RE-AWAKENING WONDER:
CREATIVITY IN ELEMENTARY MATHEMATICS

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Dedication

To my students: past, present and future. It is because of you I have continued to ask questions, to seek answers, and strive to be a better teacher tomorrow than I am today. Thank you for challenging my current understanding of what works for you and insisting I be creative in my teaching.

To my parents, Doug and Jean Waite, whose love and support mean the world to me. Thank you for encouraging me to follow my dreams and for continually modeling the desire and passion to learn.

To my sister, Janice, whom I miss more every day. You made me promise to finish this, no matter what! I kept my promise.

Abstract

This thesis begins with the premise that in order to be mathematical students must first discover and develop their creativity. Within the context of classroom-based action research, the following questions are examined: What is mathematical creativity? Under what conditions does mathematical creativity flourish? And, how is creativity manifested in young children? To this end, the definition of creativity is expanded to include those daily moments of discovery, where clarity is reached and we say, "Oh! I get it!" It outlines how an inquiry methodology increases creativity and allows students to view mathematics from a place of wonder and excitement. In addition, different language-learning strategies are used to gain insight into how these strategies helped a group of grade three French Immersion students begin to define themselves as mathematically creative. Furthermore, the thesis explores the importance of relationship, relevance and rigour in planning for creativity in mathematics. It explains why a culture of not knowing is crucial to the development of mathematical understanding and confidence in young children and how ambiguity, frustration and perseverance are necessary elements in creative thinking. Also, it considers the importance of second language development and its implications for mathematics. Finally, it suggests creativity in mathematics is possible if students use dialogue and reflection to explain how their thinking is changing, or what new things they are discovering about mathematics.

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Chapter One: Why Wonder?

Math isn't a creative subject!

(A reaction to the topic of my thesis.)

The Magic of Wonder

> A child's world is fresh and new and beautiful, full of wonder and excitement. It is our misfortune that for most of us that clear-eyed vision, that true instinct for what is beautiful and awe-inspiring, is dimmed and even lost before we reach adulthood...If facts are the seeds that later produce knowledge and wisdom, then the emotions and the impressions of the senses are the fertile soil in which the seeds must grow...Once the emotions have been aroused--a sense of the beautiful, the excitement of the new and the unknown, a feeling of sympathy, pity, admiration or love--then we wish for knowledge about the object of our emotional response. Once found, it has lasting meaning. It is more important to pave the way for the child to want to know than to put him on a diet of facts he is not ready to assimilate. (Carson, 1956, in Carson, Kelsh, & Lear, 1998 p. 54-56)

Why is wonder so important to the study of mathematics? Is it a simple matter of evoking curiosity about the world in which we live, with the hope that mathematical concepts will emerge? Or, is it important to stimulate a feeling of awe or amazement about how the world works mathematically? Those who are not mathematicians do not often consider wonderment, creativity, and mathematics in the same context. I would suggest these similar, yet disparate, ideas must be considered with equal measure, especially within the context of mathematics.

Mathematics must cease to be regarded by students and teachers as a discipline for which all the answers have already been discovered. Rather, it needs to be viewed as a vast unknown from which endless discoveries have yet to be made. This will require a shift in thinking about what it means to be mathematical and in how students acquire the skill and knowledge of this discipline. It asks us to consider how we create knowledge from experience and how we explain to others in what ways we are creative. Wonder is at the heart of learning. It leads to puzzlement and curiosity, which in turn leads to the burning questions of our three year-old selves. Questions, which simply *must* be answered.

The Problem

I remember watching my three-year niece try to figure out how many rocks she could put into her dump truck before they all spilled out. I was struck with the fact that this invented game was also helping her learning about capacity, about more and less, and about mathematics. Her curiosity led her to ask, "What if...?" and the ever present "Why?". This wondering led her to create different arrangements of the rocks to see if she could fit in one more rock before the balance was tipped. She was discovering that if she placed the rocks carefully in the dump truck, it would hold more. She was also discovering that the size of the rocks in relation to the size of the truck was important. If we had followed up this playtime with a discussion about her discoveries, even in the simplest three year-old terms, I am sure some solid mathematical foundations would have been consolidated.

Her innocent curiosity and play was in fact a complex process of creation. She was creating a pathway of experience to more mathematical discoveries, or her logico-mathematical knowledge (Kamii, 1996). She was testing hypotheses and making judgments about what information to keep and what to reject. She was creating her knowledge of how the world around her works. She was experiencing many ah-ha moments as she put her knowledge together in novel ways. In short, she was engaged in creativity.

When my niece entered school and began to engage with mathematics as formal subject, she slowly stopped asking the inquisitive questions and playing with mathematical ideas. Mathematics became about the *facts and formulae*, things to be memorized and regurgitated. It was no longer the mystical, magical world of discovery, rather a subject she has learned to dislike and fear. Students do not understand how they construct and create knowledge or why it is important to do so.

Mathematics is a rich, dynamic, fun, wonderful way in which to discover and understand the world around us, but students do not always view it this way. By the time many school-aged children reach grade two or three, much of this curiosity and creativity with mathematical concepts has been lost (Fisher, 2005; Fosnot & Dolk, 2001a). Mathematics appears to have been reduced to a series of algorithms to memorize, where much work is done with little thought (Burns, 2007; Fosnot & Dolk, 2001a; Seely, 2009). Somewhere children lose the sense of wonder. Their sense of wonder and creative solution finding has become a ghost of their babyhood, not valued or deemed necessary to succeed in the world of school. How can we re-awaken this sense of wonder and ability to create in mathematics? Better yet, how do we ensure it is never lost in the first place?

The Research Questions and Goals

The Questions

My curiosity about mathematics and creativity led me to many questions. Firstly, what does mathematical creativity look like in a grade three French Immersion (FI) classroom? Will I recognize it in my students? What structures and strategies will promote the growth of mathematical creativity? Can mathematical creativity be captured and discussed by 8-year olds?

The Goals

Creativity appears once again to be in the spotlight in education, thanks in part to the work of Mihaly Csikszentmihalyi (1996) and Sir Ken Robinson (2001). However, the theory for its application in mathematics is limited, especially at the elementary level. I believe strongly that we construct our own knowledge and understanding through our experiences with a given topic. My experiences as an adult learner in mathematics have led me to question how I was taught and to acknowledge that my ideas about the teaching of mathematics needed an overhaul. What I *knew* about learning mathematics no longer matched what I was *learning to know*. There was some serious dissonance, which needed to be unpacked, examined, spun in different ways, and repackaged. In short, I needed to re-create my understanding of the *what*, *why* and *how* of mathematics.

This epiphany about my own experience as a learner of mathematics led me to wonder about how young students construct their understanding of mathematics. I wanted to discover how targeted learning strategies might help them make sense of mathematics so their knowledge had deep, meaningful roots. I also sought to deepen my understanding of *little c* creativity, both in my own learning and in that of my students. Most importantly, I wanted to re-awaken a sense of wonder in my students, as it had been awakened in me, instilling in them the knowledge that they are all mathematicians and that making sense of the world mathematically is a natural part of being human.

Beliefs and Background

I approached this work from the assumption that children possess innate abilities in mathematics and that somewhere in their early years their experience with mathematics skews their perceptions of this subject, making them either enjoy it or fear it. These assumptions stem from my personal journey with mathematics and my observations while working with teacher colleagues as a consultant.

My Beliefs About Learning and Mathematics

One of the first steps in any inquiry is to outline the purpose for the inquiry. Appendix A represents the mind-map of this research, as the ideas unfolded during the writing of the proposal for this thesis. I believe children create their knowledge and skill in any concept by experiencing the ideas first-hand, discussing what they notice, and reflecting upon how their current understanding meshes with these new experiences. Also, I believe educators need to begin to examine the role of *'little c creativity'* (Sawyer, 2006) as children construct understanding and skills in mathematics. The ability to identify these *'oh, I get it'* moments, which indicate a connection has been made between what is known and what is being learned, is important if we want children to see themselves as mathematically competent, or indeed competent in any discipline.

Mathematics is not a dead subject but there remains the misconception that it is a subject to be memorized and regurgitated (Mighton, 2007). When students become more aware of how their thinking is changing, they are better able to articulate things that might be causing them to get stuck with an idea. When they can identify the problem, they are better able to think of ways to get unstuck.

I believe second language learners (SLLs), especially those in immersive settings, can and should engage in inquiry. Language is acquired through meaningful experiences and the target language *sticks* more readily when new ideas and vocabulary are investigated in concert, not as separate entities. It is through an inquiry approach immersion students are best able to develop understanding of concepts and acquire the language with which to communicate learning.

My passion for reading and writing with young learners led me to wonder how effective language arts strategies might transfer to the construction of knowledge and skill in mathematics. In my past experience as a grade one teacher, *Quick Writes* and *Double Entry journals* (See Appendix B) have proved efficient tools for SLLs to develop risk-taking in writing. Why then, would the same not be true in mathematics?

My Personal Journey of Discovery

Six years ago I would have never dreamed the topic of my thesis work would have anything to do with mathematics. I very clearly defined myself as a 'language arts' person, whose passion lay in helping young children discover the wonders of reading and writing. Mathematics had been a struggle for me throughout my early schooling career and, while I did the best I could as a teacher of elementary mathematics, I admit I was not very committed to or passionate about the subject. Early experience had taught me that there were right answers and wrong answers, and that only the truly smart people did well in mathematics. I clearly remember being told by my Math 10 teacher, "Just do it this way. You don't need to understand why." In his defense, he was undoubtedly frustrated with my inability to grasp what he was trying to teach me, and with my incessant need to know why things worked the way they did. My math-brain was definitely coated with layers of Teflon--nothing stuck. It did not stick because I was not the one constructing the knowledge and understanding, I was simply trying to follow someone else's ideas about mathematics; ideas that made absolutely no sense to me.

In the spring of 2006, I was informed that part of my assignment as a learning specialist would include working with the middle school French Immersion teachers in the area of mathematics. It is an understatement to say I felt woefully unprepared and extremely intimidated. How was I going to facilitate discussion and discovery about a significant shift in practice and philosophy required by the new Program of Studies (PoS) for Mathematics (Ministry of Education, Alberta, 2007) when I did not see myself as mathematically inclined? I knew, from conversations with my colleagues spear-heading the professional learning in mathematics, this new PoS required many teachers to examine, re-evaluate, and ask questions about their teaching practices and how children learn mathematics.

In an attempt to appear somewhat competent, I sought out any and all professional learning opportunities I felt might help me fulfill this part of my assigned workload. In so doing, I made a pivotal discovery: If given the right conditions (processing time, manipulatives, discussion, and reflection) in which to made sense of the concepts, I was a mathematician! The methods used in teaching me mathematics did not connect with the manner in which I needed to learn mathematics. Again, I lay no blame for my failure to thrive in mathematics at the feet of my teachers. They were undoubtedly using the most effective practices of the day, and understanding of how children learn mathematics has grown tremendously in recent years. However, unless our beliefs are challenged, we tend to teach as we were taught. Thus, creating a vicious circle of perpetuating less effective practices.

As I began to work with my teacher colleagues, I realized many of them held the same misconceptions about ability in mathematics: Mathematics is the providence of the few. I also realized many had similar experiences as learners of mathematics and were trying, to the best of their abilities, to teach a subject they did not truly understand at a deep level. As we sat together and struggled to make sense of a new way of teaching mathematics we each had our own ah-ha moments about the mathematical concepts. We were creating new connections between what we thought we knew and what we were coming to understand. We were engaged in *little c creativity* (Sawyer, 2006). What made these creative moments significant was our ability to discuss the process of discovery that was occurring in our brains, our ability to be metacognitive.

In the fall of 2011, I was re-assigned to a classroom: grade three French Immersion. The school was beginning its journey toward accreditation with the International Baccalaureate Organization by offering the Primary Years Programme (PYP). I was new to both the grade three curricula and the framework of the PYP. My *creativity* would be challenged in many ways!

Despite the newness of my situation, my curiosity about mathematics remained. Many of my ideas and beliefs about mathematics had changed. However, I had only witnessed the power of these new ideas from the periphery, as an observer and collaborator in the planning for instruction. I was eager to play a more intimate role with the process.

Significance

The literature and research pertaining to creativity in mathematics is limited. Many elementary school teachers express inadequate understanding about how to effectively engage students in the construction of mathematical concepts. Another gap in professional literature lies with French Immersion (FI) and elementary mathematics. I was able to find some research pertaining to FI and middle school or secondary mathematics, but was only able to uncover references to literacy skill development in reading and writing for elementary immersion. While the literature and research pertaining to English Language Learners (ELLs) is more and more abundant, much of which can be applied to an FI classroom, there are subtle differences between learning the language of the culture, as is the case with most ELLs, and learning a language that differs from the one heard on television, in stores, on the playground, or even within the school, as is the case in many FI programs. This is a distinction that is not often addressed, but is significant.

In suggesting mathematics is a creative endeavor, many of my colleagues regard me as if I have lost my mind. However, upon further discussion of the ideas I am exploring, most expressed they had never thought of mathematics in terms of creativity and wonder, and that the ideas had merit. This work asks its readers to consider the study of mathematics from a different viewpoint. As Proust suggests, "The real voyage of discovery consists not in seeking new landscapes but in having new eyes" (www.thinkexist.com). Adding to the professional literature with *new eyes* may help improve mathematics instruction and understanding for elementary teachers, which may in turn improve retention and understanding of mathematics for students. This work may also help shed light upon the significance of language development in mathematics, especially for second language learners.

On a smaller scale, as a classroom-based researcher I embarked upon this work with the sincere wish to become a better educator. I need to understand how my students might regain their sense of wonder about the mathematical world, as I had done, and to gain insight into how students construct and communicate their growing understanding of mathematical concepts.

Chapter Two: Literature Review

Overview

Creativity is an attribute that many people would say they understand, but do not necessarily possess. Since its inclusion into the English language in the 1870s, the word *creativity* has caused angst for those who attempt to define it or study its existence. There are many misconceptions as to its concept and conditions (Csikszentmihalyi, 1996; Robinson, 2001; Sawyer, 2006; Singer, 2011). Csikszentmihalyi (1996) suggests, "The problem is that the term "creativity" as commonly used covers too much ground. It refers to very different entities, thus causing a great deal of confusion" (p. 25). The process of creation implies the coming together of two or more ideas, which are then mixed and remixed into something new.

For young mathematicians, creativity resides in their ability to make sense of mathematical ideas by *creating* links between what they currently know and what they are discovering (Burns, 2000; Chapin, O'Connor & Cavanan-Anderson, 2009; Fosnot & Dolk, 2001a). They engage in the process of remixing information to create new, refined knowledge. Creativity in mathematics allows students to continually deepen and improve their understanding and to grow lasting connections to the complex ideas of mathematics.

This chapter presents some of the literature related to creativity and its place in education, specifically mathematics. First, I plan to dispel some of the misconceptions surrounding the current ideas about what constitutes a creative mind, who is or is not creative, and under what conditions creativity might be unleashed. Next, I consider what beliefs and actions are necessary in schools in order to foster creativity in all students. In examining creativity through the lenses of inquiry and thinking, I hope to expand the ideas commonly associated with the concept of creativity. Finally, I examine the specific contexts of creativity in mathematics and briefly introduce ideas about its place in immersive settings, such as French Immersion.

Defining Creativity

Curiosity about life in all of its aspects,
I think, is still the secret of great creative people.
(Leo Burnett)

Creativity is just connecting things. When you ask creative people how they did
something; they feel a little guilty because they didn't really do it;
they just saw something. It seemed obvious to them after a while.
(Steve Jobs (a))

What Is It?

It is perhaps germane to begin with a dictionary definition of creativity. Dictionary.com (2011) defines it as "the ability to transcend traditional ideas, rules, patterns, relationships, or the like, and to create meaningful new ideas, forms, methods, interpretations, etc.; originality, progressiveness, or imagination" (http://dictionary.reference.com). Weston and Stoyles (2010) view it as "the ability that allows us to expand possibility—to find unexpected movement in problems that have us stumped" (preface, p. v). Sternberg, Jarvin, and Grigorenko (2009) agree that "creativity is not only what enables us to come up with new ideas (whatever the field); it is also the skill that enables us to deal with new situations that we have never confronted before" (p. 35). Csikszentmihalyi (1996) suggests creativity is "a process by which a symbolic domain in the culture is changed" (p. 8). He elaborates this definition by adding, "creativity does not happen inside people's heads, but in the interaction between a person's thoughts and a socio-cultural context. It is a systematic rather than an individual phenomenon" (ibid, p.23). Lehrer (2012) suggests it is "about our most important mental talent: the ability to imagine what has never existed before" (p. xv).

Creativity is an action, a thing, and an attribute. The lines between verb, noun and adjective are sometimes blurry, which adds to the difficulties in finding an agreed-upon definition. Creativity is a collective endeavor, but is an individual attribute. Are there definite characteristics of creativity? Which is more valuable: the process or the product? How does social interaction influence individual creativity? Creativity, by any definition, is a complex construct.

Where Do We Find It?

Creativity has been a part of the human condition since the beginning of time. Human history is punctuated by periods of significant innovation and creativity: the Greeks, the Romans, 15th century Florence, 19th century Paris, and the late 20th century stand as shining examples of a convergence of creative thought, which changed the world (Csikszentmihalyi, 1996; Sawyer, 2006). Csikszentmihalyi (1996) suggests these creative civilizations and centers provide "an intersection of different cultures, where beliefs, lifestyles, and knowledge mingle and allow individuals to see new combinations of ideas with greater ease" (p. 9).

The study of creativity is also a study of culture and the desire to improve the human condition. It is the "cultural equivalent of the process of genetic changes that result in biological evolution" (ibid, p. 7). Creativity exists in almost every thing humans do. The human brain continually makes new connections between events and information and, in so doing, *creates* new knowledge. Singer (2011) suggests, "nothing can be creative without having emanated from a store of knowledge and imagination" (p. 59). It would seem, then, that human beings are wired for creativity. If this is true, why do so few people describe themselves as creative?

It is perhaps the view of creativity as a 'big bang' event in which the world is set on its head that has contributed most to the misunderstandings about the nature of the creative process and its importance in every day life. Whether it changes all of society or simply sharpens one person's focus on a problem, creativity alters our perception and understanding of the world. Creativity is everywhere, but it is not always recognized or acknowledged.

Who Has It?

While creativity is recognized as an essential part of survival on earth, deciding who has it remains a bit of a conundrum. It is difficult to pin down a definition upon which all can agree. Some see creativity as the domain of a few exceptional individuals, who, in a flash of brilliance, develop new, unheard of technologies, art, and ideas (Csikszentmihalyi, 1996; Feldman, Csikszentmihalyi, & Gardner, 1994; Robinson, 2001; Sawyer, 2006, Singer, 2011). Others believe creativity resides in every person, requiring the right conditions and diligence to bring it to the fore of consciousness (Dweck, 2006; Liu & Noppe-Brandon, 2009; Robinson, 2001).

"Creativity" versus "creativity". Sawyer (2006) differentiates between two types of creativity: "Big C" creativity and "little c" creativity. *Big C* creativity implies something is new to the world. In contrast, *little c* creativity refers to that which is new to the learner.

Big C creativity involves innovations and originality that significantly change what is valued in society (Csikszentmihalyi, 1996; Sawyer, 2006). People associated with this type of creativity are often viewed as geniuses: Galileo, Guttenberg, Edison, Ford, and Zuckerburg are a few of the creative geniuses linked to *Big C* creativity. Their contributions to the world are well known and their work exercised tremendous influence upon the views and values of modern society. It is society that decides the appropriateness of a new creation, which in turn leads to the adoption or rejection of the innovation. These *Big C* creators change the world.

Little c creativity refers to "activities that people engage in every day: modifying a recipe...avoiding a traffic jam...figuring out how to apologize to a friend for an unintended insult" (Sawyer, 2006, p. 27). In this sense, every human being has the potential to be immensely creative. *Little c* creativity involves action and reflection. As people are learning, they are constantly evaluating how new information fits with their existing understanding (Fisher, 2005). Either this conscious reflection will confirm what is known or it will cause dissonance. The dissonance may lead to further conjecture and experimentation until connections are made between the known and the new. It is the creation of these connections-this new knowledge-that lives at the heart of *little c* creativity (Sawyer, 2006). The knowledge created need not be lasting, for it may be overwritten as new discoveries and connections are made.

The important feature of this creativity is that the learner must judge the appropriateness of the new understanding. Therefore, "even those [works] of a beginning student" (ibid, p. 27) can be considered creative. These *little c* creators change their individual understanding of how the world works. One could argue that no *Big C* creativity can be achieved without first engaging in *little c* creativity.

