching goals has been to be more present in the moment—to avoid other tasks in the classroom and to really be present for the whole hour with each class. Teaching through inquiry has really made me focus on my students. Gone are the class periods where kids worked quietly on text assignments and I got a bit of marking completed or entered some grades in the computer.

The tables in the room lend themselves well to differentiating instruction, as I can arrange a table of kids who need extra help or who need to be taught a concept they missed. I like the ability to sit in with kids, talk with them, and work beside them.

Observations

Student Engagement

Arlene:

When I first attempted an inquiry lesson, I remember all too well how I felt. Though my students were willing participants, they could not understand why I would expect them to try to solve a problem without first showing them how to do the math. Comments like "I don't know how to do it, please show me" or "I don't understand what to do" were all too common. I can't be sure, but I could only imagine that dinner time talk included the fact that Mrs. Prestie was a tough math teacher who didn't teach students how to do the work. I reflected on the transition of my new students in this journal entry:

Journal Entry – December 2009

> I am feeling frustrated by my Grade 7 class. After one month, it seems virtually impossible for this new crop of students to think on their own, to communicate, or to attempt to unravel any of the mysteries of mathematics. In short, they expect me to show them exactly what to do, and when I don't, they look at me, annoyed and blinking. It takes so long before we accomplish anything; I feel worn out from the constant frustration. If I was new to the inquiry-based method of teaching math, I'm sure that I would want to quit right now and revert back to the traditional ways. However, then I think about my current Grade 8 class. When they came to me in Grade 7, they were equally unwilling and I was just as frustrated for the better part of the first semester. It wasn't until near the end of October that I saw them begin to improve. This year, though not the best academic group I've taught, they are enjoyable. Today, we were exploring the theorem of Pythagoras by working through a problem that involved getting a piece of plywood through a door. Mathematically, they all understood. Some were creating a diagram involving ratio while others were using the theorem. The satisfying part was the variety of solutions they offered to the problem. We have many great discussions and I am always surprised by what they come up with. They are proud of their ideas and solutions. For any teacher who thinks that the inquiry-based approach isn't worth the time and effort, don't be hasty. Allow the students transition time. I will take my own advice knowing that my Grade 7s have great potential and only need time to adjust.

Decisions we make regarding instruction are affected by our students' responses to what we do, and that is why one of my key sub-questions reflected this fact. I asked my students if they preferred the traditional method of teaching math or what they liked to call the new way of teaching math. I had mixed responses. In a video interview with some of my students of differing abilities, this is what they said:

> **Student One:** I like working in groups better. I remember it better when I work in a group because sometimes they have a strategy that is easier for me.

> **Student Two:** It helps me remember with manipulatives and group work because other people help me learn instead of just one person telling me. It's easier when there are different methods and you can pick your favourite.
>
> **Student Three:** It's easier to learn the new way because it lets us try to figure it out before you help us or tell us. We get a chance to explore different ways to do it ourselves.
>
> **Student Four:** The new way lets you work with others and listen to other group members, and think of your own strategy that is easier. It doesn't need to be one strategy to go by.
>
> **Student Five:** Hearing a bunch of different methods confuses me a lot. I get lost when everyone is telling how to do it. I wish you would just show us one way to do it.

These student responses indicate that many students prefer learning through problem-solving, and having the opportunity to experiment and to generate their own ideas. However, not all students prefer to work collaboratively. In their journals, some students wrote that they preferred solving problems independently. In the following blog entry, I reflect on the student comments:

> I believe that an important part of the math classroom is collaboration. However, I am finding that some of my best math students do not appreciate working with and sharing with others. In their journals, these students commented that they felt their own learning was hindered by having to work with others, even if they were of a similar ability level. As a teacher, I must respect their needs and perhaps adjust the times I've allotted for collaboration and sharing.

At the Saskatchewan Mathematics Teachers' Society (SUM) conference in May, I had the privilege of attending a session led by Peter Ladner from Simon Fraser University. He has been field testing various inquiry problems that he has written for BC teachers to use. During the field test for these problems, he allows ample opportunity for students to discuss the problem and to formulate initial strategies, but after that the students go off on their own to generate solutions individually rather than collaboratively. After much thought, I concluded, at least for now, that I need to devote more time to collaboration and discussion. I need to allow students more time to solve problems independently before making final connections in small or large groups. That doesn't mean that I will stop allowing pairs or small groups to solve problems together, but I will plan for more independent time during lessons.

