Lego Mindstorms and Critical Thinking Skills in the Elementary Classroom

by

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Thesis

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Abstract

This 12 week qualitative, action research, study examined the impact on grade four students' ability to use critical thinking skills when manipulating the Lego Mindstorms robotic kit in a classroom environment. In collaborative groups of 3, participants programmed and built robots to solve open-ended challenges.

Participants completed a self-assessment rubric on their critical thinking ability to provide a benchmark prior to the beginning of the study. Data was collected for 3 cycles of research using field notes, self-reflection questions, semi-structured interviews and self-assessment rubrics. The data was analyzed using thematic analysis.

The study provides some evidence that Lego Mindstorms supports elementary aged children in their ability to think critically by leveraging collaborative group work, employment of multiple problem solving strategies and reflection.

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Chapter 1

"…society expects more of its new generations than mere imitation: it expects enrichment." (Jean Piaget, 1971 p. 138)

Introduction

Critical thinking is the cognitive process of evaluating and analyzing data (Facione, 2006; Jonassen, 1996). The theory of critical thinking has been researched, discussed and analyzed for over 200 years. Even today, defining critical thinking remains a challenge (Bissell and Lemons, 2006). Chapter 2 identifies definitions for critical thinking and examines why higher level thinking skills are important to express in society.

Over the last forty years critical thinking and its elements have been endorsed as key learning outcomes by education systems throughout North America (Carr, 1990, p. 1). The education system plays a large role in ensuring students become good critical thinkers. Typically, educators have addressed critical thinking skills in the past by questioning students based on levels from Bloom's Taxonomy (Forehand, 2005), by posing open-ended problems and by having student's complete tasks in collaborative groups. While the research shows that it is possible to engage children at higher levels of reasoning through these methods, the action research project described, herein, considers a new way to engage critical thinking skills in elementary school children with specific uses of technology.

The purpose of this research study is to investigate how an interactive "digital manipulative" (Hussain, Lindh & Shukur, 2006, p. 191), known as Lego Mindstorms, impacts students' abilities to think critically while solving open-ended problems (called 'challenges' during this investigation) in a grade four classroom. Action research was the methodology used because of its participative, introspective nature that supports flexibility in the application of the variables. Action research is a tool suited for use in an elementary school classroom and accommodates the dual role of the teacher-researcher. Action research provided the framework for an in-depth investigation into critical thinking and the application of it in the elementary classroom.

By introducing open-ended problems based in the subject areas of math and science, the learners used Lego Mindstorms to attempt to resolve various challenges. The educational benefits of Mindstorms include the ability to support a range of learning styles and abilities and the opportunity for students to develop problem solving solutions.

Lego Mindstorms NXT is a computer programming package utilizing Lego "bricks" and is an example of new technology that can be integrated into the elementary school classroom. It combines traditional Lego building bricks with a 32-bit microprocessor (called the NXT) that has touch, sound, sight and audio sensors. Users can create robots from Lego bricks and program the robots to complete tasks as dictated by a computer program.

The Lego Company recently celebrated its 50th anniversary and, because of the enduring popularity of this product, many students have building experience with Lego bricks. Mindstorms (in various forms) has been available to educational institutions for approximately 10 years and has been integrated into science and math curriculums in some schools across North America.

Seymour Papert (who was a protégée of Jean Piaget) was one of the first educators to link computers and learning. His vision of a simple computer language (called LOGO) based on mathematics, embraced constructivist learning theory. Papert worked in conjunction with MIT and the Lego Company to create the Mindstorms product (Papert, n.d.). The name 'Mindstorms' comes from the book of the same name, *Mindstorms: Children, Computers, and Powerful Ideas* (1980) by Seymour Papert.

Constructivist learning theory was the framework for this research because constructivism supports the use of technology in a classroom environment. Constructivism is the process of accommodation and assimilation, whereby learners construct new knowledge from their past experiences (Epstein, 2002; Jonassen, 1996). In a constructivist learning environment, students are not the passive recipients of knowledge from their teacher. Rather, learners participate in hands-on building 'experiences' that allow them to assimilate new expertise into their existing knowledge framework. They adjust their thinking when these new experiences do not fit into their pre-existing thought structure.