Little c creativity in mathematics. Young mathematicians develop their skills and understanding when they are asked to make connections between what they knew yesterday and what they have discovered today (Burns, 2000; Chapin, O'Connor & Cavanan-Anderson, 2009; Fosnot & Dolk, 2001a). They must encounter situations where they are asked to "develop mathematizing--to promote steps and shifts in thinking, to help [them] develop mental maps" (Fosnot & Dolk, 2001a, p. 28). Singer (2011) contends, "effective learning is basically creative; and the creativity we revere may itself be thought of as an extension and application of the learning process" (p. 61). These creative baby steps are important pieces to capture in order to understand how young students construct their ever-expanding knowledge of mathematics.

When viewed through the lens of *little c* creativity, it can be argued that every human being possesses the ability to be wildly creative. In this sense, young mathematicians need to become aware of how their thinking is changing over time. They need to examine what has helped or hindered their thinking. They need to be encouraged to question and experiment with their ideas. This metacognition will enable them to recognize and define for themselves in what ways they are mathematically creative.

Why Is It Important?

In the first decade of the 21st century as the pace of change seemed to spin out of control, many businesses and governments began to recognize the need for creative solutions to existing issues. As Einstein said, "We can't solve today's problems by using the same kind of thinking we used when creating them" (www.brainyquotes.com). Some educators have taken up a cry for developing and enhancing creativity in *all* students across *all* disciplines. The International Society for Technology in Education (ISTE) contends that creativity is "critical for students to learn effectively for a lifetime and live productively in our emerging global society" (www.iste.org). The Partnership for 21st Century Skills (P21) counts creativity as one of its four core learning and innovation skills (www.p21.org). Most Alberta School Divisions list creativity as an essential skill for students and staff to be successful in the 21st century (http://education.alberta.ca). ISTE, P21 and Alberta Education all contend creativity is an extremely important part of the learning process, but these organizations do not outline what this creativity looks likes or sounds like in a classroom. If we cannot agree what it is, who has it, or why it matters, how will we recognize and nurture this important life skill in our students?

Conditions for Creativity

When Archimedes ran through the streets shouting "Eureka," a bolt of intellectual enlightenment had not hit him out of the blue. The new connections he made were the result of much wondering and reflection. He had engaged in the recursive process of creation (Singer, 2011). Despite the difficulties in defining creativity, there does appear to be some consensus as to the conditions necessary to be creative (Csiksentzmihalyi, 1996; Sawyer, 2009; Singer 2011; Robinson, 2001). The process of creating new knowledge may involve the following:

a. a problem or idea which causes intellectual dissonance and that leads to conjecture or arouses curiosity,
b. incubation time during which the idea simmers and bubbles in both the conscious and unconscious mind,
c. experimentation or playing with the idea from various perspectives,

d. making connections, or the ah-ha moment, where the known and new merge to become fresh knowledge or understanding,

e. evaluation or judgment as to whether the new idea is of sufficient value (Csiksentzmihalyi, 1996; Fisher, 2005; Sawyer, 2006; Robinson, 2001).

Imagine the world today without the PostIt Note©. This essential piece of equipment in many classrooms and offices might never have been discovered had Arthur Fry not found an innovative use for Spencer Silvers' perceived failure to develop a sufficiently strong adhesive (www.ideafinder.com). This social interaction appears to be an additional condition for creativity. Individual creativity is unlikely without exposure to the ideas of others. Those who are associated with creative genius, such as Galileo or Edison, do not work in an isolated vacuum. They are connected through their questions, ideas, and passions. They attend the same conferences or subscribe to the same magazines. They seek out others who share their questions and passions (Fisher, 2005; Sawyer, 2006; Robinson, 2001). Fisher (2005) contends the "paradox of creativity is that in order to think creatively we need to be stimulated by the thinking of others...It (creativity) derives from the disposition to be curious, to wonder and to question" (p. 31). Sawyer (2006) suggests, "everyday creativity is collaborative...It is about social encounters" (p. 296). This social interaction is imperative. Learners, at any age, must be given the opportunity to work together, to discuss their emerging ideas, and to reflect upon the ideas of their peers.

It is not enough to ask students to be creative. They must also continue to hone their skills and increase their knowledge in the area of interest. Creativity will not emerge from a 'blank slate'. In order to make connections in new or novel ways, there must be a foundation of understanding about which questions can be raised and from which novel ideas can be evaluated (Csikszentmihalyi, 1996). Csikszentmihalyi (1996) believes "a good creative person is well trained. So he has first of all an enormous amount of knowledge in the field" (p. 50). Creative people *want* to know more about the subject of interest. They are motivated to learn as much as possible and enjoy discovering many different ways of doing a particular aspect of the discipline (Sawyer, 2006). Their motivation leads them to deeper understanding, which, in turn, allows them to be more creative.

Creativity in Education

> Young children of today have to cope in adulthood with uncertainties, complexities and choices in a fast-changing world. It is impossible to predict the types of knowledge, skills and attitudes that children will require in order to lead creative, fulfilled lives. It is essential therefore that we help children to learn how to learn. (Ministry of Education, Northern Ireland, 2000, pp. 13)

Fisher (2005) speculates that in education, creativity "has been regarded as a special and rather mysterious attribute" (p. 24). Due to its mystic aura many teachers avoid dealing with it altogether, preferring to view it as "a nice and fun add-on to the regular curriculum" (Sternberg, Jarvin, & Grigorenko, 2009, p. 5). No two humans are creative in exactly the same way, which creates issues when it is time to acknowledge its existence. It is not a simple case of sitting a standardized exam. Teachers may fear passing judgment on such a subjective enterprise, seeing it as a personal task upon which they could never assign a mark (Sawyer, 2006). Singer (2011) argues for the importance of creativity in education, saying,

> Education that is not creative is static and generic, a form of indoctrination that descends mechanically upon everyone subjected to it, initially by the teacher but finally by the pupils whose differences of mentality and potential growth are systematically thwarted or neglected. In contrast, effective learning is basically creative; and the creativity we revere may itself be thought of as an extension and application of the learning process. (p. 61)

Creativity has also been regarded as the domain of only certain disciplines. Most people, when asked about creativity, default to the arts: artists, poets, dancers, actors, novelists, and sculptors top the lists of creative people. Fine arts, music, and creative writing have come to define and represent creativity in schools. Some suggest creativity is squashed by 'traditional' learning activities, such as *skill and drill, rote memorization,* and *fill-in-the blanks worksheets,* and the pressure from government to raise academic standards (Costa, 2008; Fisher, 2005; Robinson, 2001). These 'traditional' activities typically ask students to regurgitate facts, not create their own understanding of these facts. While knowledge of these ideas is an important part of the creative process, if students are not involved in remixing new ideas with what they currently know, deep learning does not occur (Fisher, 2005; Robinson, 2001).

Sternberg, Jarvin and Grigorenko (2009) suggest misconceptions exist about the nature of creativity in other disciplines, specifically mathematics, stating, "When we ask mathematics teachers to think of creative learning experiences, we are often told that they cannot imagine how mathematical thinking, at the K-12 level, can be creative in nature" (p. 39). Do teachers understand what it means to be creative in the every day, *little c* concept? Is the classroom culture conducive to deepening conceptual understanding through experimentation, dialogue, and reflection?

On the educational landscape there is a profound fear of failure; a fear that not knowing something as soon as it is asked will reflect poorly on our academic selves. Children are given the impression that they cannot be wrong, that mistakes are to be seen as a negative space to be avoided at all costs. Fisher (2005) suggests, "A damaging change happens around the age of three or four, which can last a lifetime. The child learns to stop guessing and inventing answers when his efforts are rejected...He learns that answers lie not in what the child thinks but what the parent/teacher thinks" (p. 23). Robinson (2006) suggests, "We do not grow into creativity, we grow out of it. Or, rather we are educated out of it" (TED video clip). Meier (1995) believes, "children [are] being driven into dumbness by a failure to challenge their curiosity, to build on their natural drive toward competence and...to evoke a sense of wonder" (p. 21). Creativity, by its definition, implies that the answers are not yet known or discovered. In order to be creative one must take risks, fail, reflect, adapt, and persevere in a multi-looped cycle (Costa, 2008; Fisher, 2005; Robinson, 2001). "If you're not prepared to be wrong, you will never come up with anything original. By the time they (students) get to be adults, most kids have lost that capacity. They have become frightened of being wrong" (Robinson, 2006, TED video clip). Learners need to embrace ambiguity, failure, and struggle as a crucial part of the learning process.

Creativity is a critical element in learning. That we fail to recognize it or value its existence is not due to its absence in our experience, rather that we have reduced learning to the memorization of facts and figures. Costa (2008) suggests, "Meaning making is not a spectator sport. Knowledge is a constructive process rather than a finding. It is not content stored in memory but the activity of constructing it that gets stored in memory. Humans don't *get* ideas, they *make* them" (p. 95, italics in original). Robinson (2006) concludes,

> We must reconstitute our conception of the richness of human capacity. Our education system has mined our minds in the way we have strip-mined the Earth, for a particular commodity and for the future it won't service. We have to rethink the fundamental principles on which we are educating our children. (video clip www.ted.com)

Educators must begin to see their students not as empty vessels to be filled with knowledge. Rather, they must view learning as a canvas upon which the artist, a.k.a. the student, will paint an original piece of art, where each brush stroke represents the knowledge and understanding constructed through interaction with and reflection upon the ideas of the discipline.

In education, there is increasing dissonance between the current state and the desired state. As has been suggested by proponents for reform in education, the only thing a time traveler arriving from the year 1850 would recognize is a classroom, where children are to learn quietly as the teacher imparts his or her knowledge. Educators are becoming more cognizant of the fact that the 19th century factory model of school can no longer fulfill its promises and are beginning to ask, "What if...?" and "Why not...?". Educators are questioning the "tried and true" methods of the past and are looking for new ways in which students become active participants in the construction of knowledge. There is recognition that the problems students face today, and in the future, are more complex and varied, and cannot be solved with "old" thoughts. Educators are acknowledging the need for thinking that goes beyond what is currently known. The path to these solutions cannot be taught, it must be discovered. In other words, educators are engaging in the work of creativity as they "make connections between ideas or experiences that were previously unconnected" (Robinson, 2001, p. 11).

Creativity and Inquiry

Inquiry is another term in education with many diverse interpretations and for which there are differing opinions of effectiveness (Barell, 2008; Knodt, 2008; Short, 2009). Inquiry is interpreted by some as project-based learning, by others as activity-based learning, and by yet others as research-based learning. It is linked to the constructivist theories of Piaget, Dewey, and Vygotsky (Egan, 2002; Short 2009) and is rooted in the ideas of Plato that, "knowledge is formed within the learner and is brought to the surface by a skilled teacher though the process of inquiry" (Walker & Lambert, 1995, p. 16). For some, it is a methodology, for others, a philosophy of education.

Inquiry as philosophy. In 1928, Herbert Spencer espoused, "Children should be led to make their own investigations, and to draw their own inferences. They should be *told* as little as possible, and induced to *discover* as much as possible" (as cited in Egan, 2002, p. 19. Italics in original). Spencer was puzzled by the disconnect between what he saw as a child's ability to learn a myriad of things outside the classroom with enthusiasm, pleasure, and sustained effort and this same child's inability to learn within the formal school setting (Egan, 2002). Spencer believed children should learn in their natural environment where their innate curiosity, creativity and ability to solve problems would be nurtured and enhanced (Egan, 2002; Gutex, 2009). Dewey, during the same historical timeframe, was reflecting similar ideas in his desire to develop an education system "based on a continuum of ongoing experiences that unites the past and the present and leads to the shaping of the future" (Gutex, 2009, p. 346). Both Dewey and Spencer wanted learning to be joyful, meaningful and wonderful (as in full of wonder) for children as they engaged in 'formal' learning. They believed the natural inquisitiveness of children was the most effective way in which to educate them about the world.

The word *inquiry* means to question, to investigate, to seek answers, or to explore. Short (2009) contends, "inquiry is not a particular teaching method but a stance that underlies our approach to living as learners" (p. 1). Educators, for whom inquiry is a way of being, believe human beings must be active participants in the construction of their knowledge as they engage in a cyclical process of wondering, experimentation, analysis, reflection, and judgment; a process very similar to what Csiksentzmihalyi (1996), Sawyer (2006), and Robinson (2001) believe is necessary to be creative. Freire (2005) believed "learning is before anything else a critical, creative, re-creating activity" (p. 33). Wilhelm (2007) defines inquiry as "the process of accessing, building, extending, and using knowledge consistent with what is thought and known in a discipline" (p. 11). Students are seen as apprentices of a discipline of study, where "they engage in the same kind of processes and dialogues that practitioners do, and make use of the same tools as well" (Ibid, p. 10). Inquiry as philosophy is deemed to be the natural course for growth of understanding and skill development every time human beings seek to improve and understand something on a deeper level.

The lived experiences of the learner are of utmost importance in this philosophy. Learners are viewed as masters of their own learning because, even when participating in the same learning episode, each learner brings a unique set of experiences to the situation. As a result each will take away different ideas and emphasis from the new experience (Walker & Lambert, 1995). No two learners can know something in exactly the same way. For those who espouse inquiry as a philosophy, the *how* of inquiry seems straightforward and intuitive; they cannot imagine teaching in any other way. For others, a more synoptic approach is necessary in order to embrace this approach to teaching and learning.

Inquiry as methodology. When educators begin to embrace the *why* of inquiry, they must begin to make sense of the *how* of inquiry. This is especially true if an inquiry approach to learning is not part of a teacher's lived experience. Short (2009) argues,

> Inquiry makes us nervous as teachers because we may feel as though we are turning over control to our students. By retaining our role as problem-posers, we keep control, while at the same time seeming to actively engage students as inquirers. The problem is that they are asking questions about the problems we have posed, not the issues significant in their lives. They never fully experience inquiry. (p. 16)

Engaging in inquiry when it does not fully jive with philosophy requires a great deal of faith. Teachers and students must be open to ambiguity, be willing to take risks, be able to reflect upon failure and success, and be able to persevere. They must also be willing to give up control and the fear of failing.

An inquiry approach requires careful planning and large blocks of time in which learners may hypothesize, experiment, reflect, and make conclusions. The purpose of the learning must be clear to all involved (Barell, 2008; Short, 2009). This time commitment is often what pushes educators away from an inquiry methodology because they feel there is not enough time to "cover" everything in the curriculum. This is especially true when a disconnect exists between philosophy and methodology.

The process of learning through inquiry in education is the subject of much literature (Alberta Education, 2004; Barell, 2008; Knodt, 2008; Meier, 1995; Wiggins & McTighe, 2005; & Wilhelm, 2007). While the terminology might vary slightly, the ideas surrounding the process of inquiry are similar. Table 1 outlines four variations on the inquiry process theme: Alberta Learning's (2004) *Focus on Inquiry* jigsaw, W.H.E.R.E.T.O. from Wiggins and McTighe (2005), Barell' (2008) K.W.H.L.A.Q. long-range strategy, and Wilhelm and Friedemann (1998, as found in Wilhelm, 2007) framework of critical inquiry as a means to "*knowledge production*" (Wilhelm, 2007, p. 13).

Table 1

Variations of the Inquiry Process

Focus on Inquiry *(Adapted from Alberta Learning (2004))*	**Understanding by Design** *(Adapted from Wiggins & McTighe (2005))*
INQUIRY MODEL	**W. H. E. R. E. T. O.**
Planning: What do we want to learn? Where might we find resources? Who is the audience? How will the learning be evaluated?	***Where* are we going? *Why* do we need to go there?** What will students know and be able to do, as a result of this inquiry?
Retrieving: How will information be retrieved? How do we determine if information is appropriate? Which pieces of information are most relevant?	**What will *Hook* the learners?** What essential question might we ask? How will students connect to the inquiry? **What *Experiences* will *Equip* students with the knowledge and skills required to address the essential questions?**
Processing: What is the focus of the inquiry? How will new information be recorded? What connections are being made? What is most important to know or understand about the topic?	What needs to be directly taught and what is left to discovery? **What opportunities will allow students to *Reflect* upon and *Revise* their work?** How will students give and receive
Creating: What product will present the information most effectively? Who is the audience?	feedback? What will they do with it? **What role will *Evaluation* play?** How will students use self-assessment?
Sharing: How will the product be shared with the audience? How will the audience interact with the information?	How will the final product(s) be evaluated? **How will the work be *Tailored* to individual students?**
Evaluating: What have we learned? How can this information be used in other contexts?	How will learning be differentiated to reflect the individual needs and style of learners?
	How will the learning be *Organized* for *Optimal* success? How will the learning be sequenced?

Inquiry and Design *(Adapted from Wilhelm & Friedemann (1998, as found in Wilhelm, 2007))*	K.W. H. L. A. Q. *(Adapted from Barell (2008))*
Frame the inquiry. What is the purpose of this inquiry? Why is it important? How will students show what they know?	**K.** What **knowledge** do we currently hold about this idea?
Frontload a connection to the concepts. How will prior knowledge be activated? What questions might stimulate interest?	**W.** **What** do we want to discover about this idea? What do we need to find out in order to answer our questions?
Uncover the curriculum. How will students uncover new understanding and skill? What sequences of learning is required?	**H.** **How** will we go about find the answers?
Create *knowledge artifacts*. What product might be most effective in presenting what has been learned? How will peers assess the learning for the purpose of rethinking and revising?	**L.** What are we **learning**? What have we **learned** as a result of our inquiry?
	A. What **action** will result from our inquiry? How can our learning be **applied** in other contexts?
Publish learning. How can the learning be represented for real purposes? How might the learning promote new applications or social action?	**Q.** What new **questions** do we have?

The process of inquiry has distinct touchstones: There are questions to be asked and answered; learners need to be able to access what they already know about the topic or concept; they need to have a plan of action; they need to reflect and revise as they uncover new and interesting information. In some models, such as *Focus on Inquiry* and *Inquiry and Design,* it is recommended that the learning should be shared publicly in a manner that best communicates what is most important to the learner. In others, while engaging in inquiry with a specific audience or purpose in mind is important, the learning need not be shared publicly.

Creativity and Thinking

That's been one of my mantras —focus and simplicity. Simple can be harder than complex: You have to work hard to get your thinking clean to make it simple. But it's worth it in the end because once you get there, you can move mountains.
(Steve Jobs (b))

Thinking is an important part of the learning process. Students are often instructed to put on their *thinking caps* when completing their assignments. In some classrooms they might even be told *what* to think. However, they are rarely helped to understand *how* they think or how to access the thinking process for clues to understanding a new concept or fine-tuning something they think they already know (Costa, 2008; de Bono, 1985).

Visualize this picture of the brain. In the left hemisphere there are dozens of cubicles, where little thinkers sit, heads down in heavy concentration. Everything is grey and uniform. In the right hemisphere the thinkers are engaged with one another. They are running, playing and laughing. Everything is brightly coloured and seemingly random [This picture can be found via a Google image search for right brain-left brain]. In the past thinking and, therefore learning, was believed to be the providence of the left hemisphere: the logical, solemn side of the brain. Thinking was a very serious subject, not to be taken lightly. The right hemisphere, on the other hand, was the fun centre, where wild and unruly thoughts occurred. It was thought that too much time spent in the right brain, the creative, frivolous side, would lead to chaos and illogical decisions (Pink, 2006).

The image described here appears to encourage this construct of the left brain-right brain dichotomy, but the picture is not yet complete. Add several bridges between the two halves. Imagine the little logical left-brain thinkers interacting with the little random right-brain thinkers as they travel between the hemispheres. It is this image of a whole-brain working in harmony that is needed to be creative (Pink, 2006; Weston & Stoyles, 2010). Table 2, adapted from Pink (2006), outlines how both hemispheres work together to promote a creative, thinking mind.

Table 2

How the Hemispheres Work Together

The Left Brain	**The Right Brain**
✓ controls the right side of the body.	✓ controls the left side of the body.
✓ is sequential and processes sounds and symbols.	✓ is simultaneous and can interpret many things at once.
✓ likes text (written or spoken) and will understand what was said.	✓ likes context and will understand how the words should be interpreted.
✓ analyzes the details.	✓ synthesizes the big picture.
✓ focuses on categories.	✓ focuses on relationships.
✓ is logical	✓ is emotional

Costa (2008) contends, "we should focus on teaching students how to *produce* knowledge rather than merely how to *reproduce* knowledge" (p. 29, italics in original). This knowledge production requires the use of both hemispheres. For example, when a student reads (left-brain) an open-ended mathematical problem, he or she must first understand the words (left-brain). Then the words must be interpreted or put into a context (right-brain). The student considers what is needed to solve the problem by dissecting the problem (left-brain, details). He or she then thinks of the different ways in which the problem might be solved (right-brain, big picture). Next, the solutions are synthesized (right-brain); decisions are made about what works and what does not (left-brain). Pictures, numbers or words are used to describe what was done (left-brain). Next, a justification for the choice of solution methods is made (right-brain, relationships) and the student describes how he or she solved the problem (left-brain). Finally, the student reflects upon (right-brain), whether consciously or not, what has been learned during the process and overwrites (right-brain) what he or she knows about the concept. It is a very complicated process.