CINDY:

I have always felt that I taught math for understanding, by linking each concept to the next and by explaining the reasons behind relationships. I resented when proponents of problem-based learning or inquiry learning implied that our current math curriculum and rushed pace teaches students to memorize math concepts. I have always derived any formulas we use, have shown students how to construct the concept, and have discouraged memorization of anything. However, I had an epiphany when I was trying to help a struggling student catch up, and I took note of the language the student used when describing where he needed help and where he didn't. "Equations, I get that, but I don't get graphing." What did this student mean by "I get equations"? I think he meant that he remembered a procedure: a way of isolating a variable. He remembered what to do, or what the question was asking. But did he actually know what he was doing? What is a variable for? Did he know that an equal sign expresses an identical value or quantity? Is it what Gale Russel (personal communication, April 18, 2010) said once, "Students think an equal sign means do the question"?

We have learned to teach math by teaching skills. We explain what mathematical symbols mean but students have no language for them. Math becomes compartmentalized—separate bits of knowledge or individual procedures that students can learn so they get it. But we have never had time to truly communicate understanding. Our courses are lacking a fluency where students can start with an understanding of a concept and then stretch it to the next level and the next. Ideally, inquiry teaching would allow for this. Sadly, we are under time constraints and providing learning opportunities this way takes more time than we have. Teachers need time to search for and to develop good inquiry activities that address curriculum objectives or outcomes. Teachers also need teaching time for students to work their way through concepts and to establish meaning themselves. I was very far behind by the time I reached the geometry unit in Grade 10. This unit would have lent itself well to inquiry, but I had to teach it with direct instruction to save time.

One of the most encouraging observations I made in the classroom was the quality of student dialogue. I taught the introduction to graphing section using activities. First, students were each given a graph of a real-world relation and were asked to describe the graph to a partner, including what relationship was graphed on the x and y axes, and what trend the graph depicted. The next day we did an activity where students were given a scenario such as your height above the ground versus time while on a Ferris wheel, and they had to pick the correct graph from several graphs that depicted the relationship. I had the graphs on cards and students could lay them out, pass them around, and discuss them. This is always an interesting activity because students instinctively think that the graph is a picture of the path of an object. It was very interesting to hear the debate as students pointed out to one another the appropriate attributes of the graphs. In several cases, graphs would move forward and backward in time, and usually one or two astute students in each group would realize that, and give a good explanation of why those graphs were disallowed. Often students who weren't very confident in whole-class discussions were able to participate meaningfully in groups. Sometimes the organizer of a group was a person who was not the strongest math student of the group.

In these activities, I presented a careful warm-up of the goal of the activity, explained the reason we were completing it in groups, then gave a debriefing, asking students how the dialogue had gone and how the debates were handled. As groups were debating the graphs, I reminded them that I was listening for mathematically appropriate communication or the use of mathematical language. I was impressed with how well students included correct terminology. In one or two cases, a very vocal and dynamic student at a table was able to convince his group members of the wrong answer (these were somewhat open-ended situations, but there were clearly some graphs that would not apply). I say *his* because in each case it was a male who dominated discussion to that extent. This is consistent with literature that says boys will argue longer and more forcefully for their answer (Guzzetti & Williams, 1996).

I was also impressed with the strong collaboration that took place. Students had opportunities to explain concepts to each other and to use each other's collected work or data in group activities. When teaching slope-intercept form of a line, I used an inquiry activity with TI83 calculators. Often students helped each other with the technology, discussed the graphs or explained what they were seeing on the graphs, and helped each other draw conclusions based on observations. We also learned the relationships between slopes of parallel and perpendicular lines using an inquiry activity, and students looked at each other's work mats for data to help draw conclusions.

Part of my experiment this semester included student journals and adding more written explanations or justifications to exams.

CONCEPT ATTAINMENT

CINDY:

In some cases I was disappointed with how little students picked up concepts taught through inquiry. An example is the lesson on slopes of parallel and perpendicular lines. I found many students did not pick up the concept well from that activity. When I teach it directly, there are students who don't grasp the concept either; they memorize the relationship but don't understand why it is that way. I need to point out, for instance, why the reciprocals have opposite signs. In Math 20 and A30, I always have students who think the reciprocal of 5 is $^{-1}/_{5}$, which tells me they don't really know what they are doing or why.