We live in the Information Age (or the Digital Age), and we have access to more data than at any other time in history. This information revolution is primarily a result of access to new technology related products such as networks, computers and communication devices. This access has created the perceived need for constant, instantaneous communication and feedback. Our society is in a state of "always on" with a focus to acquire the 'newest' technological tool (Snyder, 1997) because it may just make our life 'easier.' These advances in technology affect the way the present generation of students think and learn. Students expect computers to be in their classroom, linked to the Internet, and to have easy access to them while completing engaging learning activities. Educators must realize that there are new skills these students need to master in order to participate productively in the 21^{st} century society and workplace. According to Harris (as cited in Hopson, Simms and Knezek, 2002) "Information Age citizens must learn not only to access information, but more importantly how to manage, analyze, critique, cross-reference, and transform it into usable knowledge" (p. 109). Yet research by Hopson, Simms and Knezek (2002) concludes that "The advent of the Information Age has made the development of problem solving, critical thinking, and higher-order thinking skills crucial to future success" (p. 109). While it appears that being a complete, thoughtful thinker will always be in order, demanding the 21^{st} century learner to acquire these skills remains the challenge for educators in the Digital Age. If we are to accept our professional role as educators of 21^{st} century students, we must look at new tools and methods of pedagogy that are progressive in their adaptation of technology while creating, engaging and stimulating the critical thought process.

Purpose of the Study

New methods for teaching core curriculum outcomes in all subject areas through technology are important to explore. As the review of the literature shows, researchers have determined that changing the way educators use technology in the classroom is essential to capture the interest of today's students. Identifying possible changes to students' critical thinking abilities while using Lego Mindstorms to solve several grade four math and science related problems was the focus for this study.

While the body of research completed on critical thinking skills with children is extensive, there have been only a few research projects linking Mindstorms and critical thinking together (Cameron, 2005; Gibbon, 2007; Mauch, 2001; Ricca, Lulis and Bade, 2006). Very little empirical research has been completed on Lego Mindstorms within the elementary classroom. Two large scale research studies concerning students' problem solving skills have occurred using Lego Dacta (similar to Lego Mindstorms but without a technology component) in Peru and Sweden. The Swedish study by Hussain et al. (2006) concluded by recommending that further study is needed into student's ability to solve logical problems using Lego Mindstorms (p. 192). This research project adds to the existing body of knowledge on Lego Mindstorms and questions the impact on critical thinking skills that Lego Mindstorms has for elementary students.

Research Question

The purpose of this research study was to examine the connection between critical thinking skills, Lego Mindstorms and elementary school children. The following research question directed the study:

> *Do grade four students' critical thinking skills improve when the Lego Mindstorms kit is used as an instructional tool in a constructivist learning environment?*

Limitations

During the 12 week course of the investigation, several limitations became apparent during the process. These limitations included the dual role of the teacher-researcher, attrition of participants, lack of a control group and limited resources. The limitations of the research are explained in Chapter 3.

The personal perspective of the researcher with regard to technology needs to be disclosed. While I possess an optimistic view of education, technology and learning for children, I do not see the merger of these three components without their challenges. While describing various stances towards technology, Bruce (1997) calls my particular position a "transformational" role, such that technology improves the educational environment with some limitations. This view influences my day-to-day teaching practice. Multiple forms of data was gathered and analyzed using a variety of data collection methods to mitigate personal bias in this research study.

One of the purposes of this research study was to see if any possible improvements to my professional practice could be made through the enhanced used of technology. It was therefore decided that action research would provide an acceptable methodology for this type of inquiry. This process is supported by O'Leary (2004) who reports "Action research is often used in workplaces…where the goal is to improve professional practice" (p.139).

Definition of Common Terms

For the purpose of this study the following terms are defined as:

Critical thinking: Higher level cognitive thought includes the ability to attempt to resolve challenges and issues through problem solving strategies, the opportunity to reflect on the problem solving method and the capacity to give reasons why such processes were used.

Technology: Computer technology includes: hardware, computers, the Internet, wireless technology, multimedia/hypermedia, electronic communication and software applications, etc. In addition 'educational technology' or 'instructional technology' is the integration of hardware/software and the related process into the educational environment.

Organization

This thesis is organized into five chapters. This chapter has provided an introduction to the research on elementary school children's critical thinking skills, technology and Mindstorms. To provide a context, the next chapter will be a review of the relevant literature on the subject matters, followed by a chapter on the methodology of the research. Chapter 4 will report the results of the study and Chapter 5 will conclude with a discussion of the findings.

Chapter 2

"The challenges facing educators then are to understand the nature of these New Times and to respond to them ethically, strategically and effectively." (Snyder, 1997)

Literature Review

The specific focus for this review of the literature will be an examination of critical thinking, of technology and its changing role in education, of today's student in a constructivist learning environment and of technology applications that engage critical inquiry. These issues comprise the content for this review of the relevant literature and underpin the theoretical framework that guides this study.