Creativity also requires a flexible mind (Costa, 2008). De Bono (1985) believes this *lateral thinking* may hold the most important role in our ability to create new knowledge and understanding. He contends, "Creativity involves provocation, exploration and risk taking. Creativity involves "thought experiments." You cannot tell in advance how the experiment is going to turn out" (p. 137). This provocation and experimentation allows the thinker to "cut *across* patterns instead of just following along them. The thinker cuts across a new pattern, and when this is seen to make sense, we have the eureka effect" (Ibid., p. 141, italics in original). Flexible thinkers can consider various perspectives and are "open to change based on additional information and data or reasoning that contradicts their beliefs" (Costa, 2008, p. 34). This flexibility is important for students when they face ambiguity and the perception of failure.

Creativity is "an evolutional process, where current reality becomes rapidly obsolete, and one must be on the alert for the shape of things to come. At the same time, the emerging reality is not fanciful conceit but something inherent in the here and now" (Csikszentmihayli, 1996, p. 65). When new connections are made in learning, we overwite the changes made in our understanding. Much like when we hit the save button after editing ideas in a document, what was previously in existence has been altered. This process of overwriting is often not a conscious one. Our ability to express how thinking is changing is dependent, to a large degree, upon our perceptions about what we are doing.

This metacognitive skill, or ability to discuss how we think, is another important aspect of creativity. According to Costa (2008),

> Metacognition means becoming increasingly aware of one's actions and the effect of those actions on others and on the environment, forming internal questions as one searches for information and meaning, developing mental maps or plans of action, mentally rehearsing prior to performances, monitoring those plans as they are employed--being conscious of the need for midcourse correction if the plan is not meeting expectations, reflection to the plan upon completion of the implementation for the purpose of self-evaluation, and editing mental pictures for improved performance. (p. 35)

The ability to think metacognitively is important if students hope to recognize how their knowledge and skills are changing and how aspects of their environment help or hinder their ability to learn.

Creativity and Mathematics

> Every child who is well cared for naturally develops a sense of the mysterious. The feeling that behind every door another world is waiting can make a child's world a paradise. But, once at school, children often begin to lose their sense of the hidden beauty of the world. By having to compete and be compared to their peers, many lose faith in their intelligence and their imagination; by having to struggle so hard to keep up, many come to believe that the world is beyond their understanding. (Mighton, 2007, p. 4)

Is mathematical knowledge learned or created? This question is at the heart of reform movements across North America. How teachers answer this question is greatly influenced by their own experiences as students of mathematics. Many elementary teachers are of the opinion that mathematics is to be learned through rote memorization and application of algorithms (Burns, 2000; Haylock & McDougall, 1999; Fosnot & Dolk, 2001a, 2001b; Small, 2010). Haylock and McDougall (1999) suggest this attitude is cultivated by feelings of anxiety, inadequacy and guilt and that "there are proper ways of doing mathematics and that the subject is characterized by questions to which answers are either right or wrong" (p. 2). These feelings are not only for teachers. Fosnot and Dolk (2001a) contend "most students...[do] not see mathematics as creative, but instead as something to be explained by their teacher, then practiced and applied. One might call this traditional view *school mathematics*" (p. 4, Italics in original).

There is a sense that mathematics is a dead subject with no new discoveries left to be made. Csikszentimihalyi (1996) suggests, "Students generally find the basic academic subjects threatening or dull" (p. 12). The study of mathematics has been reduced to a linear progression of isolated facts and algorithms to be memorized rather than an interconnected, mysterious, magical world to be discovered (Mighton, 2007). Seeley (2009) contends "traditional" teaching of mathematics is crippling our students' potential to make significant contributions to the global world in which we live. Csikszentmihalyi (1996) also believes "traditional" methods will have far-reaching implications for the future as they do not "[encourage] originality and creative thinking...So, if the next generation is to face the future with zest and self-confidence, we must educate them to be original as well as competent" (p. 12). There appears to be a tendency to 'spoon-feed' students or to give them too much assistance in mathematics rather than allowing them to hypothesize, experiment, re-evaluate, re-think, and redo. Fosnot and Dolk (2001a) ask, "Have we traditionally been teaching mathematics in our classrooms or only the "history" of mathematics--some past mathematicians' constructions and their applications?" (p. 4). The reduction of mathematics to a "plug and play" mentality is a disservice to students, as it perpetuates the belief that mathematics is for the select few.

This more traditional approach effectively eliminates the appropriate challenge and struggle needed to learn (Fisher, 2005; Fosnot & Dolk, 2001a; Mighton, 2007). There is little dissonance created in the minds of students when they are simply asked to 'plug in the correct formula or rule'. Fisher (2005) suggests, "The trouble with rules is that they are easily forgotten" (p. 171). There is no motivation to discover a different way, or to persevere when faced with a problem for which there is not an immediate answer. Without disconnection between what students know and what they are discovering, there is no creativity and, therefore, no long-term learning.

In reality, mathematics is the study of relationships, patterns, and transformations, words used to define creativity (www.dictionary.com). Mathematicians engage in "setting up relationships and trying to prove these relationships, mathematically, in order to communicate them to others. Creativity is at the core of what mathematicians do" (Fosnot & Dolk, 2001a, p. 4). The philosophy of the Alberta Program of Studies for Mathematics (2007) indicates the need for a shift in focus from *what* is to be taught to *how* it should be learned. In order to make this shift, educators need to understand mathematics "as mathematizing one's world--interpreting, organizing, inquiring about, and constructing meaning with a mathematical lens, [so that] it becomes creative and alive" (Fosnot & Dolk, 2001a, p. 13). Deep understanding in mathematics comes from understanding the relationships and reasons behind the rules and algorithms. Students need to take apart and reconstruct the rules, which allows them to gain an understanding of mathematics that is "deeper, more lasting and more easily recalled to memory" (Fisher, 2005, p. 171).

Students are curious, active learners, who require diverse pedagogical approaches that allow them to construct concept knowledge and to make sense of mathematics through the use of personal strategies. By focusing on the big ideas of mathematics, students develop their ability to think mathematically. The emphasis shifts from the quest for a correct answer to the ability to explain how one has arrived at an answer and whether or not the solution is a viable one (Seeley, 2009; Alberta Education, 2007; Burns, 2007; Western and Northern Canadian Protocol, 2006). When mathematics is viewed as a living discipline students "will rise to the challenge. They will grapple with mathematical ideas...they will create mathematical models as they attempt to understand and represent their world" (Fosnot & Dolk, 2001b, p. 12). It requires a shift in the mind-set of teachers and students from the fixed, content driven curriculum to a more flexible, process driven one.

Knowledge construction in mathematics demands an inquiry approach (Burns, 2007, Fosnot & Dolk, 2001b). Students must interact with mathematical concepts in meaningful and purposeful ways. This approach to mathematics allows students to "mathematize one's *living* world" (Fosnot & Dolk, 2001b, p. 12, Italics in original). Students must be able to identify the ways in which mathematics crosses their path in their day-to-day life.

Creativity and French Immersion

Learning *in* a language must not be confused with learning *a* language. According to Alberta Education (2011), the goal of a French Immersion (FI) programme, is to become functionally fluent in French. Functional fluency is a goal after six to thirteen years of exposure to the target language in an academic setting. A functionally fluent speaker should be able to discuss and dialogue with others, communicate both personal and professional needs, pursue post-secondary endeavors in French, and work in a French milieu. In an FI approach, students learn to understand, speak, read, and write in French at the same time as they are discovering the concepts of the Programs of Study. They "learn a language and about the language as [they] use it in meaningful contexts" (Alberta Education, 2010, para. 2)

Students in FI construct their language competency together with their academic skills and knowledge as they experience a variety of learning tasks and school settings. An immersive setting necessitates particular attention to the development of target language vocabulary and structures in concert with the construction of knowledge in the mathematical concepts, or those of any other discipline. Therefore, it is important to structure the learning episodes much as we would for native speakers of the target language. However, a greater emphasis is placed on the language of the discipline than might be in a classroom full of native speakers. So, what does this have to do with creativity?

In any language, the ability to communicate with words travels the same path. A child is exposed to the language while interacting with others; he or she begins to experiment with the sounds; these sounds are honed into meaningful bits through a process of trial and error; the bits become fully comprehensible words, which in turn, are strung together into sentences; and the child has achieved mastery of the basics in his or her native tongue. This process of first exposure to mastery takes place over a period of five to six years (Fillmore & Snow, 2000). During these experiments with language the child is engaged in *little c* creativity. He or she is creating an understanding of how language works to communicate needs, wants and ideas. With every experiment, the child is unconsciously reflecting upon whether prior knowledge is making useful connections or if it needs to be adjusted in some way (Fisher, 2005). As pointed out earlier, this new knowledge may be fleeting as new experiences overwrite what is previously thought (Fisher, 2005; Sawyer, 2006).

In an FI approach, students engage with language and concepts at the same time, but not necessarily at the same rate of competency. Their concept knowledge may very well exceed their ability to communicate in French (Alford & Niña, 2011; & Bresser, Malenese, & Sphar, 2009). This discrepancy between understanding and communication must be considered when students are asked to reflect upon their learning in mathematics.

Bresser, Malenese and Sphar (2009) contend, "Many educators share the misconception that because it uses symbols, mathematics is not associated with any language or culture" (p. 4). Mathematics is its own language, but it is also taught with language. The target language is used to explain, to pose problems, to discuss reasoning, and to assess competence. It is important to scaffold the building of vocabulary, the same way we scaffold the building of content.

Summary

Creativity is a complex idea with many interpretations and implications for society. For some, it resides in a select few who have the talents and abilities necessary to change the world through innovation or artistic endeavors. For others, creativity is the domain of every human being, regardless of age or experience. This creativity manifests itself in the day-to-day events, which are tweaked by individuals in order to simplify their worlds. From an educational perspective, creativity is characterized by the construction of knowledge and skill through inquiry, in which learners interact with the discipline in authentic ways by posing questions, trial and error, and reflecting upon what is being discovered.

Creativity is an action and an attribute. Both manifestations need to be considered when discussing how learners are mathematically creative. In order to be seen as a creative individual, one must engage in creative endeavors. Creativity in mathematics occurs when learners figure things out for themselves. This does not mean the teacher no longer has a role to play in the process. If anything, the teacher's role becomes more critical as he or she shifts from the traditional "sage on the stage" to the inquiring "guide on the side". Teachers must be aware of the types of questions learners are asking and to the misconceptions that may occur in early constructs of ideas. They must be able to structure learning to enhance the creative process in their students. In addition, they must allow the time and space necessary for individual creativity to flourish.

The study of mathematics needs to evoke in learners an insatiable desire to know why and how ideas connect. Creativity thrives when it is acknowledged and monitored by the learner. Students need to become aware of what helps or hinders the development of understanding. The learning episodes in which they engage must result in intellectual dissonance, thus creating the necessary conditions that drive learners to engage deeply with a concept, and from which they recognize an ah-ha, or creative moment. These creative moments result in meaning making, which is the goal of any educational endeavor.

Chapter Three: Methodology

Introduction

Through this study, I sought to understand and highlight an elemental essence of being human: creativity and its application in mathematics. I did not attempt to engender *big C creativity* (Sawyer, 2006) in students. I looked to discover if their ability to recognize and discuss how they know they understand mathematics differently changes as a result of targeted strategies. I believe a classroom climate of tolerance for mistakes, the teaching of specific metacognitive strategies or protocols (See Appendix B), and fostering of positive attitudes will contribute to the creation of mathematical skills and knowledge, or *small c creativity* (Sawyer, 2006).

Small c creativity manifests itself physically and intellectually. The physical is more readily recognized as an "ah-ha" moment where we notice we understand something in a different manner (Csikszentmihalyi, 1996; Costa, 2008; Fisher, 2005; & Sawyer, 2006). It is usually preceded by a swift intake of air, followed by an exclamation of "Oh! I get it!” or "Now I see it!" The intellectual manifestation of creativity requires that the learner articulate what is happening deep within his or her brain. It requires the ability to reflect upon what is known and how this knowledge changes, or does not change, as the learner engages in the various tasks designed to promote learning.

As I returned to the classroom, my burning questions remained: Will the mathematical ideas and strategies, which as a consultant, I have espoused with my peers for the past five years translate into my practice? Will the ideas I have gathered about creativity and mathematics translate into observable action? It was important to choose a research methodology flexible enough to allow for a *creative* approach. One that would help me understand why I teach the way I do and allow me to improve as a teacher of mathematics based upon my experience and the research I was reading. This careful dance between theory and practice is a hallmark of action research (Knoerr, 2001; Newman, 2000).

Rationale for Research Approach

The study of creativity is a study of human action and thought. As such it lends itself to a qualitative approach, where people interact and are observed in their environment (Punch, 2009). Action research situates the teacher-researcher in the research. Reason and Bradbury (as cited in Punch, 2009) suggest, "action research seeks to bring together action and reflection; theory and practice...in the pursuit of practical solutions to issues of pressing concern" (p. 136). The Action Research Network (n. d.) defines it as "a systematic look at some educational practice and recording what was done, why it was done, collecting data, analyzing the data and reflecting on how the results might influence future teaching endeavors". Martin-Kniep (2000) defines action research as "a process of asking important questions and looking for answers in a methodical way. The questions are meaningful...and the questions are closely connected to the teacher's work" (p. 89). Adams (2011) concludes, "the process [action research] may not often achieve the levels of critical analysis that some promote, it frequently succeeds in providing participants with intellectual experiences that are illuminative rather than prescriptive, and empowering rather than coercive" (p. 8). Reason and Marshall (as cited in Adams, 2011) suggest action research is a beneficial process for classroom teachers to grapple with puzzling ideas. They suggest, "It is for *me* [the teacher] to the extent that the process and outcomes respond directly to the individual researcher's being-in-the-world, and so, elicits the response "That's exciting!"...Research thus contributes to personal motivation and development" (Ibid. p. 113, as cited in Adams, 2011).

The questions asked in this study are personally relevant and, therefore, required a degree of intimacy between the work and the environment. Not only was I interested in learning which strategies might influence the development of mathematical creativity in grade-three French Immersion (FI) students, but also how my teaching and understanding of how children attain mathematical concepts through inquiry might develop as a result of using these same strategies. This curiosity came from returning to a classroom after five years as a consultant, knowing my experiences had changed what I believe constitutes effective practice in mathematics: I had the theoretical knowledge, but not the practical application with a cohort of learners over a sustained period of time.

As a classroom practitioner, I find there is much appeal in conducting research within the walls of my classroom. McNiff (2002) defines action research as "a strategy to help you live in a way that you feel is a good way" (p. 6). Newman (2001) suggests, "There is no one 'right' way of doing action research, of being a teacher researcher...Practitioners engaging in these more open, reflective ways are inventing methodology as they go along" (http://www.qualitative-research.net). The open-ended nature of action research holds great appeal because, not only does it offer a sense of freedom, but also because it mirrors the creative process upon which I hope to shed some light.

I was curious to see how the day-to-day interactions coupled with targeted strategies might increase our capacity to recognize and discuss creativity. The components of questions, action and reflection were critical to this inquiry. This cycle of learning was important as we reflected upon the ways in which we were becoming mathematically creative.

An action research approach afforded me the opportunity to include my students as active participants in the research. Their perceptions and growing understanding of how creativity manifests itself are key components to this work. It required the cooperation and willingness of my students to be open and honest about personal creativity and growth as it relates to mathematics. It also empowered my students to be critical and reflective about their accountability to their learning.

As a *reflective practitioner* (Schön, 1983), it is important for me to assess and reflect upon the strategies introduced and the learning culture created within the walls of the classroom. I was curious about which of these strategies would be most effective for my students. Freire (2005) contends, "the learning of those who teach...is observed to the extent that, humble and open, teachers find themselves continually ready to rethink what has been thought and to revise their positions" (p. 32). I wanted to "become involved in [my] students' curiosity" (Ibid, p. 32) and capture their increasing awareness of what it means to learn. An action research methodology allowed me to rethink and revise what I believed might occur as I introduced the metacognitive protocols and strategies (see Appendix B) as part of the learning culture. It also allowed me to adjust the strategies to meet the individual needs of learners.

The Learning Environment

The school is configured kindergarten to grade five in one of the fastest growing small towns in Canada (http://news.nationalpost.com/2012/02/08/canada-census-2011). It became a dual-track French immersion (FI) school three years ago and currently offers FI from kindergarten to grade three. Subsequent grades will be added as the lead class is promoted to grades four and five. The population of the school is 595 students. Second language learners, for whom the language of instruction is not the mother tongue of the student, account for 50% of the population. This number is divided into 35% English language learners and 15% FI students.

The school recently began seeking candidacy for the International Baccalaureate School Primary Years Programme (IB-PYP). The IB-PYP approach is constructivist in nature and "aims to develop inquiring, knowledgeable and caring young people...[who] become active, compassionate and lifelong learners who understand that other people, with their differences, can also be right" (IBO, 2008, p. 28). Six interdisciplinary units of inquiry are developed using the PYP framework (see Appendix C). As part of this inquiry process, students are asked to reflect upon their learning and themselves as learners, not only what they have learned, but also how they have engaged with the materials and made sense of it (IBO, 2008).

Cohort of Learners

The cohort of learners is comprised of eighteen grade three French Immersion students. With the exception of two students, who were new to the classroom at the beginning of grade three, these learners have been in the same class since grade one. Their exposure to mathematics in a formal setting has been stable and consistent.

There are six girls and twelve boys in the cohort. All students follow the grade-level Programs of Study mandated by the province of Alberta. Three students follow

Individual Program Plans (IPP), which address difficulties processing written language, language-processing delays, and giftedness in Language Arts.

This is the lead French Immersion class in a dual-track school. This cohort works in an immersive setting where French is the language of the classroom and, therefore, all students are second language learners (SLLs). Two members of the cohort are learning in their third language, as neither French nor English is their mother tongue. Both these children are proficient speakers of English. All students experienced little to no exposure to the French language prior to entering grade one, which was the first year of availability for this program.

Overview of Methodology

A qualitative study looks for insights and connections to the research questions in spoken words, written artifacts (drawings or text), and observational accounts of experiences (Punch, 2009). Conversations, observations and products were collected as part of the data for this research.

Participant Selection

All eighteen students of the cohort were invited to be part of this study, with no thought of exclusion. Students were informed of the questions surrounding this work and the reasons behind the questions. Parents were invited to read the research proposal, which was posted to our class website for the duration of the research timeline. Parents of students who agreed to have their child participate were invited to sign an informed consent letter (see Appendix D), which outlined the parameters of this project. Permission to participate was secured from sixteen of the eighteen students. At no time were the non-participating students identified to those participating.

Data Collection

Data collection occurred over the course of a three-month period, from April to June, through a variety of sources: student and teacher journals, structured interviews, student work samples and recordings of classroom discussion. Student work and journal samples were collected from the daily work of the classroom. While I remained in control of when the discussions were recorded and the journals were used, the pre- and post-interviews were conducted by other educators. This variance of data sources was important in order to triangulate the discoveries, as well as allow for the communication of strengths of individual students. Students in their third year of an immersion program may not yet display clarity of thought in speaking or writing, so it was important to differentiate how they expressed their ideas and insights.

The students were involved in the data collection as part of the normal routine of the classroom. During this time, there was no differentiation of product or expectation for those participating versus the non-participants. All students were expected to complete and participate in the protocols, regardless of their participation in the study. However, evidence and conclusions were gleaned only from the work and words of participating students.

Work samples and journals. Students maintained a double-entry journal (son journal à double pensées) as part of their study of mathematics. They recorded initial ideas about concepts, engaged in exploration of the ideas, and, after reading what they had initially thought, reflected upon how their thinking had changed. Students were also asked to indicate how confident they felt with the concept. On their work, they indicated *je l'ai* (I've got it), *ça-va* (I'm okay, but still a bit confused) or *au secours* (help!) to communicate how confident they were with the concept. This self-reflection was part of the on-going assessment for learning, which was a key component of the classroom.