Similarly, the graphing calculator activity worked very well for a few students, but to many the amount of learning involved with using the technology overshadowed the conceptualization of the relationship of the equation to the graph.

Some activities worked very well. I think our discussion of real-world graphs was very effective and these Grade 10s will likely have a better concept of what a graph is than any other group I've taught. Similarly, the small group debates were powerful, such as the exponent law example discussed earlier. These debates, I think, were more effective at solidifying understanding for students than any further explanation I could have given at the board because students were more engaged with the problem at hand than if I would have just explained it.

When I am discouraged about how effective an inquiry activity was, I need to remind myself that direct instruction does not reach every student either. This point was driven home to me when I tested the geometry unit, which, because of time constraints, I taught with direct lecture. The marks on that exam were low, so apparently students did not learn better with direct instruction.

Another strength of group learning is the ability of students to get feedback from each other. When we were establishing a procedure for presenting answers to word problems, I would have students do the work, then switch places around the table and critique each other's work. This seemed to be successful. In questions such as order of operation problems that require an understanding of sequencing of steps, I assigned one question per group where each group member did one step then passed the problem to the next student. A review activity I did was to have each group design a concept map of the unit, then present their concept map to a neighbouring group, explaining each topic relationship and why they placed it where they did. This went very well in one very large but motivated class. In another class that had several less mature students, it was not an effective activity at all.

Another activity I feel was successful was a concept-attainment activity at the beginning of Unit III, which introduces the Cartesian plane. I gave each group a package of cut-out and laminated material. There were graphs, ordered pairs, equations in both standard and slope-intercept form, and slopes. Without having studied any of these concepts, students had to sort the material and explain their sorting method to me. Most groups put the ordered pairs together, the equations together, the graphs together, and so on. At the end of Unit IV, I gave each group the package of material back, and they sorted it again. This time they were able to match each equation with its graph, match the ordered pair that belonged to each relation, and match the slope. I got the sense that students felt a sense of "Aha!" at the end of the activity.

Resources

Arlene:

I had to outline my job as a teacher of mathematical inquiry. I knew I had to begin my lessons with good problems. That is not as easy as one may think. The recommendation is that problems have multiple entry levels to allow for all levels of learners in the classroom, allow for a variety of strategies, and possibly many solutions. That is a tall order. Where do you find such problems? I didn't feel competent enough to generate all of my own problems, nor did I have the time to do so. I realized that because of time constraints, I had to make use of the problems provided in the text, at least in the initial phase of my transition to an inquiry-based classroom. I changed the wording of the problems to make them more open-ended.

When using the textbook as a guide to lessons, it is tempting to begin with the first problems in the chapter. I reflected on this practice after attending a session by Bruce Grip (2009) at the California State Math Conference, and in this part of my journal, I recall a significant point that he made:

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> The California Math Conference predominantly featured facilitators who promoted constructivism. In one session, Bruce Grip told us he writes his own real-world problems, but that it has taken him a very long time to generate good, worthwhile problems. Bruce suggested teachers should never begin with the first problems in the chapter; rather, begin with the problems at the end of the chapter and construct meaning through them. That made a lot of sense to me.

Why begin at the end? Check any text and you will find that the richest problems are always at the end of the chapter. These are the problems that allow students to demonstrate that they have achieved the outcome. As a beginner in the inquiry process, I often find it necessary to simply use the resources that I have around with which to build inquiry experiences for the students. Attempting to generate good problems is time-consuming and challenging; if you teach several different math classes, it is even more difficult.

Teaching through inquiry demands that teachers know the math content without any uncertainty, and they understand the content deeply themselves. Since I've been facilitating the inquiry approach, I've been forced to think about math in more complex ways which has deepened my own understanding. This is especially true when I have to generate those probing questions as students are problem-solving and discussing their strategies and solutions with peers. One of our most important roles as math teachers has become that of questioner. Through good questions, the teacher assesses student learning and makes decisions about what to do in the next lesson. Initially, it took me a great deal of prep time trying to anticipate student thinking in order to prepare questions. I often carried a clipboard with questions that I wrote ahead of time. What if questions, how do you know questions, and questions that demanded verification of solution were always on the list. After some time, I depended less on pregenerated questions; it seems more natural now to think of the questions to ask while I am in discussion with a student or group. The best discussions I have with students are the exchanges in the moment.