Math discussions. Whole class and small group discussion were recorded throughout the exploration of a concept. These discussions usually occurred at the end of a math class, when students had engaged with an aspect of that particular concept, either as individuals or in small groups. Each discussion involved the elements of *Think-Pair-Share* and *Spokesperson* (see Appendix B).

Over the course of the three months, ten mathematical conversations were recorded using GarageBand. Nine conversations did not focus on the idea of creativity in mathematics. Rather, they captured the discourse that occurred as the students debriefed the activities and discoveries of the day. The final conversation was recorded on the second last day of school. This conversation focused on what the students had come to understand about creativity and how being able to recognize it was a useful tool in mathematics.

Interviews. Five pre-study and nine post-study interviews were conducted. The same five students participated in the pre- and post-interviews. More interviews were conducted at the end of the study simply because the students were eager to share their ideas. The interview consisted of eight pre-determined questions (see Appendix E).

The interviewers were not part of the day-to-day action of the classroom, rather three colleagues who volunteered to assist with this aspect of the data collection process. A colleague from outside the school division conducted the first set of interviews. While she was aware of the nature of the research, she had no connection to the school and met the students on the day of the interviews. The interviews were conducted away from the classroom. The school's administrative team conducted the post-interviews. GarageBand was also used to capture these interviews.

Procedures for Data Analysis

The data was analyzed following Neuman and Robson's (2012) suggested practices for the analysis of qualitative research. These include open coding, axial coding, and selective coding.

Open Coding

The data analysis began with the examination of my journal. I had tried to write in my journal every second day, but found there were times I wrote every day and other times where more time elapsed between entries. The entries consisted of my thoughts, discoveries, and questions that arose as we worked with the ideas of creativity in mathematics. I read all 31 entries through, without stopping, to get a sense of my thoughts and observations over the data collection period. Next, I re-read each entry while asking myself, "What does this tell me?" As I read my journal for the second time, I jotted down the key words that recurred. These key words provided me a glimpse of the emerging themes from this data. Four major themes emerged: physical manifestations of creativity, attitudes toward mathematics, recognizing creativity as an ah-ha moment, and connections made between mathematical concepts. I assigned a colour to each emerging theme. I read through the journal several more times looking for the concrete examples of each theme. Using its assigned colour, I underlined, circled and made comments for each instance the theme occurred in the journal entries.

This was followed by verbatim transcriptions of all interviews and class discussions, using ExpressScribe©. ExpressScribe© is computer software that slows down the rate of speech of audio files, allowing for easier transcriptions of interviews and discussions. I began with the five pre-interviews. Then, I transcribed the ten class discussions in order of occurrence. Finally, I transcribed the nine post-interviews. It was important to listen to the work as it unfolded. This gave me a sense of if and how the students' ability to discuss their understanding and creativity was changing, and if the use of the targeted protocols appeared to make a difference.

As the transcriptions were taking place, I listened for emerging themes and key words in what the students were saying. I made note of these instances on Post-It™ notes. Once each transcription was complete, it was converted to a Word document. Subsequently, I read each transcription several times to ensure I was "hearing" what I thought and not reading sub-text into the words of my students.

Similarly, student work was examined for themes. First, I looked through both the math journals and math duo-tangs for all participating students. I used Post-It™ flags to mark pieces I wanted to investigate further. Next, I went back to the flagged pieces to determine the themes. The colour-coded system, established while reading my journal, was used to highlight each emerging theme.

Axial Coding

The next step involved putting the data from all sources into a visual format, which allowed me to see how the themes were related. I began with a concept map of each emerging themes in broad strokes. This gave me an overall sense of what the data was indicating. Next, more detailed concept maps with concrete examples for each of the four major themes were developed. These individual maps were then put into one large map. Appendix F represents the coding at this point in the analysis.

Selective Coding

As the data was organized and re-organized, the headings for this thesis began to surface. At this point, I selected the pieces of student work, journal entries, and student quotations that would best illustrate what I have come to understand about creativity in elementary mathematics.

Ethical Considerations

As a teacher conducting research in my classroom it is vital to remain as objective as possible about the data. As a classroom teacher, I also have the moral obligation to do what I can to help my students achieve success in all areas of their school life.

The teacher-student paradigm is traditionally one of authority over subject. Parents trust the teacher will behave morally and ethically in all aspects of their child's development. This is especially true for students in division one, who may not be able to voice concerns if this trust is broken. As the adult in the room, I am perceived to hold the most authority, and therefore, the loudest voice. My stance on authority in the classroom can have far-reaching repercussions to the lives of the students who have been place in my care.

I believe *critical trust* must be established in a classroom. *Critical trust* is having confidence and believing a person’s actions will be in the best interest of all parties involved in any situation. Trust is earned slowly, one interaction at a time. It is characterized by consistency, open-mindedness, reliability, transparency, integrity, and humility (Bryk & Schneider, 2002; Kochanek, 2005; Tschannen-Moran, 2004). Bryk and Schneider (2002) contend that trust grows from a shared understanding of role obligations where “individuals understand what is expected of them and the consequences that may ensue if obligations are not met" (p. 33). It is important to establish this dynamic as a two-way track within a classroom: I, the teacher, will hold you, the student, accountable just as you may hold me accountable to my actions and words. While children in grade three may not be able to articulate the aspects of this trust, they are able to recognize its existence or absence in those around them.

According to Bryk and Schneider (2002), trust is rooted in "a shared set of primary beliefs about who we are and how we should live together as people" (p. 15). Actions are based in values and beliefs about moral or ethical behaviour, which reflects an imperative to 'do what is right' for the good of society, or in this case, the classroom and all its occupants. This perspective of trust "sustains an ethical imperative among organizational members to advance the best interests of children" (Ibid, p. 34). It is to this perspective that I aspire as I work daily with children to build a culture of *critical trust*.

This *critical trust* relationship becomes even more important in the presence of university research within the classroom. Young children cannot give permission to participate in research, even when a large part of the work involved the day-to-day operations of the classroom. This is where the teacher's authority is most apparent. To a large degree, the teacher is responsible for the planning and execution of the learning episodes from which data is collected. Parents, and students, must trust the research process is transparent and ethical.

To that end, all parents of this cohort were sent an informed consent letter (see Appendix D), which outlined the goals and expectations of participation. The parents maintained the right to exclude their child's work and words from this study at any time without fear of reprisal. The research proposal was posted to our classroom website so parents could read it at any time. To protect their identity, students selected a *nom de plume*. To further protect the identity of students, a second pseudonym, known only to myself, was assigned to each student.

Students also maintained the right to exclude work from this study, without fear of reprisal. Students or parents were free to discuss them with me at any time, should questions or concerns arise. They were also invited to discuss concerns with the principal, or his designate at any time during the research cycle.

Students were aware of the nature of the research questions and that their work samples and ideas would play a role in the completion of this thesis. After participants had been selected, all discussion of this work evolved as part of the normal routine of the classroom. No students were excluded from the discussions or work, as this was how mathematics was being taught in the classroom. The use of metacognitive strategies, recording of discussions, and collection of samples were not new, as these methods were already in place as part of the learning environment. All students were asked to reflect upon their learning as it relates to the learner outcomes of the Alberta Program of Studies for Mathematics (2007). Work samples collected were used as part of the on-going assessment of and for learning practices of the classroom. All students, for whom consent had been granted, were given the choice to include or exclude pieces of work.

Limitation of Study

This research is limited to one classroom and one cohort of students. This sample size is statistically small and may impact the reliability of the data. It is also the nature of classroom-based action research that the findings may not be generalisable to a larger context (Evans, Lomax, & Morgan, 2000; & Knoerr, 2001). What works for this cohort of learners may fail miserably with a different group. However, action research "relies on being transferred into other classrooms and institutions, where ideas could be tried and adapted to the new context" (Evans, Lomax, & Morgan, 2000, p. 407).

This cohort is also comprised of second-language learners. This may impact the complexity of responses, as students may lack the necessary vocabulary for deep discussions.

Chapter Four: Discoveries and Discussion

This chapter begins with an examination of the students' construct of creativity prior to experiencing the structures and strategies used as a part of this study. It then outlines four *ah-ha's* that emerged from the data: the importance of connection to the context in mathematics, the importance of giving students permission not to know, the necessity of struggle and ambiguity, recognizing creativity as a physical manifestation, and the importance of scaffolding vocabulary as a path to understanding. The conditions under which each discovery was made are described and supported with concrete examples of student work and reflection. The chapter concludes with an examination of how students discussed creativity at the end of the year.

Initial Thoughts About Creativity and Mathematics

Like when you draw stuff or when you make crafts. Um...that's it.
(David, beginning of April)

Creativity is when you make something out of your own ideas and
your own thoughts and you make whatever you want.
(Justin, beginning of April)

When I play, I use my imagination...you think of something and you pretend you have it.
Like in class I used a juice box and paper and tape and my granola bar wrapper and
made a cell phone video game yesterday in indoor recess.
(Michael, beginning of April)

When you have something good in you, like a talent or something.
(Polly, beginning of April)

In answering the questions "What is creativity?" and "How are you creative at school?" during the pre-interview, student responses indicate they hold many of the same ideas about creativity outlined in chapter two:

- Creativity is expressed in drawing, making crafts or inventing things.
- To be creative one must have talent.
- Creativity was expressed at school during Art or free time when they could "invent" things using the K'nex© or linking straws.
- Imagination and creativity are needed to invent *things*.

These misconceptions were not a surprise, rather a confirmation that the idea of *little c* (Sawyer, 2006) creativity would be new to my students and that its exploration in mathematics might open their minds to the possibility of their potential and to see mathematics as a creative discipline.

The questions "What is important to know or do in mathematics?" and "How are you a mathematician?" elicited the expected responses. The students viewed mathematics as the operations of addition, subtraction, multiplication and division. They felt it was important to know which sign to use, and as David stated, "The numbers. If you don't know the numbers, you can't do math".

As far as the work of mathematicians went, the students seemed stumped by this role. "Do they teach math?" asked Valerie. Michael was convinced they did math competitions and made up math questions. Polly thought they might be helpful, but could not describe for what they might be helpful. Justin believed "it is important that mathematicians have to follow by their math rules". They did not see themselves as mathematicians; mathematics was the work of others, not grade three students. Valerie was not sure she was a mathematician because she "didn't always get the right answer".

This was our starting point.

Got It! Almost! Help!

One of the first learning protocols introduced, as part of this study, was an assessment for learning tool for self-assessment: *Je l'ai* (Got it!), *Presque!* (Almost!), or *Au Secours!* (Help!). In order for students to articulate if and how their thinking is changing, first they must be able to ascertain whether or not they understand a concept. Even if they possess misconceptions, it is critical they be able to justify where they are with relation to new learning.

As demonstrated in Figure 1, Colin indicates he needs assistance with this concept. This tool proved useful as a planning tool for me, allowing me to group students according to needs and strengths. It also provided a way for students to communicate if any new connections had been made. This self-assessment is an important first step in recognizing creativity in mathematics.

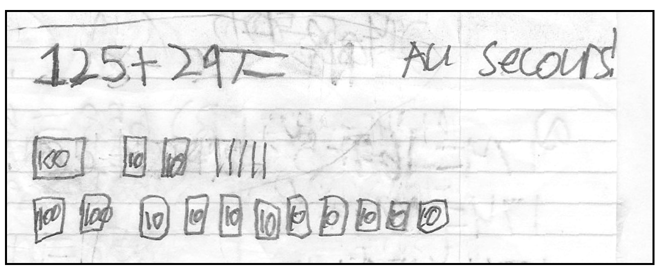


Figure 1. Colin's self-assessment.

Context, Connection, and Problem Solving

Ah-ha #1: *Personal connections to the context of the problems make the concept 'stickier'.*

Context and Personal Experience

Fosnot and Dolk (2001a) contend, "Context must allow children to mathematize--they must be more than word problems camouflaging "school mathematics." They must be real or be able to be imagined by children" (p. 157). The importance of connection and context became glaringly clear to me on three separate occasions between April and June. What made these episodes stand out? How did the design of the creativity of the students?

Problematic scenarios and stickiness. One of the challenges in an inquiry approach to mathematics is finding suitably problematic scenarios or investigations. A problematic scenario is one to which the path to a solution is not immediately evident or for which several viable solutions may exist (Fosnot & Dolk, 2001a, 2001b). This type of problem takes time, thought and perseverance to solve. These problems are not "being used for *application* at the end of a unit of instruction. [They are] being used at the start, for *construction*" (Fosnot & Dolk, 2001a, p. 19, italics in the original). A problematic scenario need not be long and involved, but it must intrigue students enough and remain accessible to them based on their experience and skill level.

The goal of any problem solving is for students to create their conceptual knowledge while doing the work of mathematicians in ways that are engaging and purposeful (Burns, 2007; Fosnot & Dolk, 2001a, 2001b). The mathematical ideas embedded in the activity must stick in the minds of the students so that they begin to "[set] up relationships and [try] to prove these relationships mathematically" (Fosnot & Dolk, 2001a, p. 4). "Stickiness" is more likely when students are able to put themselves in the context of the problem being posed. Ideally students should have experience with the context so they may draw upon their memories while working through the problem. Fostnot and Dolk (2001a) contend, "any new ideas constructed...will be directly linked in learners' minds to *their* past ideas, because they arise from reorganizing the initial ideas"

(p. 23, italics in original). Context and connection are vital for new learning. Many problems found in traditional textbooks are outside the realm of the students' experiences. How, then, do we remove the teflon coating from problems so they will stick in the minds of students?

Designing problems that stick. Designing problematic scenarios takes careful consideration and planning. Not only is it important to respect the mathematics, it is also important to be mindful of the potential connections students may have with the context of the problem. Heath and Heath (2007) contend there are six principles required for ideas to stick: simplicity, unexpectedness, concreteness, credibility, emotions, and stories. They use the acronym "SUCCES" to help this idea stick (Ibid. p. 18). These same principles are useful when designing "successful" problematic situation in mathematics. A problem must be simple enough that students can easily understand what is being asked of them. Simple does not mean easy. It means there is clarity of purpose. It must also hold students' interest so they will persevere. I might replace the word *unexpectedness* with *intriguing* when using this concept for a math problem. The problem must also relate to the students' lived experience. They must have concrete experience with the context of the problem. Also, students must believe the problem is worthy of a solution. This is its credibility. Finally, students must care about the context, which is most easily achieved by posing the problem with a story.

Pink (2006) contends that play, humour, laughter and joyfulness "can lead to greater creativity, productivity, and collaboration" (p. 204). This aspect of playfulness is also an important aspect of problematic situations in mathematics. If students perceive the work they are doing in mathematics is important, interesting, and fun, they are much more likely to persevere with purposeful engagement.

Investigations That Led to Creativity

The mathematical investigations I will describe were designed to help students create or refine their understanding of multiplication, division and fractions respectively. The investigations were *The Chocolate Boxes*, adapted from Burns (2007), *Cake for Émilé,* and *What is a Fraction?* both designed by me. These examples serve to highlight the importance of planning, reflection, and adjusting to student responses in order to facilitate the students' creation of mathematical ideas. Also, they underscore the importance of time for experimentation and reflection on the part of the students.

Investigation One: The Chocolate Boxes

This problem, adapted from Burns (2007), was presented at the beginning of our investigation into *multiplication* and *arrays*. The specific vocabulary was not introduced until several days later. When introduced to the students they were very excited to begin. They were intrigued by the idea of different sized boxes for chocolates and the scenario fell within a realm of possibility in their lives, as many of my students' parents are excellent candy makers. Therefore, this problem had the potential to be a "sticky" one.

Scenario. Your mom makes incredible chocolates. She has decided to open her own business and sell her chocolates from home via the internet. She has decided to put the chocolates into different sized boxes. She has asked you to help her design the best boxes for her candy. She only wants to use square or rectangular boxes because it will cost less to mail them and they are easier to make. Each box will have only one layer of chocolates.

You want to present as many boxes that can hold 1 to 25 chocolates as possible to your mom. Use manipulatives, graph paper, and pens to figure out the different sizes of boxes your mom can use.

- Which boxes do you think would be best? Why?
- Which boxes do you think will not work? Why?
- For which numbers of chocolates can you use a square box?
- For which number of chocolates can you use the most boxes?

The process. Students had the choice to work in pairs or alone. Most chose to work with a partner and share the load. They first used manipulatives (blocks, double-sided algebra tiles, centimetre cubes, etc) to represent the chocolates for each box. They then drew and labeled each box on to graph paper. Next they cut and pasted their boxes on to large pieces of paper.

At the end of the first day of investigation, the students did a *Gallery Walk*. During a *Gallery Walk,* students leave their work on their desks and proceed to examine the work of others in order to discover techniques or ideas that both mirror and differ from what they have done with the same questions. A *Gallery Walk* allows for the refinement of ideas.

My students were asked to look for similarities and differences in what others had discovered. Some students noticed they had missed boxes for certain numbers, especially the square boxes for the numbers 4 and 9. They began to notice that some numbers only had one box. At this point they were not differentiating between a 1X5 box and a 5X1 box, assuming that these boxes were the same because they could overlay the boxes by turning them. I did not address this misconception, as I knew it would become part of an investigation later in the unit. The Gallery Walk was repeated at the end of day two.

Once they had discovered all the boxes from 1 to 25 chocolates and they had discussed their discoveries with another group (*Pair-Share*), they transferred what they had discovered from their work with the graph paper to a T-chart (see Figure 2). As they completed the chart, they began to notice patterns and make connections, which were noted in their journals (see Figure 3). These entries were read aloud by students as part of the sharing process. Figure 2 demonstrates how Amy had begun to circle boxes for which a row or column of 3 and 4 could be found. She was looking for patterns and making connections to skip counting when she remarked, "Madame, these boxes skip count!" (*Madame, les boîtes comptent en bonds!*). Michael and Adam made similar observations.

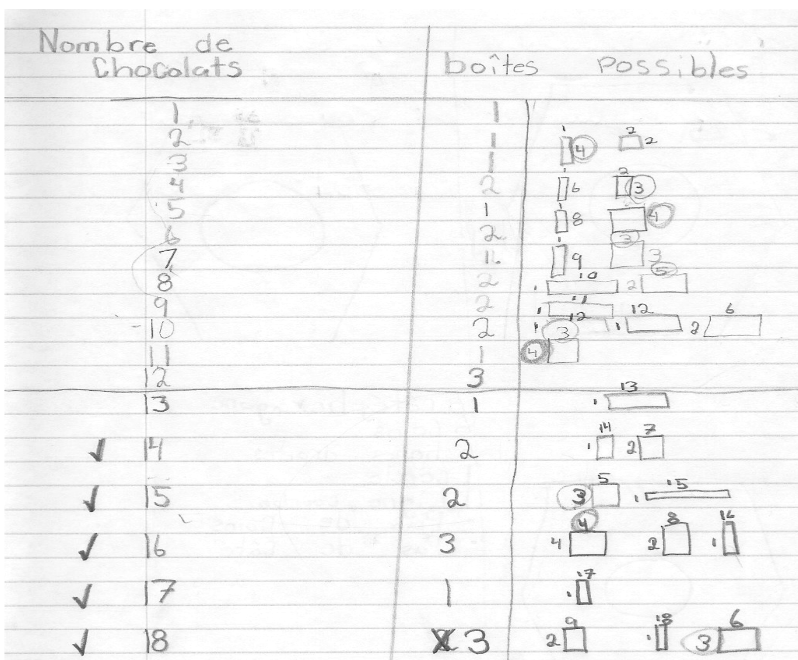
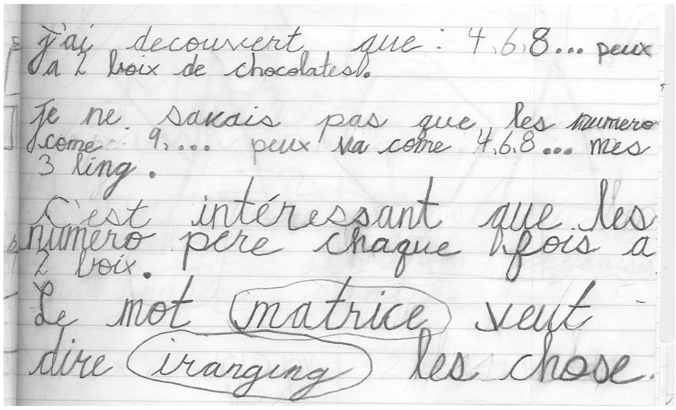


Figure 2. Results for The Chocolate Boxes.

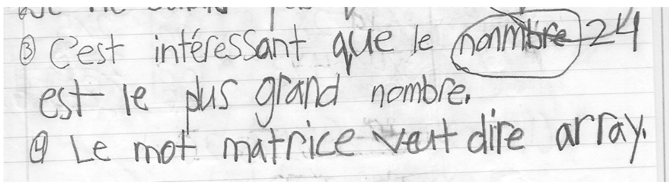

j'ai decouvert que: 4.6.8... peux a 2 boix de chocolates.
Je ne savais pas que les numero come 9.... peux va come 4.6.8... mes 3 ling.
C'est intéressant que les numero pere chaque fois a 2 boix.
Le mot matrice veut dire iranging les chose.

I discovered that 4, 6, 8,... have 2 boxes.

I did not know that numbers like 9 are like 4, 6, 8...but has 3 lines.

It is interesting that even numbers always have 2 boxes.

The word array (matrice) means arranging things.


③ C'est intéressant que le nombre 24 est le plus grand nombre.
④ Le mot matrice veut dire array.

It is interesting that the number 24 is the biggest number. (has the most boxes)

The word array means array*.

**One of the students had discussed the work we were doing with his parents and came back to school with this word, which he shared with his group.*

Figure 3. Journal reflection for The Chocolate Boxes.

Stating what they were discovering, both orally and in writing, was the next step. Students shared what they had noticed while working on this problem over the past few days. These ideas were recorded on the board so the vocabulary was readily available for students to use in their writing. Figure 3 presents some examples of these journal reflections. There is evidence of beginning understanding of the ideas of multiplication: most even numbers will have at least two factors; some numbers have more factors, etcetera.

As a final aspect of this investigation, the class negotiated a definition for an array (une matrice). The students reviewed and discussed all the information they had discovered while creating the chocolate boxes. They also consulted the textbook, from which they gleaned some specific vocabulary. Again, in pairs they decided upon a definition, which was shared with the larger group and written on the board.

As a class, and with some guidance, they word-smithed a definition, which they all felt summed up what they had learned: an array is a number of objects arranged in equal rows (see Figure 4).

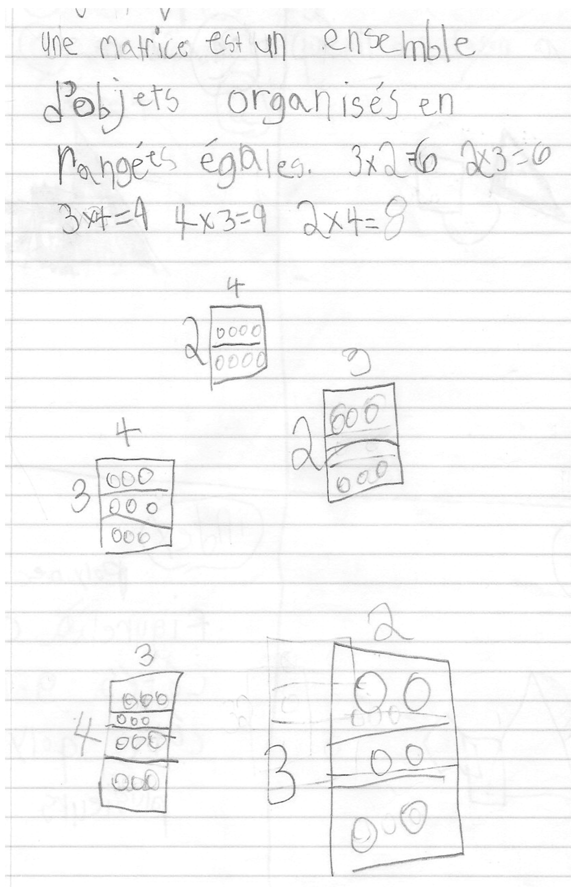


Figure 4. Negotiated definition of an array.

This experience with multiplication within a concrete scenario became a sort of touchstone for some students. When asked how he was creative in the post-interviews, James referenced this activity saying, "By drawing and learning new stuff in math. We did the boîtes de chocolat (chocolate boxes). It was pretty hard and we had to draw pictures for it to help [us] understand. But now I get how I can figure out multiplication".

It is now in his repertoire of experiences from which he can draw when faced with new learning.

This investigation helped build a foundation for understanding multiplication. It was a "sticky" one because it held the students' attention over an extended period of time. They would enter the classroom in the morning and ask excitedly when we would be continuing our math work, which is music to any mathematics teacher's ears! Additionally, this work made the transition from school to home. One student shared what we were investigating with his parents and he was excited to share the new word (array) he had learned at home (see Figure 4). While the introduction of the English term for the ideas we were investigating compelled me to adjust the timeline for this work, it did provide me with evidence that this investigation was allowing students to create their understanding in meaningful, engaging ways.

Investigation Two: Cake for Émilie

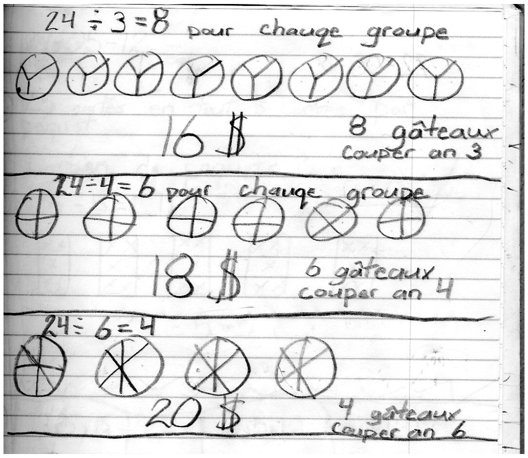
When our French Language Monitor was due to finish her time with us in mid-May, it became the perfect opportunity to reinforce the concepts of fair share and division. We were in the middle of our larger inquiry into the properties of division and multiplication. In my on-going assessment I had noticed that some children were struggling to grasp the idea of division as fair share. I also wanted to link division to what the students already knew about the ideas of multiplication.

I introduced the problem by telling the students I wanted to get some cake for Madame Émilie's farewell party. I explained that when I got to the store I discovered the cakes could be cut into different numbers of pieces. I could get cakes cut into 3, 4, 5, 6, 7, or 8 pieces. I told them there would be 24 people attending our little party and indicated that I did not want to have any leftover pieces because I did not want to have to deal with them after the party. I also assigned a price point to each type of cake. This ranged from $2.00 for a cake cut into 3 pieces, $3.00 for a cake cut into 4 pieces, and so on to $7.00 for a cake cut into 8 pieces. My question was two-fold: Which cakes would serve 24 people equally with no leftovers and which cake would be the most cost effective?

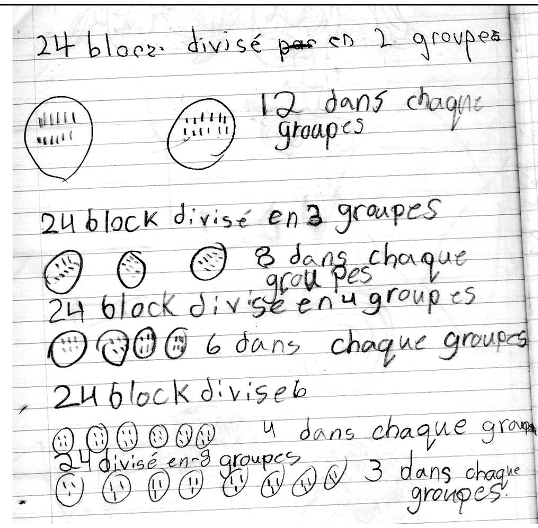
This investigation is not as involved as the Chocolate Boxes, but it does meet the criteria for a "sticky" problem. The situation, told as a story, was relevant to the students' lives and they cared deeply about the subject, both the cake and Émilie. It was also a concrete situation; we really were having a party and we really were going to eat cake.

> The best part of the day was our investigation of cakes...because they had an emotional connection with the problem they were asked to do, they were eager to get started. They pulled out manipulatives and drew pictures. Very quickly arguments started--they were showing each other their thinking and defending their ideas. I'll be excited to debrief this one tomorrow! (Personal Reflection)

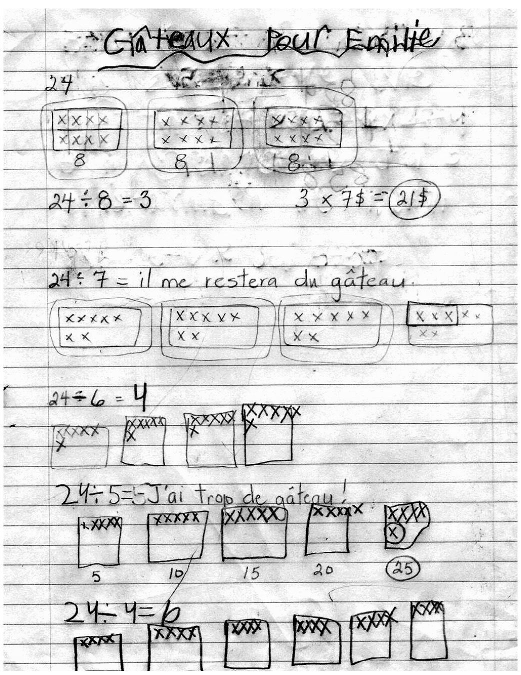
There was palatable excitement in the room as students worked through this problem. As with any of our investigations, students had the choice to work independently or with partners. This problem did not have multiple solutions, but it certainly allowed for multiple entry points and approaches. Figure 5 illustrates some of the different representations used by students to show what they had discovered. The freedom to represent their discoveries in a manner that made sense to them is important when considering the growth of mathematical creativity. The degree to which a student can represent and speak to his or her work is an indicator of how well the concept is understood. To paraphrase a famous movie quote: If they can build it, understanding will come.



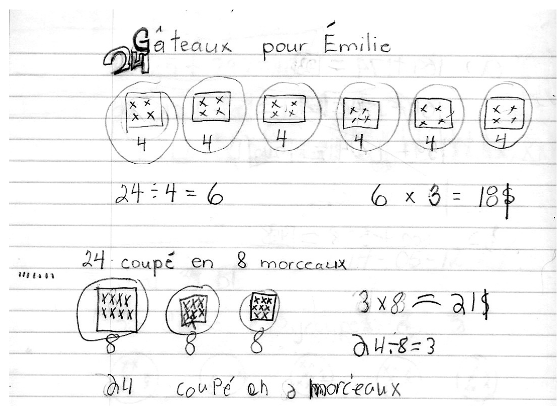
James used circles to represent the cakes.



April used tally marks and words to represent what she had discovered using blocks.



Douglas used boxes and x's.



Mary initially used manipulatives to figure out which cakes could be shared without leftovers. She then transferred her ideas into her math book.

Figure 5. Solutions for Cakes for Émilie

The work samples in Figure 5 provide evidence of burgeoning understanding and ability to represent knowledge effectively. James and April were able to transfer their understanding to a symbolic representation with relative ease. Mary and Douglas, while able to demonstrate their work using manipulatives, needed to see a model of a symbolic representation that they could then follow. They explained what they had done with the manipulatives while I scribed. Once they had this model, they were able to transfer the work they had done with their manipulatives into their math scribblers.

Investigation Three: What Is a Fraction?

The concept of fractions is introduced formally in grade three. Students must demonstrate an understanding of fractions as part of a whole, compare fractions with common denominators, and indicate areas where fractions might be used (Alberta Education, 2007). This provided a perfect opportunity to gather evidence of how thinking was changing, as this concept was new to most students.

Scenario. The investigation began with students' journaling what they thought a fraction was. Some thought it was a story. Others thought it involved multiplication. A few were able to write some fractions, such as ½, ¼, and ¾, but were not able to explain what the fractions meant. Figure 6 shows examples of initial thinking about this concept and how the thinking changed after engaging in the inquiry activities.

To introduce the concept, all students had four double-sided counters. Using the document camera, I modelled each of the representations for ¼, ½, ¾, and a whole. There were some "Oh, that's what it is!" but mostly this mini-lesson was met with scrunched up faces, frowns and, "I don't get this!". I realized I had tried to go too far too quickly. I had not given students enough time to build their background knowledge of fractions in concrete, relatable ways.

I quickly took a step back and reflected upon a way we could attack this concept from a different angle, evidence of my own small c creativity in action. I had not asked them to truly think during this lesson, only to follow along with my explanation. I decided we needed to get physically involved with this concept. My students needed more than a visual representation of fraction, they needed to become fractions.

I asked the students to sit in a circle. Then I asked different students to stand. The students thought we were playing a sorting game and began to try to figure out the sorting rule, as this was their experience with this type of activity. The activity unfolded like this:

Mme Leslie: Polly, Valerie, Amy, John and Paul, please stand up. (These students stood up.) There are five people in this group. How many are wearing glasses?

Several Students: Three!

Mme Leslie: Yes, that is correct. Three out of five students are wearing glasses. How many students are not wearing glasses?

Chorus of students: Two!

Mme Leslie: Yes. Two out of five students are not wearing glasses. David, Michael, Douglas, and John, please stand up. There are 4 boys in this group. How many of the boys standing up have sisters?

Chorus of students: One!

Mme Leslie: Yes, one out of four of these boys have sisters. How many of these boys do not have sisters? What *fraction* of them do not have sisters?

Chorus of students: Three!

Mme Leslie: Yes, three out of the four, or *three quarters*, do not have sisters.

We continued in this vein for about 10 minutes, using as many different examples of fractions as I could invent. I was modelling the language of fractions as well as giving the students physical experience with the concept. We did several examples that demonstrated thirds, quarters, fifths and tenths. Once I felt they were catching on to the idea, I then asked different students to invent the fraction puzzles.

Small c creativity in action: This activity provided clarity to some students, but not all. Valerie was still wearing her "I'm confused" look. I encouraged her to 'let things stew' (l*aisse ça mijoter un peu*). As we worked through the various examples of fractions of people who shared a trait, she would make a connection, step back, shake her head, and say, "No, I still don't see it." John, who was sitting next to her, was sharing his fraction example. Suddenly, Valerie cried, "Oh, I see it! That's it? That's so easy!" She had made an important connection in her learning and was in the process of over-writing her understanding of fractions with new ideas; she was creating her mathematical knowledge.

Increasing clarity. At the end of this game, students wrote what they had learned about fractions and how their thinking had changed (see Figure 6). Most were able to articulate the idea that fractions involved a group of things and within that group some of the things were the same and some were different. This was the beginning of understanding fractions as part of a whole.

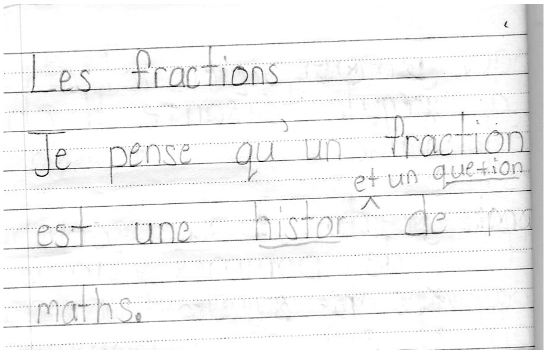
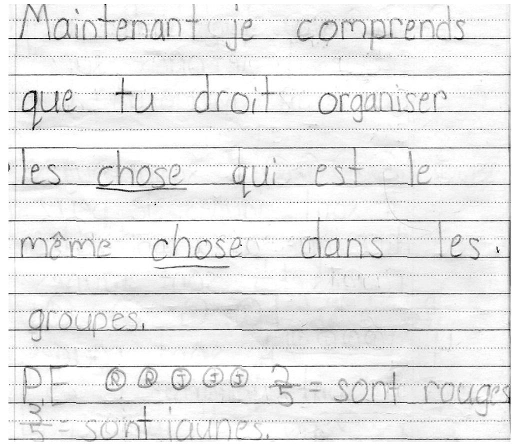
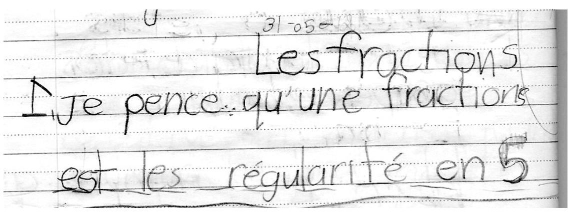
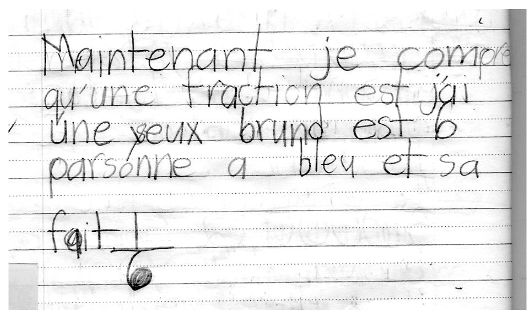
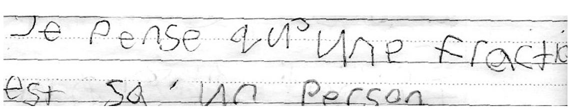
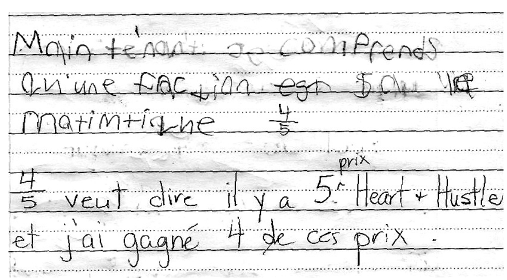
Before Exploration: *I think a fraction is...*	**After Exploration**: *Now I've learned that a fraction is*
 I think a fraction is a story and a question in math.	 Now I understand you have to organize things that are the same things in groups. IE. ⅖ are red and ⅗ are yellow.
 I think a fraction is a pattern of 5.	 Now I understand that a fraction is [if] I have brown eyes and there are 6 people and the rest have blue [eyes] and that makes ⅙.
 I think a fraction is a person.	 Now I understand that a fraction is about math. ⅘ means there are 5 Heart and Hustle prizes and I have won 4 of the prizes. (The last part of this reflection was scribed for the student after probing for clarity.)

Figure 6. Fractions - before and after.

The next step of this investigation involved representing and writing fractions. I had prepared several bags of jellybeans containing from three to ten beans each. Students shared what they recalled from the previous day and I modelled on the board how we write fractions mathematically, using one of the bags. Students were then invited to choose a bag and write the fraction of each colour of jellybean in their math scribblers (see Figure 7).

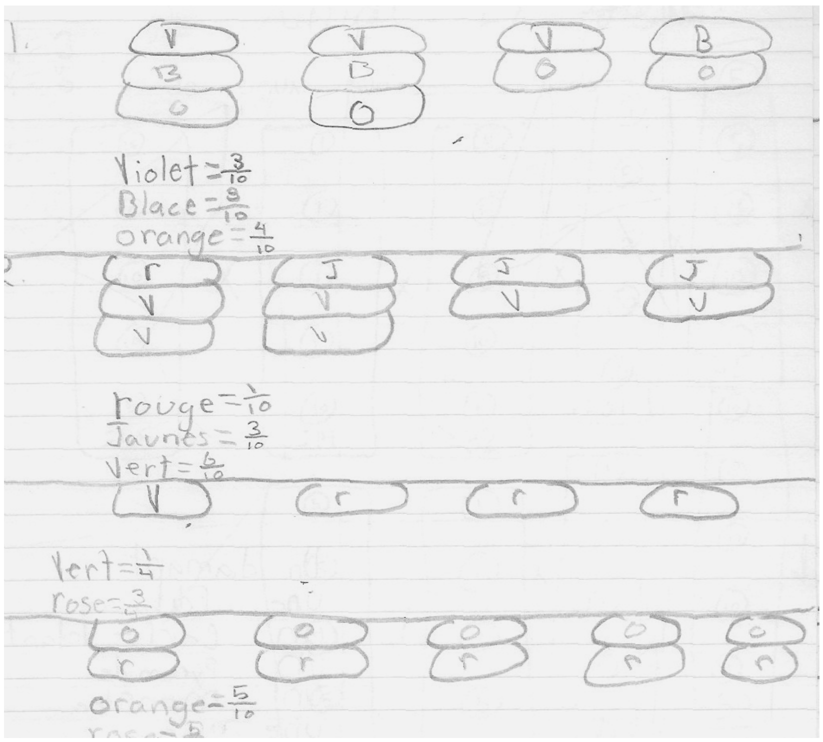


Figure 7. Representation of jellybean fractions.

Small c creativity in action: Four students were absent from the classroom when the mini-lesson took place. When they returned, their peers were very engaged in exchanging jellybean bags and writing the fractions. I asked their elbow partners to explain the purpose and expectations of the activity, as I was working with a small group of students. After a few moments, Amy approached me and said excitedly, "Madame, Paul just had a creative moment!" I asked Paul to explain what Amy meant.