I found it difficult to plan sets for my lessons because it is a challenge to begin a lesson with a question instead of first telling the students how they are supposed to do the math. Seeing the value of the why questions in getting a student to look deeper into a math concept is imperative, but not automatic.

CINDY:

I began the semester using release days to search for lessons and resources that support the Grade 10 math curriculum. This was the most frustrating part of the project by far, because although there is copious research into the advantages of inquiry-based learning, actual lessons are very scarce. There are books that advocate a problem-solving approach that have interesting problems, but finding such problems that address curriculum objectives specifically was difficult. I thought at first that I could find larger projects or math labs that would cover several objectives and therefore be worth the time, but I found very little. Many projects would take two or three days to complete and would not target specific objectives significantly. I am teaching the last year of the old curriculum (we will implement the new curriculum next semester). It is always a struggle to finish this curriculum in the 85 teaching days we have, so I needed to be very conscious of wasting time.

The amount of time out of the classroom searching for resources and creating lessons became a concern for me. It is hard to establish classroom routines at the semester outset when I am removed from the classroom frequently. Furthermore, because the entire process was new to me, I didn't really know what I was looking for. Researchers have reported a lack of studies that portray what inquiry actually looks like within the concrete realities of learning situations (Latta et al., 2007). It was very difficult to start when I really didn't know how to start. I received valuable guidance from our superintendent, Susan Masarek, who advised me to try to use the lessons I already had, but change the approach. This proved to be a very good starting point for me.

Often text assignments begin with knowledge-based questions: identifying which graph is a function or identifying which shape is convex. I would assign these parts of assignments as group discussions, having the reader/moderator alternate, and asking groups to discuss and to come to a consensus. Some students resisted this, wanting to write answers in their book. I asked them, "How do you think you would understand it better, by writing a true/false or always/sometimes/never answer down or discussing with your group?" They all agreed that discussion would create better learning.

Use of Technology and Concrete Manipulatives

ARLENE:

I once believed that using concrete manipulatives was a waste of precious time that I could use to cover the curriculum. However, once I realized how and when to use manipulatives, how technology could enhance this process, and the usefulness of manipulatives in constructing student learning, I could not imagine teaching a math class without them.

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> Why use manipulatives or technology? It takes so long. When you see the Aha! moments, you realize that allowing students the opportunity to develop an outcome through different activities is one way to differentiate instruction. I have a new student who just didn't understand how to do basic operations with fractions, so imagine the difficulty in trying to do order of operations with rational numbers. She had learned operations on fractions through the abstract pencil and paper methods and, as a result, could neither remember nor understand procedures. I resisted directly teaching her how to do it on paper. I pulled out the fraction circles and started with exploring equivalent fractions and mixed numbers versus improper fractions. Then we moved on to adding and subtracting. "I get that now!" was her eventual response. With some students who are less academic and less willing, I am not sure that I have enough time to fill the holes. It is critical for most students to experience the concrete in the elementary and early middle years or they are sure to have difficulty in Grade 9 and above, as the math becomes more abstract.

At some point in the past, someone in my administration saw the potential value in using concrete manipulatives and found it reasonable to stock our school with them. I discovered tubs of dusty geoboards, base ten blocks, and fraction circles in most of our hidden storage cupboards. I swept the dust from these tools and set out to experiment with their use in my middle years classroom. Professional reading both sparked my interest and guided me in using them. It was quite easy to create lessons with concretes in my Grades 7 and 8 classes, but more of a challenge in Math 9. At the Grade 9 level, I found there is a move into the abstract which makes it more difficult to model procedures with the usual concrete manipulatives. However, for the first time, I allowed the students to use algebra tiles in order to construct meaning related to polynomials. I used to teach Math 10 and 20 and found that operations with polynomials and later, factoring polynomials, were very difficult for weak-to-average students. I experimented. I taught one group how to add polynomials through direct instruction—a how-to session. For a second group, I gave them the experience of using the alge-tiles. I used the document camera and my SMART Board to help model their use. Very quickly, this group recalled the concept of zero pairs and paralleled what we had done with integers to that of adding like terms. After the weekend, I gave the entire class an entrance slip that assessed their ability to add polynomials. Of the weak-to-average students, those who had learned with the algebra tiles scored significantly higher on average than the group that had learned the procedure directly without the use of manipulatives. There didn't seem to be any short-term difference between the scores of my best math students, regardless of their grouping. I realized that these results may be only short-term, and given the fact that all students used the algebra tiles for the remainder of the unit, I am not sure that the results would hold true long-term.