He replied, "Well, I didn't really understand what fractions were. I didn't get how the top and bottom numbers went together. Amy showed me a couple of time with different jellybean bags and all of a sudden, I just get it!"

"What do you get?" I probed.

"Well, it's like this. The bottom number is the number of jellybeans in the bag and the top number is the number of red ones or yellow ones or orange ones." Paul had create a new understanding of fractions.

Addressing misconceptions about fractions. A common misconception with fractions for young mathematicians is that they assume a big denominator means a bigger piece of the pie, so to speak (Small, 2008). I knew this might be the result of working with the jellybeans and the concept of fractions as part of a set. It was important to introduce fractions as part of a whole.

On the board I wrote the questions: Which fraction of licorice would you like? Under this question I had a table with ⅓, ¼, ⅕, ⅙ and $^{1}/10$. Students were directed to write their names under the fraction size they would like, without being influenced by their friends. Figure 8 is a representation of the results, which were exactly as I had envisioned.

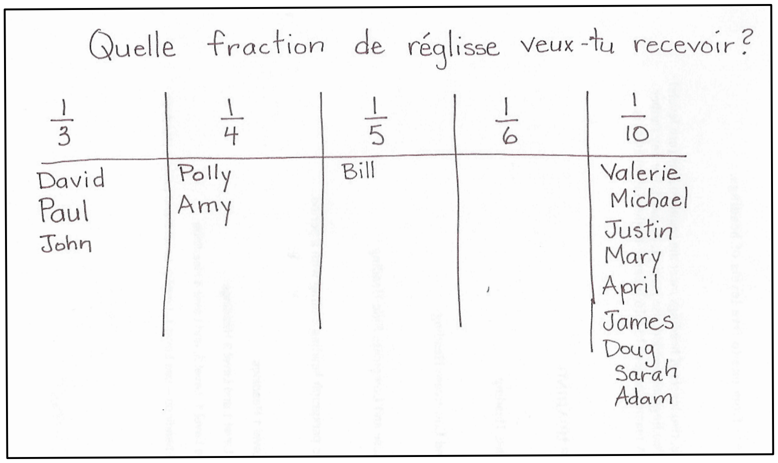


Figure 8. What fraction do you want?

I asked students to share why they had chosen a particular fraction. Most who chose one tenth indicated that it was the biggest and they would get more licorice. David attempted to convince his peers that the licorice would be cut into ten pieces, but based on their experience from the previous day and the jellybeans, they were not willing to believe him.

We gathered around the table, I took a piece of licorice out of the bag, and using my ruler began to cut it into ten equal pieces. Incidentally, a piece of red licorice measures exactly 20 centimetres, so each tenth was 2 centimetres in length. As I passed the one tenth piece to each student who had requested it there were cries of "What! That's hardly any!" As we worked through each fraction the cries of "Not fair!" from the tenths group got louder, especially when those who chose a third got their pieces of licorice.

This demonstration led to a wonderful discussion about fractions and how they can represent different things, for example a group of objects or a whole thing. The students concluded fractions are cut up or separated into groups, either by a characteristic or as an equal piece. The bottom number is important because it tells you how many pieces there are and the bigger the number, the smaller the piece.

Small c creativity in action: It was easy to see students making connections and creating their understanding with regards to fractions: this was a new concept to the majority of them. The ah-ha moments were remarkable due in large part to the fact that everyone was having them. John's initial thinking led me to believe he had seen fractions represented as a circle. Initially he was very confused about the idea of fractions as part of a set, as evidenced by the puzzled look on his face during the first part of the game. In his journal he wrote that he had discovered "there wasn't just one way, but there are many ways [to do fractions]" (*Maintenant, je comprends qu'une fraction n'a pas juste une façon mais il y a beaucoup de façons*).

The opportunity to engage in learning on a collective blank slate seemed to level the playing field for many students. Especially those who did not see themselves as equally competent to their peers. They appeared to be less intimidated because they were seeing their "capable" friends struggle to understand and in some instances gained understanding first.

How Did These Investigations Contribute to Mathematical Creativity?

The Alberta Program of Studies for Mathematics (2007) states, "students come to classrooms with varying knowledge, life experiences and backgrounds. A key component in successfully developing numeracy is making connections to these backgrounds and experiences" (p. 1). When life experiences with the concept are limited, teachers must design learning episodes from which background and experience may be gained. My students were anxious about multiplication, division and fractions. Therefore, I had to find ways to sharpen the detail in the background so new discoveries could be layered overtop and make way for a shifting landscape of learning.

Ambiguity, Perseverance, and Frustration

Ah-ha #2: *Students need to be given permission to not yet understand and to think divergently.*

Ah-ha #3: *Students need to be able to connect concepts to language in order to discuss their learning.*

Early in the year the class was introduced to the vocabulary of the International Baccalaureate Organization's (IBO) Learner Profile (See Appendix G). This profile "promotes the education of the whole person, emphasizing intellectual, personal, emotional and social growth through all domains of knowledge" (IBO, 2006, p. 1). It is not a recipe for the "perfect" student. Rather, it helps center the student "firmly at the heart...and focuses attention on the processes and the outcomes of learning" (Ibid, p. 2). This vocabulary, and the concepts it envelops, was new to the students. It was important to help students understand they possess all these attributes and attitudes, and that one of the goals of learning is to seek improvement in these areas.

The process of inquiry was also new to the students, especially in the area of mathematics. Short (2009), defines inquiry as "a collaborative process of connecting to and reaching beyond current understandings to explore tensions significant to learners" (p. 12). These tensions result from the disequilibrium that occurs when learners realize there is a disconnection between what they know and what they are experiencing. Learners must be able to tolerate the ambiguity of learning and be comfortable taking a stance of not knowing.

Ambiguity

You're not going to tell me, are you?
*(*Question from student during a math class.)

I just know it in my head.
*(*David, beginning of April)

This cohort of learners exhibited a common misconception about the nature of learning mathematics: They believed they needed to understand a concept on the first try. As Costa (2008) notes, "Students often give up in despair when the answer to a problem is not immediately known...saying, "I can't do this", "This is too hard", or they write down any answer to get the task over with" (p. 32). As I noted in my journal,

> The children have somehow learned that there cannot be ambiguity in mathematics. You either understand or you don't. If you do not immediately understand, there is really no point in puzzling or wondering. You are simply not good at math. This is a difficult paradigm to shift--especially in 8 and 9-year olds.

Early in the year, they were very reluctant to take risks in their problem solving and exhibited little perseverance with mathematics. They expected me to give them the answers after a first, unsuccessful attempt and they sought affirmation of their ideas before beginning any work. "Is this how I'm *supposed* to do it, Madame?" was the default question. My standard response, "I don't know, what do you think?" would often cause frustration and, at times, panic. Struggle and perseverance were not concepts with which they were comfortable.

Some students also held the misconception that they could not use divergent strategies. Despite all the conversations with regard to personal strategies, they still felt there was a "right" way to proceed. Permission, and indeed encouragement, to use different methods were ah-ha moments for many. In her journal, Valerie wrote, "Before I didn't think I could use pictures to help me understand. Now I know I can use them, even if others do not need them". This discovery opened a new world of understanding for Valerie. She began drawing pictures as her go-to strategy, which helped her visualize and make sense of the mathematics. James, April and Polly had similar epiphanies with manipulatives. James was under the impression that manipulatives were only used to create patterns. Sarah and Amy felt that using manipulatives were a sign of lack of ability. They did not yet understand how important physical models were to their individual understanding of mathematics.

Perseverance

We began by defining the word perseverance, under the attitude of tolerance (see Appendix G). At first, the students had no idea how to describe what this word meant; it was not yet in their vocabulary. After sharing examples of how I had been perseverant in my life, I asked students to share things with which they had struggled, but with conscious effort and practice had improved in their abilities. Hands shot up. They shared how with practice and concerted effort they had improved in their ability in dance, sports, singing and video games. It is interesting to note, not one example had to do with their school life. This was followed up by a discussion about what had most frustrated them while they transitioned from beginners to experts. Again, they were able to provide many examples.

When it came time to begin our math investigation that day, I asked my students to think about what we had learned about perseverance while they were completing the activities for the day. This was met with many puzzled looks. As we debriefed at the end our math time, I asked students to share their thinking and to provide evidence of perseverance with the activities. This was met with a lot of dead air.

Perseverance was the main focus of our reflections, not only in mathematics, for many weeks. Some catch phrases resulted from this focus: *Laisse ça mijoter un peu*-Let it stew a bit and *débloque les freins de ton cerveau*-unlock your brain brakes. These phrases were used increasingly by students when they got stuck in their thinking. The first one was initiated by me. The second was initiated by a student when he used the English version to describe how he persevered to understand subtraction with regrouping. It was quickly adopted as an important reminder to persevere past ambiguity, doubt and frustration.

Frustration

Frustration and uncertainty are often most difficult for children who see themselves as able. They hold high expectations and when they stumble, it is difficult for them to reconcile this moment of not-knowing and the hit to their self-esteem. They will often compensate by choosing not to participate, thus not risking being found less than capable. Establishing a culture where not knowing was not only acceptable, but preferred, was crucial for my mathematically "able" students. In their experience, they had yet to meet a mathematical concept that was puzzling, or that was presented to them in a problematic way. It took patience, understanding and strategies to help these children shift their paradigm from searching for the "right" answer as quickly as possible to understanding why this strategy helped them make sense of a concept.

One of the most important things in creativity is knowing what to do when you do not know what to do. This is also true in problem solving. However, for students who have limited experience with struggle and failure, not immediately knowing what to do can lead to panic and abandonment. As I observed a couple of my students, who were beginning to show signs of the stress of not knowing, I realized they needed the reassurance of an exit-strategy. So, we developed one as a class.

First, we brainstormed everything we knew about getting "unstuck". Next, we categorized ideas that were similar. Finally, we voted using a five dot system. Each student received five dots. They could choose to use all five dots for one idea if they thought it was the most important, or they could distribute their dots as they saw fit. Our list ended up looking like this:

1. Do not panic.
2. Reread the problem.
    a. What do you know?
    b. What do you need to find out?
    c. How might you begin? Can you think of a strategy that you have used before?
3. Try out your strategy.
4. Ask a friend for help.
5. Ask another friend.
6. If you and your friends are still stuck, go ask Mme.

This get-unstuck list became an important tool for many students, especially those who believed they had to know things quickly and without struggle. It provided every student with permission to be stuck and a way to work through a problem without feeling like a failure or fraud.

This permission to be unsure or unable gave comfort to many and courage to others. In our classroom, it was okay to try. It was okay to be incorrect. It was okay to admit you needed help. These ideas were reflected in the post-interviews when asked, What do you do when you do not know where to begin? Justin said, "What do I do? Well...first of all I don't panic. I try to do all the things I can think of and if that doesn't work, I can ask for help". April thought, "Sometimes I just really think about it hard, and if that doesn't work, I'll ask a friend for help. (How does a friend help?) Because sometimes they can tell me a different way of looking at it". Polly answered the question this way,

> Sometimes I just know the answer just because I know it, just because sometimes it's pretty easy. Sometimes all I do is just try to do the same thing that I did before...(Interviewer: What strategies do you use if you don't know what to do?) I go ask a friend sometimes, and if my friend doesn't know then sometimes I ask the teacher. And sometimes I just try and figure it out...I keep trying.

The ability to persevere and to see ambiguity as necessary for learning are key elements in the growth of personal creativity in mathematics. Students must first believe they are able and accept that the task may take them time and effort to complete.

Creativity

Another attitude of the learner profile (IBO, 2006) is creativity (see Appendix G). When we first broached the subject of creativity, students could only relate to it in terms of the arts. As with our conversations about perseverance, I attempted to build on what students already believed about creativity in order to expand their personal definitions to include other subjects. During an art lesson, I asked students to reflect upon what was happening in their brains as they tried to incorporate the new technique we were working on, which was a perspective drawing of the hallway. In the ensuing discussion, students commented that their brains were working hard, trying to make their eyes see the hallway differently. During a writing lesson, comments about creativity included thinking about new ideas for stories, using new words or trying to figure out how to spell unfamiliar words using the known sounds. Again, creativity in mathematics was met with dead air.

As we began to investigate these seemingly disparate ideas about creativity, *small c* creativity was already in action! Unlike our discussion with perseverance, I did not post a definition of creativity in the classroom. I let the idea *stew*, in part because I did not want to unduly influence the data for this thesis.

The understanding of creativity, as creating one's own understanding of an idea, grew out of our conversations surrounding metacognition, or what was happening in our brains as we tried to make sense of a problem. These dialogues, centered on sharing personal strategies, helped students make conclusions about their understanding of the mathematics and allowed them to consider other ways of doing the math. Chapin, O'Connor and Canavan-Anderson (2009) suggest, "Unless we are put in a situation where we *must* talk or write about the concept, we may never come to realize that our knowledge is incomplete, shallow, or passive" (p. 7).

When the students first began discussing their ideas, they were not able to articulate how their ideas were changing as a result of our discussions. There were physical manifestations of creativity: nodding heads, smiles, widening eyes, and indrawn breaths, which preceded a declaration of "Oh! I get it!" However, they were not yet able to talk about what these physical changes meant for changes in their thinking. They were not yet able to *name* the idea. I could see their creativity in their faces, but needed to shed some light on what this meant for their learning.

This opportunity arose when the class was debriefing our problem of the day, which was to discover how many days it would take us to get to 1000 points if we collected 25 points each day. As with any problem, students had time to work independently and then with a partner in order to arrive at their solutions, in a *Think-Pair-Share.* After students had shared their reasoning, I asked them how working with a partner helped make sure their thinking was on a good path.

Sam: It helped me because I was stuck. My partner had a good idea, so I did what he did.

James: You talk so you can figure out the answer faster.

Mme: How did explaining what you did help you understand what you were thinking, or have an ah-ha?

James: I don't know. What's an ah-ha?

April: It's when you go "Oh! I get it!"

James: Oh! That happens when you are working hard.

Valerie: You just had one.

James: What?

Valerie: An ah-ha moment. You just figured out something you didn't know before.

James: Oh yeah, I did.

James, and indeed every student, was already creating his own knowledge about the mathematical concepts he encountered, but he did not recognize it as creativity. Once the students were able to recognize the physical manifestations of an ah-ha moment, they were better able to discuss what had caused a change in their thinking. They now had the words, based on their experience, to discuss how they were creative in mathematics.

The habits of *persistence* (Costa, 2008) and recognizing *small c* creativity (Sawyer, 2006) were important steps for students to begin seeing themselves as competent mathematicians. It also put us on a path to building what would define our learning culture for mathematics. My students were beginning to understand that it was acceptable 'not to know', but that they could not let this place of unknowing be the end of the journey. "I don't get this!" was replaced by "It's okay to not get this yet, isn't it," as students developed the belief they would get there eventually and that there was no time limit, they could keep trying until they found the key to "unlock the brain block".

Vocabulary and Concept Development in French Immersion

Ah-ha #4: *Ensure vocabulary development is scaffolded in multiple ways.*

I have noticed there is a real lack of math vocabulary—words like 'trier' (sort),
'régularité' (pattern), words that would have been introduced to them in grade one.
This is part of the challenge—getting them to engage purposefully
with the materials and at the same time use the vocabulary.
(Reflection, January)

Our limited vocabulary is causing many stumbling blocks.
(Reflection, April)

Am hearing more and more ideas expressed in French. Youpi!
(Reflection, May)

In an immersion classroom the target language is taught by engaging students in the development of concepts and content, not by focusing solely on the syntax and semantics of the language. French Immersion students (FISs) learn the mathematical concepts while learning the vocabulary and structures needed to discuss them. As with English Language Learners (ELLs), FISs face unique challenges when learning mathematics, especially those related to vocabulary development and making sense of word problems (Bresser, Melanese & Sphar, 2009).

Another challenge with FISs, is to convince them to use the target language while engaged in discussion or activities. This cohort of learners has a habit: they translate for one another from French into English, in the mistaken belief that this translation assists their peers. As Alford and Niño (2011) point out, "If students are in a situation in which translation is readily available and they are provided translation at will, students become conditioned to expect the translation" (p. 45). Their propensity to translate for one another had an impact on their ability to discuss mathematics in French, because they had not forced themselves to create connections between the concept and the words needed to discuss it. Breaking this habit proved to be very difficult and remains a work in progress.

Bresser, Melanese, and Sphar (2009) state, "When learning a learner is carrying out all of this cognitive work in a second language, limitations in language can lead to limitations in learning" (p. 1). The lack of vocabulary had an impact on the ability of the class to engage in purposeful discussion about the insights they were gaining in mathematics. Two protocols in particular were somewhat frustrating: *Think-Pair-Share* and *Spokesperson* (see Appendix B). I observed that when the students thought I was not listening, they would discuss their ideas in English during *Think-Pair-Share*. While this provided me with evidence of understanding of the mathematical concepts, it did little to promote the use of the target language.

To rehearse ideas, we always did a double *Think-Pair-Share* before any *Spokesperson* discussion. A double *Think-Pair-Share* involves two students discussing what they have noticed, followed by two pairs, or a quad, of students discussing their ideas. One student, always known in advance and on a rotational basis, would then act as the *Spokesperson* to the group. This rehearsal of ideas is an important step for FISs, not only in the assessment of their ideas about the mathematics, but also in the development of their vocabulary and syntax.

The first attempts at these protocols were less than successful because I assumed they would be able to sustain a conversation about activities with which they had just engaged. The students quickly grew restless waiting for their peers to find the words they needed to express their ideas. Often the student who was sharing would get so caught up in trying to remember how to say something in French that he or she would lose the train of thought. More often than not, these early discussions ended with "*J'ai oublié* (I forget)". The lack of fluency with the language was indeed a stumbling block.

Upon reflection, I realized I needed to put more structured scaffolds in place. The students needed visual support and ideas for a script they could follow. I posted several sentence starters (see Table 3) at the front of the room and in small groups we practised how we might use these sentences to guide discussions with our partners. These visual aids were helpful, but only provided the beginning of the idea. Students still struggled with how to complete these sentences in French.

In order to scaffold further the oral vocabulary development, I adjusted how we used these same sentence starters for journal writing. Before most journal-writing sessions the students engaged in a *Think-Pair-Share*, as they did for discussions, followed by a large group brainstorm for ideas. Their ideas were listed on the board.

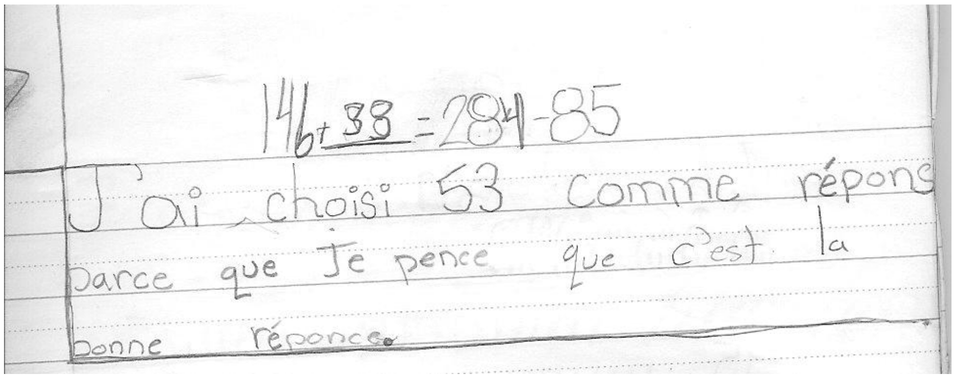
Table 3

Sentence Starters for Discussion

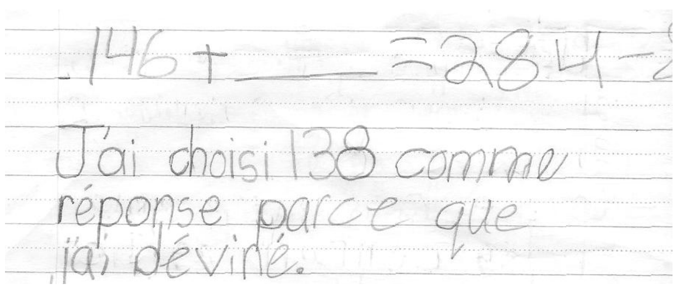
Sentence Starter (as posted in the classroom)	**English Translation (for readers of this paper)**
Je me demande pourquoi...	I wonder why...
Voici comment j'ai trouvé une solution.	This is how I found a solution.
Premièrement...Ensuite...Finalement...	First...Next...Finally...
J'ai remarqué...	I noticed...
Je sais que..	I know...
Je suis confus(e)...	I am confused about...
Je suis d'accord avec...parce que...	I agree with...because...
Je ne suis pas d'accord avec...parce que...	I do not agree with...because...
C'est important à savoir que...	It is important to know...