Allowing students to explore math with the wealth of online sites available does enhance the inquiry experience. A few years ago, I had one computer workstation in my classroom that I essentially used as a word processor. Now, I have many types of technology available to me. I have a SMART Board, document camera, webcam, smartpen, camera, flipvideo, multiple workstations, and more software for my students to use. Getting students to use technology was the least challenging part of the experience. Students naturally gravitate towards technology and have no fear when learning to use it; they will naturally experiment with it, uninhibited.

I often work in math pods—students developing the same outcome in different ways such as pencil and paper, individual computer workstations, or SMART Board. Small student groups rotate after about 20 minutes so that at the end of the lesson, they have experienced each learning station. On the individual workstations, they often work on Houghton Mifflin's Destination Math or another applet or game related to the outcome. When asked about using technology, one student remarked, "It makes learning math fun; when we use the computer it makes the stuff more interesting to think about. I remember it better."

The most challenging part of incorporating the use of technology is finding time to search for worthwhile sites and creating SMART Board lessons. Michelle Morley, our division's computer technology coordinator, has put countless hours into creating a website on which she has organized many sites according to grade level. In addition, she created a virtual manipulative wiki to which all teachers in our division can contribute. These sites have been very helpful. As part of our project, Cindy and I have committed to posting sites that we have found useful for Grades 9 and 10. This wiki eliminates the need for everyone to spend hours searching for useful sites.

At the beginning of the year, I started a classroom blog but found that the time I spent trying to maintain it was not worthwhile. We are a rural community with the majority of families still on dial-up internet service, so, as a result, they could not access the blog. However, many urban colleagues have been successful in developing their blogs as useful communication tools. As internet service improves, I hope to re-establish my blog.

Assessment

Cindy:

An unanswered question for me is how does my assessment change in this new learning environment? Students should be assessed consistently with how they are taught, so how do I assess in groups? I asked the students to fill in some self-evaluations about how well they felt they contributed to their groups and to the class. Those worked well and opened a door for a conversation with students about their learning and what they were getting out of the class; however, no marks were attached.

For the most part, these classes wrote paper-and-pencil, written exams. I did include more written explanation questions, which turned out to be a very good way to determine the depth of students' understanding of certain concepts. In the future, I would like to include more rubrics that incorporate grade weight on group contributions. I would like to grade some group projects and do some co-constructing of assessment.

Because this research ran over one-and-a-half semesters, it was too short a time span to determine through assessment if the students' learning was improved. I did ask them for feedback on the class in their journals, and most students expressed that they enjoyed the groups, valued the opportunity to learn from each other, and felt the class was going well. A few students expressed that they strongly disliked group work; interestingly, these were the students who had the most to benefit from some collaborative learning in terms of developing social skills. I rarely had a problem of students crutching on their group—in other words, coasting and letting their colleagues do all the work. This surprised me.

One debate I had with another math teacher was about how much to catch students with a safety net. At the end of an activity, should you draw out a conclusion for the students? Do you establish a summary of what they should have discovered? My colleague says yes, definitely, but I am not so sure. Many of my students would coast through the activity and wait for me to make sense of it for them, but I feel our goal is to help students become responsible for their own learning. I feel it's not beneficial to always explain what they should have discovered; otherwise, they can be off-task or disengaged. I had to feel my way around every topic to determine how much I had to or should re-explain concepts at the end of an activity. I tried to wean the students off this teacher summary so they knew they needed to find some relationship or rule in each discovery activity. It's a fine balance between holding students accountable and leaving them adrift, and the answer is not one-size-fits-all. Mathematics is already an insecure environment for many students. This dilemma warrants investigation.

I have unanswered questions around the role of journaling in the classroom. Our current time constraints make it nearly impossible, but there is much to be learned from reading students' journals. How do we clear up time in the semester for the meaningful use of journals? What types of information should be included in them and how should they be graded, or should they?

Grouping strategies seem debatable. When should you group students according to skill level and when should you stratify groups so there is a variety of skill levels in each group?

Challenges

CINDY:

I found that my experiences in shifting practice mirrored those reported by other teachers in research. As previously mentioned, time is an issue for teaching with activities. Everything takes longer. For instance, the activity I used to teach slopes of parallel and perpendicular lines took us a whole period and the text practice was assigned as homework. We didn't get to the higher level questions until the next day. In the past, that entire lesson has taken perhaps 15 or 20 minutes and students use class time to practice the concepts.