This appears to be a good strategy for vocabulary development. The students would give their ideas, using the limited structures and vocabulary in their repertoire and I was able to provide the specific mathematical language and proper sentence structures to follow the prompts. This *revoicing* (Chapin, O'Connor, & Canavan-Anderson, 2009), both oral and in written form, allowed students to hear the idea in the target language and also provided them with more processing time for the mathematical concepts. In my restating of their thoughts, students were also able to clarify if needed.

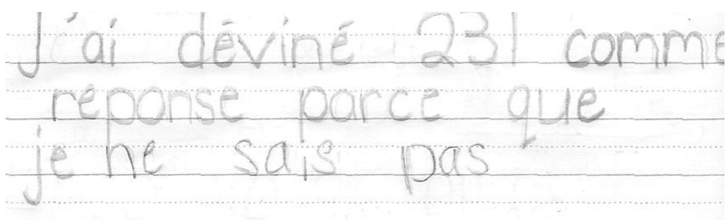
Students could then choose a beginning and end for their sentence that would adequately express the ideas they had shared during the *Think-Pair-Share*. The students did not write very often in their journals, as the focus of much of our mathematics time was on discovery and discussion. However, the use of these strategies, *Think-Pair-Share* and recording our *Brainstorms* on the board, appear to have given students more confidence to write about their learning. Figure 9 gives examples of early journal writing. The explanations are simplistic and use basic, well-known vocabulary. While the students were expressing their own ideas, they were reliant upon the words on the board to write their sentences.



I chose 53 as my answer because I think it is the right one.



I chose 138 as my answer because I guessed.



I guessed 231 as my answer because I don't know.

Figure 9. Early examples of journal vocabulary.

There was a marked improvement in their ability to talk and write about the mathematics they were encountering as we continued to use these sentence prompts for both discussions and journal writing. Their responses were longer and invented spellings began to appear. I took this evidence to mean the students were less reliant upon the board because they had gained confidence in their abilities to express their thoughts in French. Figure 10 shows how invented spellings are now incorporated into the students' reflections.

Final Thoughts About Creativity in Mathematics

Thinking about how their knowledge was changing in mathematics became part of the routine reflections conducted in the classroom, both oral and written. Students became aware of the process of creating new knowledge by examining what helped them muddle through a problem, which strategies were useful and made sense, and by listening to their peers explain how they had attacked a problem differently. They became more aware of the signs of creativity and were excited to share these moments when they occurred.

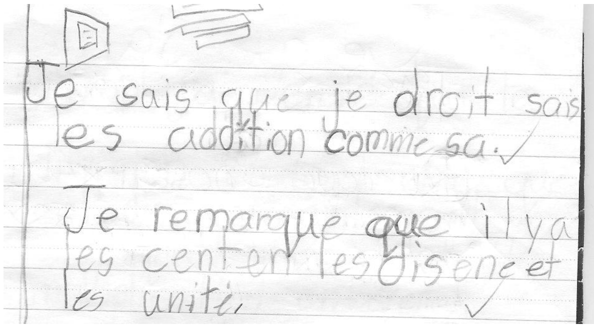
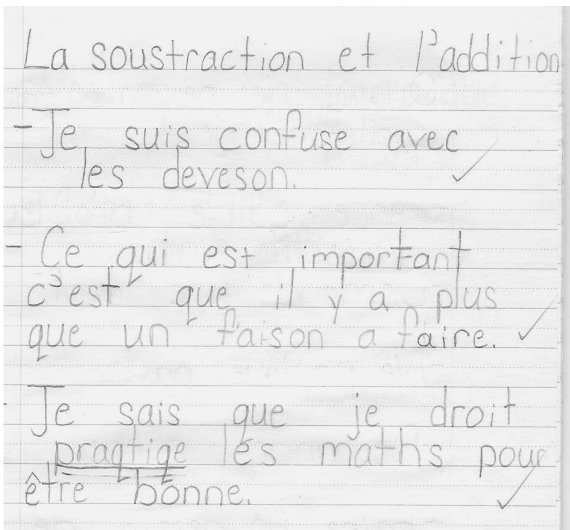
Student Sample	Grammatically correct version and translation
	Je sais que je *dois* savoir les additions comme *ça*. *(I know I need to know my addition facts.)* Je remarque qu'il y a les *centaine*s, les *dizaine*s et les unités. *(I notice there are hundreds, tens and ones.)*
	Subtraction and Addition Je suis confuse avec la *division*. *(I am confused about division.)* Ce qui est important c'est qu'il y a plus qu'une *façon de* faire [les maths]. *(What is important is that there is more than one way to do something.)* Je sais que je *dois pratiquer* les maths *afin d'*être bonne [en maths]. *(I know I need to practise to be good at math.)*

Figure 10. Evidence of growth in vocabulary development.

In June, they expressed their views about creativity this way:

- Creativity is when like you don't get something and then you find out what it is.
- When you don't know what it is before and then when someone explains it to you...you get it. They don't give you the answers. They just help you think about it.
- Creativity is when you know you have to do something but sometimes in your head it will show you different pictures, or something like that.

- It's when your brain thinks. How your brain thinks differently from anyone else's and that everyone has a different way of doing things.
- I'm creative in math when I find a way to do math that makes sense to me.
- I'm creative in math when I learn new things.

These may seem like simplistic definitions of creativity, but they mark a beginning understanding of *self-as-learner*. Students must be able to identify how they make connections as well as the connections they are making. This is important in the study of mathematics. If students are to deepen conceptual knowledge or uncover misconceptions and overwrite them, they must first be able to indicate what has led them to their ideas and be able to identify how these ideas are changing.

Chapter Five: Conclusions

It's really important as a learner that you know what is going on in your head,

so you can tell someone else how you figured something out.

(Michael, beginning of June)

This research sought to address several questions.

What Does Mathematical Creativity Look Like?

Will I Recognize It In My Students?

Creativity has a distinct look and teachers must be alert to its manifestation. Noticeable physical manifestations occur when the brain is struggling to make connections or to understand something new: a furrowed brow, pursed lips, crinkled nose. These are all signs of deep thinking, confusion or dissonance. The brain is trying to reconcile what it knows with what it is learning. When a connection or discovery is made, the eyes brighten and widen, the frown disappears, and there may be a declaration of some sort, usually an "oh!" or "I get it!"

It is important teachers recognize these signs of thinking, for they are indicators of a delicate time in the learning process: too little time spent in this thinking mode and students may not make the connections for themselves. Too much time and they may reach a point of frustration, which can shut down the brain, and, thus connection-making impossible. It is equally important to recognize at which point a question or comment will help a student find the key that unlocks the brain brake. The timing is key.

Students must also be aware of how they react physically to dissonance in their learning and understand that these reactions are necessary, not signs they are incompetent. The addition of the word "yet" to the statement, "I don't know" marks a crucial breakthrough for students who feel challenged by mathematics. "Yet" is a sign of commitment and belief. When students believe it is acceptable not to know and that they will eventually figure something out, they are much more likely to persevere.

This understanding of *self-as-learner* was perhaps a more important discovery for those students for whom mathematics comes more easily. Students who perceive themselves as "good math students" are often the first ones to give up when confronted with the chance of failure. Their ability to see ambiguity as "a feeling of uncertainty [that] encourages us to wonder and question, to move beyond current understanding to pursue new possibilities" (Short, 2009, p. 12) was significant. They began to move beyond the idea that speed equals ability and toward the realization that process is more important than product.

What Structures and Strategies Promote Mathematical Creativity?

The idea for this research began with the premise that strategies used in other curricular areas would be equally powerful within the realm of mathematics. The data does not point to the advantageous use of one strategy over another. Rather, I would suggest it is the combined use of several strategies, which had an impact on the growth of creativity in mathematics for my students. With any strategy used in a classroom, it must be appropriate for the group of learners who will be using it. I discovered that the two talking protocols were more effective as learning tools for this particular cohort of learners. That is not to say that the writing protocols do not have merit; only that they were not as effective as they might have been.

Double Entry Journals

This protocol required careful modeling and time to practise. It was introduced near the end of the school year, which I believe limited its power as a metacognitive tool. In my opinion, it was not used often enough for students to truly benefit from its potential. The limited use was due, in part, to my students' facility with the French language, which I felt was better served through discussion rather than writing.

If I had the luxury to turn back to the beginning of the year, I might have introduced this protocol in language arts or social studies so that students would be familiar with it before using it in mathematics. I still believe double entry journals might be a powerful learning tool for mathematics, but cannot definitively say it had a significant impact on the growth of mathematical creativity.

Quick Writes

Quick Writes were only slightly more successful as a way to assess how students were creating their mathematical knowledge. This protocol was familiar to the students, as we used it in both English and French language arts. However, this very fact impacted its effectiveness. Students had difficulty shifting between writing a story, which was part of this protocol in language arts, and writing about what they know regarding a mathematical concept. Perhaps, a different name was needed.

Again, I still contend this might have potential as a strategy for the development of concepts. However, I would structure this protocol differently. I would use it more as an expanding list of ideas and understandings, where students would add or amend their ideas in different coloured pencils as their knowledge and experience deepened. This would create a visual representation of how thinking was changing and allow students to be able to reflect more effectively upon how they construct mathematical knowledge.

Think-Pair-Share

This protocol had the biggest impact on the construction of mathematical knowledge and on the students' ability to engage in purposeful discussion. It also allowed students to gain confidence speaking their second language. Chapin, O'Connor and Canavan-Anderson (2009) suggest, "The mathematical thinking of many students is aided by hearing what their peers are thinking. Putting thoughts into words pushes students to clarify their thinking" (p. 5). As students struggled to make themselves understood, they began to recognize how important word choice was in the reception of their ideas.

The opportunity to practise with a friend created a safe environment in which to test their suppositions. Students, while supportive of each other's efforts, were not afraid to disagree with one another, knowing it was important to voice all ideas. They did not arrive at this place immediately. Students needed to see the protocol modeled in many different ways. As their confidence in their mathematical abilities grew, so did their ability to discuss purposefully what they had come to know. Patience and perseverance are key to the development of this strategy as an effective tool.

Spokesperson

The *Spokesperson* protocol is an extension of *Think-Pair-Share*. This was one of the students' favourite ways to debrief our mathematics sessions. This protocol was especially effective as a review of the mathematical ideas discovered the day before. It allowed students to think back and discuss what they remembered in groups of four.

Often a comment by one would spark a thought in another. The spokesperson would then share a summation statement or question that arose from the group.

Wait-time and No Hands Up

The research on *wait-time* is clear, teachers need to give students more time to process the answers to the questions asked in class (Wiliam, 2003). However, students are not used to this idea and can find the silence uncomfortable. I asked my students to hold their thumbs to their chests when they had an answer to a question, instead of raising their hands. I challenged the fast processers (the auditory learners) to try to think of other possibilities, as they waited for those who needed a longer processing time (the kinesthetic learners). This was very challenging, as habits are hard to break and group patterns are set early in schooling, especially with a group who has been together for three years.

Students have been acculturated to raise their hands when they had a thought to share. Those who can think of an answer more quickly are usually the talkers in a classroom. They are used to being the ones chosen to share their ideas. Those who take longer to process soon learn that their "faster" peers will provide the answers, and that they do not really need to put much effort into thinking during discussion. At first students found it frustrating when I did not choose those who had the answers quickly. Part of their self-identity appears to hinge on being able to answer before anyone else. Those who were used to taking a backseat during discussions were discomfited if they were asked to share first. Even when I explained the reasoning behind the wait-time, some students struggled to accept this idea. It was important to remind students on a regular basis why waiting was important for everyone in the classroom.

Wait-time is also an effective teaching tool when looking for evidence of creativity. While students are formulating their ideas, their creativity is literally written on their faces. Learning to read their faces and body language was important when it came time to solicit an answer. I knew if Valerie's head was tilted to the side and she was frowning, she did not fully understand the question. James would have his thumb up, almost before the question was asked, but if his eyes were darting around the classroom, I knew he was not sure his idea had merit and I needed to make sure I asked someone else first.

It can be concluded that the presence of dialogue and discussion in mathematics is, perhaps, the most crucial element in the construction of knowledge. At least, it was for this cohort of learners. Hearing peers share examples can be the spark that helps everything fall into place.

Can Mathematical Creativity Be Discussed By 8-Year Olds?

Yes, it can.

It is easy to recognize a learner who is creating connections by learning to read faces and body language. However, students must experience the language of creativity and develop an understanding of how creativity manifests itself if they are to effectively communicate how and when they are mathematically creative. Once students began to recognize an ah-ha moment as proof of real learning, they were able to talk about what might have helped them reorganize ideas in order to arrive at a moment of clarity.

Eight and nine-year old French Immersion students struggle to express these deep thoughts, not because the thoughts are non-existent, but due to a lack of facility with the target language. Therefore, it is important to find other ways in which they can express and capture their mathematical creativity.

The use of physical models and graphic representations allows students to express their ideas when their vocabulary is lacking. Allowing students to discuss their work in small groups in their native tongue, before sharing in the target language, is another way in which children can begin to create their understanding. Second language learners cannot discuss a concept in the target language for which they have little or no understanding in their first language.

Other Discoveries

The discoveries made as a result of this research are not necessarily new. They are things I knew were important at the outset. What makes these discoveries unique is the new perspective from which I now view them. As Marcel Proust (1923) suggests, "The voyage of discovery lies not in seeking new landscapes, rather seeing old one with new eyes".

A Culture of Unknowing

The culture of the classroom also played a significant role in our journey to discovering how we were mathematically creative. The growth of a culture in which it is acceptable to be wrong, or hold misconceptions is crucially important in mathematics. Students must feel safe and trust that in sharing their ideas they are not opening themselves up to ridicule. They must be comfortable with not knowing, even when those around them seem to understand a concept more adroitly, or on a deeper level.

At the beginning of the year, this cohort of learners was reluctant to take risks, especially when it came to mathematics. They sought confirmation of their ideas and were loath to commit anything to paper. It was not until they began to believe I really wanted to see *how* they got the answers, and was seemingly disinterested in the answers themselves that the culture in the classroom started to shift. It was very satisfying at the end of the year to hear students stating, "It's okay if I don't know this yet, isn't it Madame". The attitude about struggle with mathematics was beginning to change.

Planning for Creativity

We have to plan for creativity. This might appear to be an oxymoron, but without careful planning for inquiry, which includes big ideas, essential questions, the sequence of learning, and an assessment plan, students might not construct lasting memories of the learning. Without attending to the *what, why,* and *how* of the learning prior to engaging students, we risk leaving our students with disconnected, flashes of partial images, rather than a coherent, detailed picture.

We must also attend to students' background knowledge. When students can recall activities or learning from earlier in their schooling, which does not necessarily mean in the distant past, they have made a significant connection to that particular piece of learning. They are tethered to the idea. They can follow the thread back and begin to examine the idea with new information. Insight into the students' background experiences, both in and out of school, is important, if we are to plan for creativity.

Attending to my students' background knowledge became important when I introduced the concept of fractions. When initially planning for the development of this concept, I did not take into consideration how their experiences might impact their ability to make connections. This had the potential to be a big mistake. However, because I knew my students as I did, I was able to recognize the lack of connection to the material.

Without this awareness I might not have realized I was trying to go too quickly and that my "planned" method of instruction was not working. We did return to the mini-lesson using double-sided algebra tiles, with much greater comprehension, but first I needed to build in background experience for them.

I also needed to build my own understanding of each child as a whole person, not just a grade three student. In observing students' behaviours as they struggled to make sense of the math, I realized this awareness of their experiences made it easier for me to intervene appropriately with a question, a comment, or a clue. I knew which students had baked with mom or grandma, who had helped dad build something, who played an instrument and could read music, and for whom I would need to build in more experiential learning. I knew whom I could cajole and for whom a different approach was necessary. In essence, it made it easier for me to plan for success. Being reminded of experiences from outside of school, as they related to the learning in school, allowed students to strengthen the tether to the idea of fractions. They now have different experiences from which to draw when the concept re-emerges in grade four. Thus, relationship between student and teacher is key.

Further Inquiry

I am fortunate to have moved to grade four with my cohort of students. We are able to continue investigating how we create our understanding of mathematics through inquiry, discussion, and reflection. I will be able to extend the ideas and strategies discussed in this thesis and introduce others I am discovering as I continue to read and reflect on the topic of creativity in mathematics.

Conclusion

Did I discover how to reawaken wonder in my students? One student summed it up nicely, "I like math now. It can be lots of fun. It can be really hard, but when it is fun I don't mind working hard". Belief in self is powerful. When students begin to believe they can *do the math*, they begin to relish the challenge of the unknown, rather than fear it. I can say there was an increase in confidence, which led to greater perseverance and success. Students asked for less assistance. They appeared to know where to begin and which tools would best assist them. This confidence appears to be the key to rediscovering the wonder of mathematics.

Creativity also requires careful planning on the part of the teacher. This type of planning does not take place without profound understanding of who the learners are and how they react in a given situation. Therefore, creativity in elementary mathematics is also about relationship.

This relationship grows as students learn to trust the culture of the unknown, where it is acceptable to make mistakes or to *not yet* know. They must feel comfortable with this ambiguity. Also, the students need to develop strategies for getting past this uncomfortable place to a one where they begin to see connections between what they knew and what they are coming to know.

Students must develop the attitude that they are in control of their mathematical learning; they are the creators of this knowledge and skill. When a concept does not make sense, they must continue to ask questions and discuss their ideas with their peers. Most importantly, the strategies they choose must make sense to them. It is important they have the necessary vocabulary to discuss and justify their choices, strategies, and understanding.

Creativity is a very complex idea. This does not mean it is inaccessible to young learners.

One Last Story

The other day I was speaking with my friend on the phone. Tommy, her four-year old son, was in the midst of negotiating how much supper he had to consume. With some exasperation, Michelle exclaimed, "You have to eat five bites." Tommy thought for a few seconds and rejoined, "Okay. Then I have to eat three bites."

"No," replied mom, "You have to eat five bites."

"But I've already eaten two. So that means three, four, five--three more bites makes five, mom!" Tommy insisted with equal exasperation. This utterance was accompanied by little fingers used emphatically to count on from two to make five.

Tommy has already constructed a good sense of number. He can visualize and estimate. He can use manipulatives (his fingers) and he can justify his answers. Michelle has not *formally taught* her son the mathematical concepts of addition, missing addends, or the conservation of number. However, they have engaged in hours of games and songs, which develop number concepts. This play has resulted in Tommy's ability to live mathematically in the world. He does not yet possess the vocabulary to discuss what he knows in mathematical terms, but he does possess concept knowledge.

As he enters kindergarten in the fall, I hope he will keep hold of these ideas as concepts he owns and can continue to play with mathematics in order to create his knowledge and understanding. I hope he experiences mathematics as a wonderful world of discovery, where he can ask questions, make conjectures, experiment, and create.

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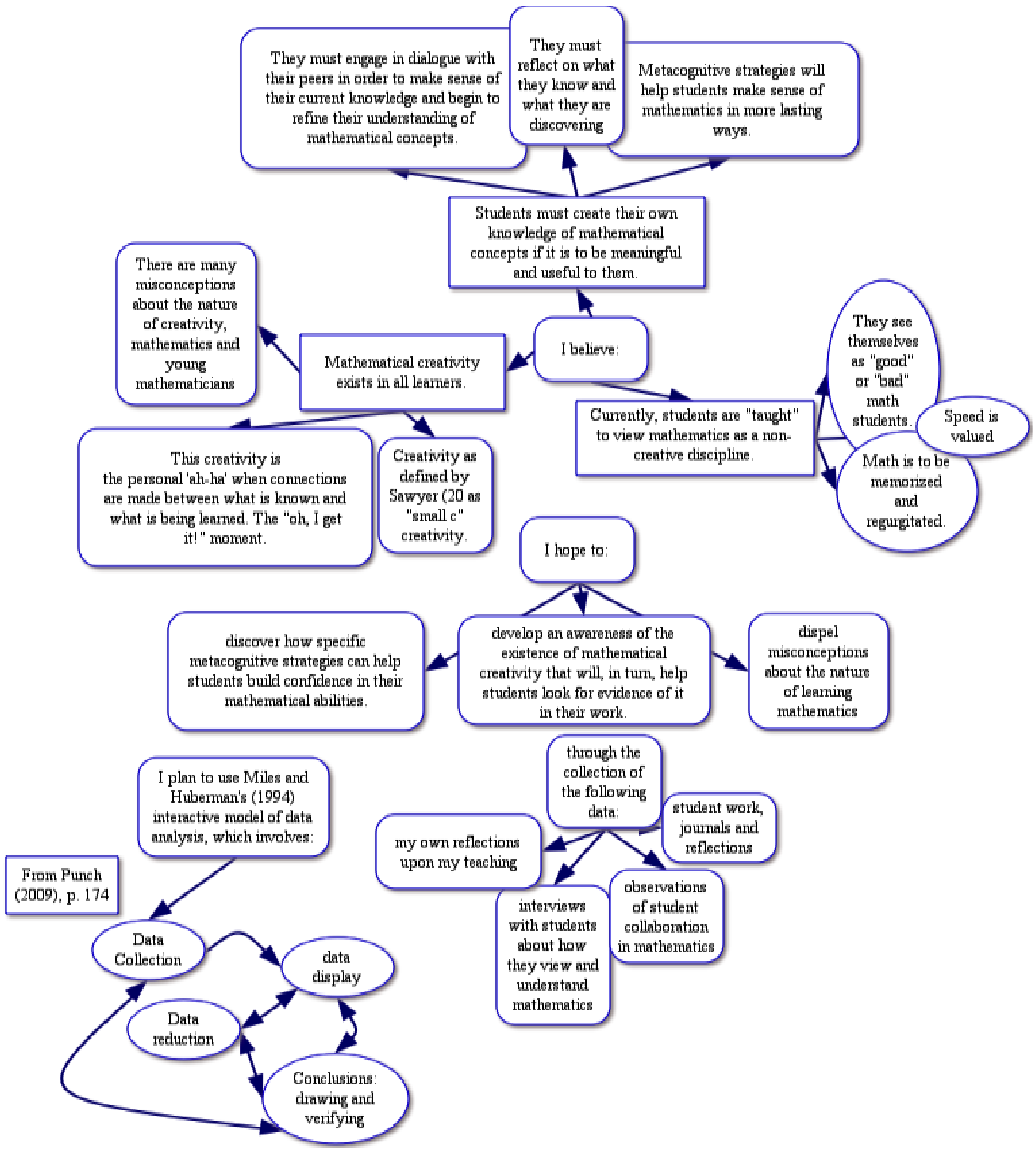
Appendix A

Concept Map of Research Proposal



Appendix B

Explanation of Metacognitive Strategies

These strategies promote higher-order thinking in students. Their use is not limited to mathematics in my classroom, but they will be highlighted in our creation of mathematical skill and knowledge.

Double-Entry Journals ~ Le journal à double pensées

Double entry journals capture the thought process of students as they engage in activities to develop their number sense. The journal pages are split into two columns, each serving a distinct purpose.

1. On the left-hand side of the journal students record their thinking, prior to any discussion by the larger group. This record of thinking is done with a pen in order to preserve the initial ideas of the student.
2. Students engage in discussion about their solutions. This discussion may take place as a pair, triad, quad, or as a whole class. (See Think-Pair-Share)
3. On the right-hand side of the journal students reflect upon their initial thinking after discussion has taken place. Questions they answer might include:
    a. Was my answer reasonable? Why? Why not?
    b. What did I learn from my peers?
    c. What did I help my peers understand?
    d. What will I do differently if asked to solve a similar problem?

Quick-Writes ~ De ma tête au papier

Quick Writes might also be called a 'brain drain'. In a quick write, students engaged in sustained writing about a given topic from a writing stem. The goal is to write as much as they can about the idea during the given time, without lifting their pencils from the paper. Sustained writing is a skill that needs to be developed over time. Students will begin with one minute of sustained writing and increase their stamina to five minutes.

When the writing is complete, students re-read their work and highlight the most thought provoking or interesting ideas. They then engage in a discussion with their peers to further discuss the topic. This strategy can be paired with *Spokesperson* for large group sharing.

Think-Pair-Share ~ Le triple P: penser-parler-partager

Think-pair-share strategies are well known. Students are given a short amount of time, usually a minute, to think how they might answer a question. They then turn to a partner to share their ideas. Together, the pair decides how best to answer the question, based on the discussion. This strategy can also be used as a *Double Think-Pair-Share*, if pairs become quads in order for students to hear the ideas of other pairs. Doubling this strategy works well when ideas will not be shared with the whole group.

Wait-Time and No Hands ~ L'attente et Qui peut répondre

Wait-time is crucial if students are to begin to formulate answers. Research indicates teachers wait less than two seconds between asking the question and soliciting an answer. Research indicates that kinesthetic learners need up to 15 seconds in order to process an oral question (Wiliam, 2003). Students can indicate they have an idea to share by quietly and respectfully giving the thumbs-up signal in front of their torsos. The teacher waits until the majority of students have give the sign and then calls on a random student.

The *No Hands* strategy refers to the manner in which students answer questions during group discussions. Asking students to put their hands up when they are ready to answer gives students an 'opt-out pass' during discussions. Those students who process verbal questions more quickly, or who are more confident, are usually the ones who volunteer an answer. The same students seem to be answering all the questions. Popsicle sticks, upon which student names are written, are placed in a jar. Names are drawn randomly when it is time to answer the question. The sticks can also be used to group students.

Pinball Questioning ~ Le Questionnement en pinball

Pinball Questioning is a strategy used to ensure more than one voice is heard during a question and answer session. In many classrooms, questions are asked in a ping-pong manner, with only two players: the teacher and the student who is answering. In *Pinball Questioning*, the goal is to have as many people involved in the answer as possible. Here is how it works:

1. The teacher, or discussion leader, asks the question.
2. One student answers the question (after sufficient wait-time, of course).
3. A second student is asked if he or she agrees and to add information to the answer.
4. A third student is asked to add to the answer.
5. A fourth student is asked to paraphrase what has been said.
6. A fifth student is asked to add any additional information.
7. A sixth student is asked if the question has been answered sufficiently.
8. A new question is asked.

This Q and A technique not only involves more students in the discussion, it also allows kinesthetic learners more time to process. Because students do not know who will be asked to add to the answer, everyone needs to be prepared.

Spokesperson ~ Le porte-parole

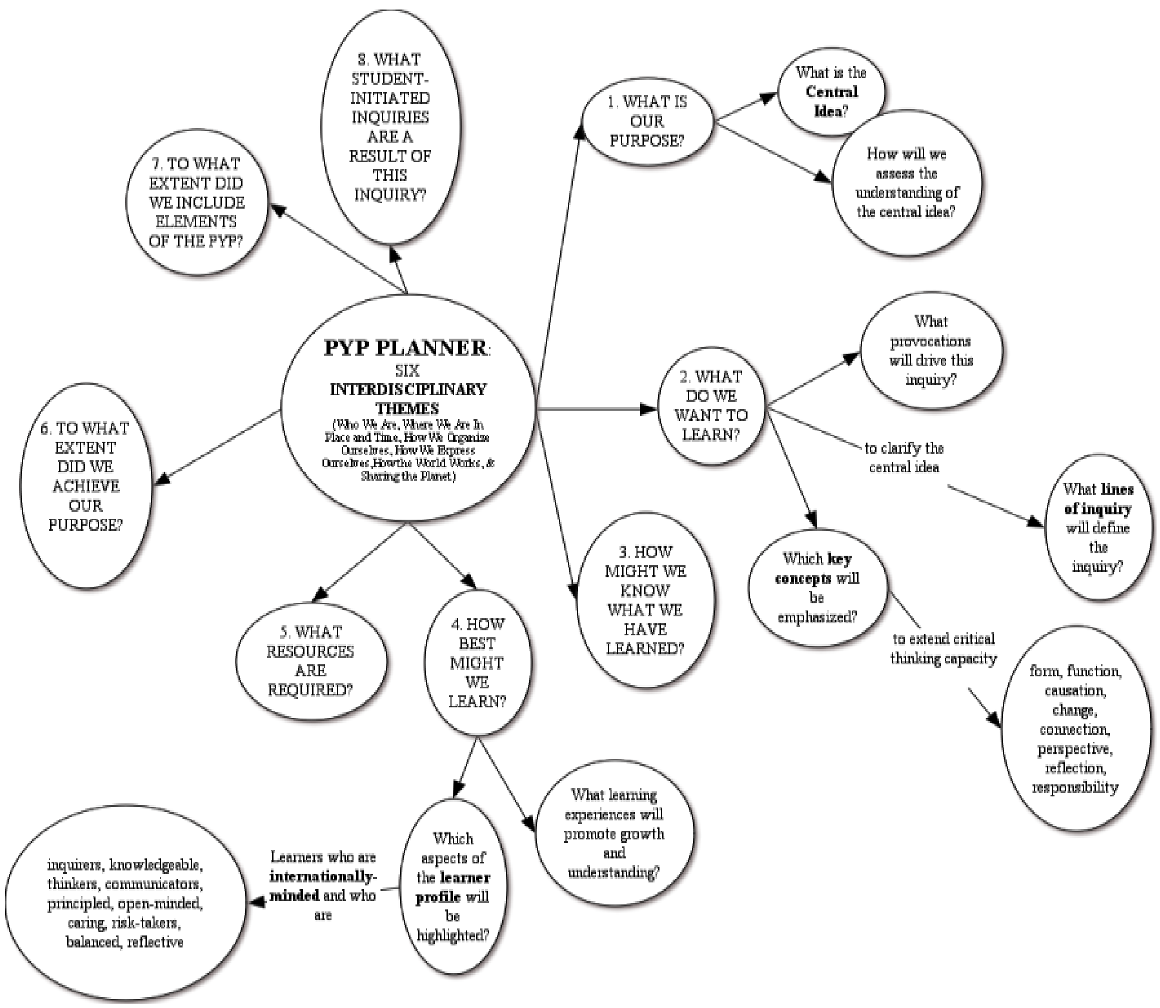
The *Spokesperson* strategy asks students to come to some consensus and/or summarize group discussions. This strategy is excellent when it is necessary to get a quick sense of the thinking of each group. It does not involve mini-presentations, as is sometimes the case when students are asked to share the ideas of their group.

1. The spokesperson is chosen at random before the beginning of a discussion.
2. His or her task is to help summarize the group's ideas in less than five sentences
3. The other members of the group must agree with the statements of the spokesperson before they are shared.
4. A written record of the summary is kept as evidence or for use in further discussions. The spokesperson need not be the recorder of the summary.

Appendix C

The Primary Years Programme Framework for Planning

The PYP framework is the planner used by all teachers who work in an IB-PYP setting. Teachers develop the plan collaboratively. The PYP framework contains aspects of philosophy and methodology.



Adapted from the IBO (2008).

Appendix D

Participant (Child) Consent Form

Your child is being invited to participate in a study entitled Re-Awakening Wonder: Creativity in Elementary Mathematics being conducted by Madame Leslie Waite. Madame Waite is a graduate student in the Faculty of Education at the University of Lethbridge. She can be contacted via e-mail at leslie.waite@uleth.ca or via telephone at 403 285 6969 for further information about this study.

As a graduate student, Madame Waite is required to conduct research as a part of the requirements for a Master's Degree in Education. This research is conducted under the supervision of Dr. Robin Bright. Dr. Bright can be contacted via e-mail at brightr@uleth.ca. Queries may also be made to the Chair of the Human Subjects Research Committee of the University of Lethbridge at 403 329 2425.

The purpose of this study is to examine how learning strategies, such as wondering, experimentation, discussion, and reflection, help students develop their understanding of personal creativity and competence in mathematics, especially number sense. It will also examine how students' growing understanding of their thought process during learning (metacognition) contributes to their ability to think and act creatively in mathematics. The results of this research will be added to the growing Canadian literature about creativity and mathematics.

Research of this type is important for the following reasons:

1. It will contribute to defining creativity in mathematics from the students' perspective.
2. It will contribute to the generation of strategies that foster creativity in young children.
3. It will help students develop their understanding of how they learn and allow them to develop effective learning strategies.

Your child is being asked to participate as he or she is a member of Madame Waite's grade three class, and as such, will be part of the learning episodes used in this study. The study will examine student responses to various teaching techniques, as well as examine how students think and act creatively during problem solving activities in mathematics.

Data will be collected using student work samples, group discussions, and interviews with students. Students to be interviewed will be selected randomly and will be interviewed by someone other than Mme Waite. Discussion and interviews will be recorded using a digital recording device. All recordings and other digital artifacts will be password protected. Pseudonyms will be used for all participants. The pseudonyms will be known only to Madame Waite and will not be disclosed at any time. All data collected will remain confidential in relation to particular participants. Data, both paper and digital, will remain in Madame Waite's possession for five (5) years, at which time it will be destroyed.

Your child's participation in this research project is voluntary. You may withdraw your child from this research at any time without explanation or consequences. Withdrawal from this study will not impact your child's academic achievement in any way. Should your child withdraw, any existing data will only be used with your signed consent. There are no known or anticipated risks to your child by participating in this research.

The results of this study will be used as part of a thesis to be submitted to the School of Graduate Studies at the University of Lethbridge. A copy of the completed thesis will be housed in the University of Lethbridge library. The insights gained from this study may also be used in public presentations and articles for educational journals and publications.

Should you wish to verify the ethical approval of this study, or to ask questions, please contact the Chair of the Faculty of Education Human Subjects Research Committee at the University of Lethbridge at 403-329-2425.

Your signature below indicates you understand the condition of participation for this study and that you consent to your child's participation in this study.

______________________	______________________	______________
Full Name of Student	*Student Signature*	*Date*
______________________	______________________	______________
Name of Parent or Guardian	*Signature*	*Date*

A copy of this consent will be given to Parents or Guardians.

Appendix E

Interview Questions

Questions have been adapted from the work of Marian Small, John Van de Walle, Marilyn Burns, Anne Davies and the Alberta Assessment Consortium

1. What is most important to know or do in mathematics?
   (Qu'est-ce qui est le plus important à savoir ou à faire en mathématiques?)

2. What is creativity?
   (Qu'est-ce que c'est la créativité?)

3. How are you creative at school?
   (Comment es-tu créatif/créative à l'école?)

4. What do mathematician do? How are you a mathematician?
   (Que font les mathématiciens? Comment es-tu un/une mathématicien/ mathématicienne?)

5. How many ways can you solve a number problem? For example 23 + 18.
   (Combien de façons différentes peux-tu résoudre une équation numérique? Par exemple: 23 +18.)

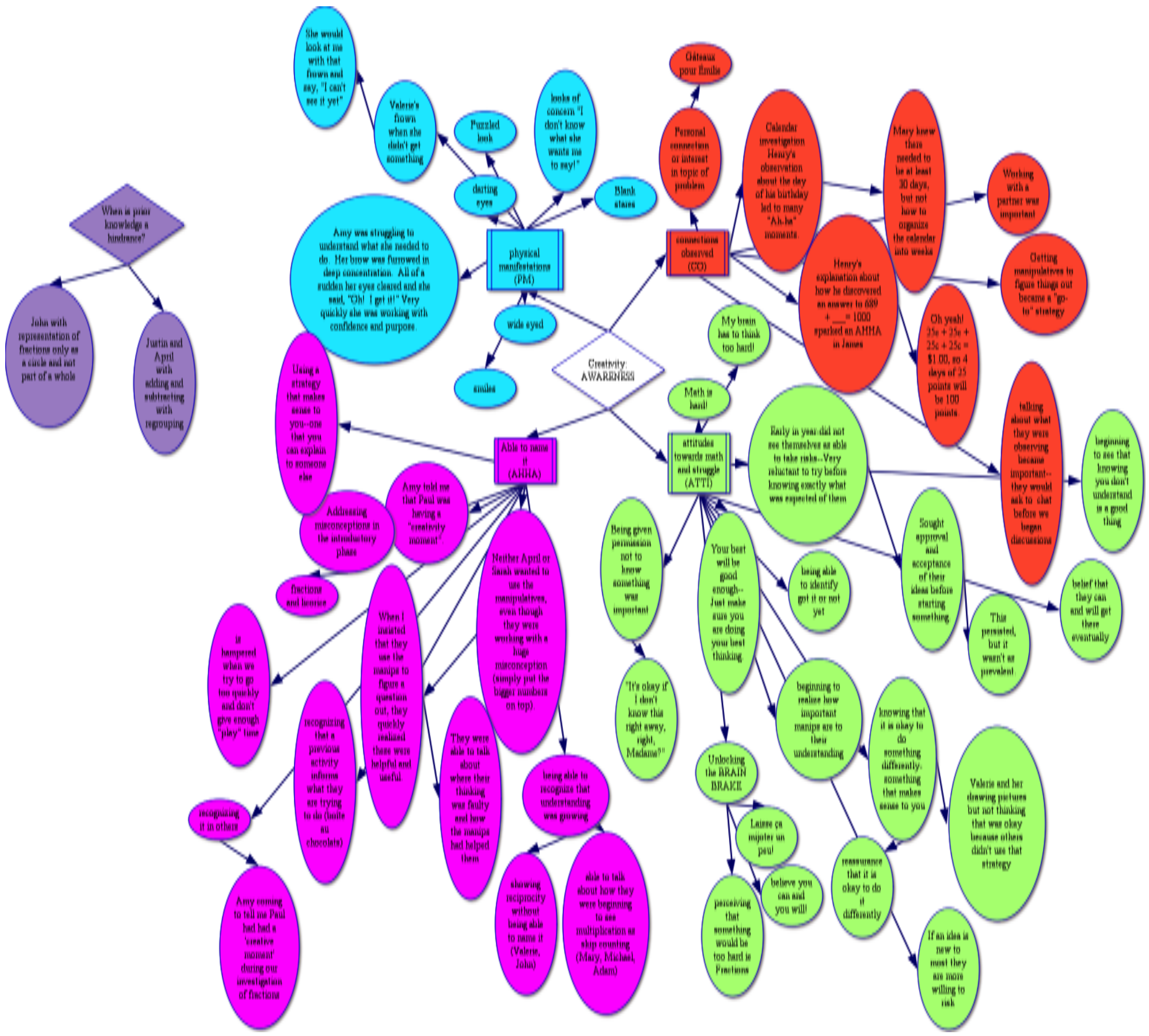
6. What strategies help you solve number problems?
   (Quelles sont les stratégies qui t'aident à résoudre des équations numériques?)

7. What do you do when you don't know where to begin to solve a math problem?
   (Que fais-tu quand tu ne sais pas par où commencer pour résoudre un problème en mathématiques?)

8. What are you wondering about in mathematics?
   (Quelles sont tes questions envers les mathématiques?)

Appendix F

Axial Coding Map



Appendix G

The Primary Years Programme Learner Attributes and Attitudes

<table>
<tr><th>Attitudes
Learners Are</th><th>Attributes
Learners Act With</th></tr>
<tr><td>INQUIRERS: They want to know. They develop the skills necessary to find answers to their questions.</td><td rowspan="10">APPRECIATION: They value the learning experiences they encounter.
COMMITMENT: They realize they have an obligation to do their best in all they undertake.
CONFIDENCE: They believe in their own capabilities and trust that these will continue to grow.
COOPERATION: They understand that learning requires a degree of collaboration and are willing to work with others to achieve their goals.
CREATIVITY: They use imagination, resourcefulness, and ingenuity to make the most of their learning.
CURIOSITY: They are inquisitive and ask questions, which move their learning forward.
EMPATHY: They are able to consider the perspectives of others.
ENTHUSIASM: They are passionate, keen learners.
INDEPENDENCE: They are able to self-regulate their learning.
INTEGRITY: They are honest and reliable.
RESPECT: They value the opinions and ideas of others.
TOLERANCE: They accept there may be ambiguity and a lack of clarity in their learning., or when dealing with others. They know they must be perseverant and patient.</td></tr>
<tr><td>KNOWLEDGEABLE: They have a base of background knowledge, which helps them in the inquiry. They are continually adding to this body of knowledge.</td></tr>
<tr><td>THINKERS: They are able to think critically and creatively. They make reasoned decisions.</td></tr>
<tr><td>COMMUNICATORS: They are able to share ideas in a variety of ways.</td></tr>
<tr><td>PRINCIPLED: They are honest and take responsibility for their actions.</td></tr>
<tr><td>OPEN-MINDED: They appreciate other perspectives. They can evaluate and change their own ideas based on what they experience.</td></tr>
<tr><td>CARING: They seek to help others and are respectful of others needs and strengths.</td></tr>
<tr><td>RISK-TAKERS: They know that in order to learn, they must work outside their comfort zone.</td></tr>
<tr><td>BALANCED: They seek to achieve personal well-being by focusing on all aspect of their lives: emotional, physical and intellectual.</td></tr>
<tr><td>REFLECTIVE: They are able to articulate their areas of strength and areas of need. They understand under which circumstances they work best.</td></tr>
</table>

*Adapted from the International Baccalaureate Organization, 2006.