It was a challenge to convince learners, parents, and sometimes faculty of the purpose behind my change in practice. One semester following the project with the Grade 10s, their Math 20 teacher asked the students how they liked the learning environment in their Grade 10 inquiry classroom. There was a 50-50 split—about half the students said it was very good and half said they felt they learned better by direct instruction and individual practice, and that they did not learn well in the collaborative groups in Grade 10. Their teacher reported this to me and said what interested him was that there were no students who were indifferent. They either passionately endorsed the collaborative inquiry process or strongly disliked the process. Since I have changed my approach to instruction, I have had weaker students complain. Struggling students blame their poor grades on the teaching style or weak group members, and for the first time in my career I've had students challenge how I do things in the classroom. I find that in my weaker classes, I have reverted back to direct instruction for most of the course, since the classes are moving slowly and the amount of time I spend helping struggling students prohibits me from preparing inquiry lessons to a great degree. These students beg me to just show them how to do it. Their lack of skill may be a result of this direct delivery approach that allows them to remember and to regurgitate skills and procedures for exams, and advance through the grades with very little understanding. As I follow these students through subsequent grades, however, I have little evidence to support a difference in understanding or retention between students who studied in a traditional room and students who studied in the inquiry classroom.

Conclusion

Cindy:

I began this project as somewhat of a sceptic, believing that I was a good math teacher, possibly, like Wong and Wong (2001) said, confusing a well-ordered classroom with a learning classroom. I know not every day can be a smoke-and -lights show, but I am now among the converted. I realize the strength in releasing control and allowing students to construct their own meaning, to test their own logic, to argue and debate, and to sort things out for themselves. This first semester is only a beginning. As teachers, we must avoid the trap of becoming complacent, just surviving the pace of our teaching days. Good teaching involves continually strive to read, to research, and to understand what it means to be a master at our craft—and a craft it is. Learning doesn't happen by accident. It is a paradox that when you plan lessons that tell your students less, you need to understand your subject area and curriculum even more.

Joyce and Calhoun (2010) believed that quality professional development includes the opportunity to incorporate new knowledge into practice. Another important element in teacher learning is collaboration with peers—colleagues who are on the same professional development course together, who can reflect together, and who revisit ideas and compare experiences. This research project has, for the first time, provided me with both of these, and it certainly is professional development that will have a significant and lasting impact on my practice. The opportunity to share experiences with Arlene, to collaborate among the four of us, and to reflect upon experiences in the classroom has maintained the momentum of the research project. Hearing suggestions from colleagues stimulates new ideas or new ways of looking at learning. The next level for us would be peer coaching or a permanent math coach at the senior level in our division.

Arlene:

After having the opportunity to experiment with inquiry and to reflect upon its effectiveness, I realize there have been two notable changes. My classroom is no longer the quiet, teacher-driven place it used to be. It has a lively atmosphere and one which encourages students to think and to construct meaning for themselves.

Second, I believe that the inquiry experience has been especially beneficial for my average students. The average student often struggles to understand the complexities of the abstract mathematical concepts, but when given the opportunity to learn with manipulatives and technology and to be involved in investigations, retention is more long term. My keen math students respond well to the questions and problems which force them to think more deeply about the math, but often resist using concretes because they feel they get it without needing manipulatives. For my weaker students, I did not see strong evidence that the inquiry approach outweighed the more traditional approaches. Their deficits make it difficult to find an entry point into many problems. These students thrive on the concrete experiences but are not always able to succeed in the transition to paper-and-pencil procedures. However, they are equally willing to share their strategies and ideas, and feel less threatened in the collaborative environment.

Though teaching through inquiry demands more of the teacher, and the initial change was both uncomfortable and often frustrating for me, I cannot imagine teaching math any other way. I feel privileged to have been given this research opportunity by the Stirling McDowell Foundation. One of the most satisfying professional experiences is having the opportunity to collaborate with colleagues, like Cindy, who share my passion for teaching. I am also grateful to Michelle Morley for her guidance and to Dr. Kathy Nolan for her advice about the research process.

I have a great deal to learn, but I am fortunate to have a very supportive school division that has provided extensive professional development and resources to aid in the implementation of the new math curricula.

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