A Definition of Critical Thinking

The concept of critical thinking has attracted numerous academics for hundreds of years. Thus begins the dissonance. For every person who has studied critical thinking, there exist an equal number of definitions. The disparity of the definitions indicates the complexity of the subject matter. Bissell and Lemon (2006) agree that there are so many definitions and components of critical thinking that defining it is a problem. Generally speaking, 'critical thinking' is a broad term used frequently to describe the employment of thinking skills such as predicting, analyzing and assessing. Critical thinking is also referred to as "higher order thinking skills" (Jonassen, 2000; Reece, 2002), "reflective thought" (Dewey as cited in Brightman, n.d.), and "meaningful learning" (Asburn, 2006). Although there are many definitions of critical thinking, it is essential to have a working definition that corresponds to practical use in an elementary classroom. This position is supported by Bissell and Lemon (2006) who state "…generating a consensus definition is less important than simply choosing a definition that meets our needs and consistently applying it" (p. 67). To create a definition for critical thinking in an elementary classroom, a review of the literature is necessary.

Scholars and researchers can be divided into two groups when it comes to defining critical thought. There is the one view that believes thinking behaviours or "dispositions" creates a meaning for critical thinking. Robert Ennis (1991, pp. 8-9) lists numerous thinking dispositions such as "to look for alternatives", "to be open-minded" and "to ask and answer questions…". Tishman, Perkins and Jay (1995) embrace "to be curious and questioning…to think broadly and adventurously…to reason clearly and carefully" and "to organize one's thinking…" (p. 42). Facione (2006, p. 8) adds "having a critical spirit." Dispositions are a functional method of organizing and describing thinking. It is possible to observe these behaviours in many students, but it is more complicated to teach someone to have "a critical spirit" and even harder to assess. Many of these dispositions are characteristics we are born with (or without) that may be difficult to teach (Reece, 2002). Teaching critical thinking is hard (van Gelder, 2005; Willingham, 2007) but not impossible. Critical thinking dispositions should be modeled in our classrooms by educators from the early stages of elementary school. The language such as "curious", "questioning", "creatively" should be taught so our students are aware of the behaviours we are seeking. Finally, by using different models of instruction and theories of learning such as constructivism, many of these learning dispositions will become evident in the elementary classroom.

Other researchers (Facione, 2006; Paul, 1990; Tama, 1989) have used 'abilities' or skills to define critical thinking (Close, 2006). According to Brightman (n.d.), the Watson-Glaser Critical Thinking Appraisal (an assessment tool to measure critical thinking skills) identifies five key skills: drawing inferences, recognizing assumptions, drawing conclusions, interpreting data and evaluating arguments. More appropriately used with older students or adults, this tool provides a framework for higher level thinking skills that can be adapted for use within an elementary classroom. One of the most famous critical thinking researchers, Richard Bloom, created the Taxonomy of Educational Objectives (Paul, 1990; Reece, 2002) which included the thinking skills of analysis, synthesis and evaluation.

Willingham (2007) states that "Critical thinking is not a set of skills that can be deployed at any time, in any context" (p. 10). Developing critical thinking takes practice and, according to Willingham, background knowledge. This provides the context for the learning process. For example, we don't want our students to draw conclusions on a genre of books after only reading one book. They need to read several of the books, know what could constitute a reasonable conclusion and have practice creating it. Even then, Willingham argues, "…they will sometimes fail to think critically" (p. 15). As educators, we should teach students the what, where, why, when and how to engage the higher level cognitive thought processes. Then we should allow the students time to practice, practice and practice some more in appropriate situations. Teaching and implementing critical thinking skills in an elementary classroom is possible and is explored further in this paper.

Reflection or metacognition (Willingham, 2007) is a common element in the ability to think critically noted by researchers: "Developing the habit of reflecting on the logic of what one learns is a key to critical thinking" (Paul, 1990, p. 57). Students who are able to reflect on their thinking are able to see strengths, weaknesses and different points of view. Reflection also helps to guide their logic and provide the next steps in the process such as "I was only partially successful at this math problem. Do I need to go back and look at another way to solve it?" Teaching the capability to question one's opinion and providing reasons why a particular train of thought is being followed is an ability that can be taught in elementary school. For example, it is relatively easy for young students to state who their favourite author is. It is more challenging (but a teachable skill) to give logical reasons why this particular author is their favourite.

The development of problem solving skills is another valuable critical thinking ability supported by research (Brightman, n.d.; Ennis, 1991; Healy, 1990; Willingham, 2007). The capacity to problem solve is "…generally regarded as the most important cognitive activity in everyday and professional contexts" (Jonassen, 2000, p. 1). Problem solving usually involves following a number of steps: identifying the problem, analyzing the problem, identifying possible solutions or strategies, evaluating possible alternatives and implementing the best or most appropriate solution (Guffey, 1998; Healy, 1990). This process is cyclical and can be repeated if necessary. It is important to note that not all problems will be solved and it is the procedure that is often more valuable than the end product (i.e., the right answer). It is possible to create elementary classrooms with learning environments and programs that enhance students' problem solving skills. For example, during math lessons, open-ended questions can be posed and students must ponder numerous problem solving strategies to solve them.

Based on these findings, a definition of critical thinking developed for this thesis that can be applied in an elementary classroom: “Higher level cognitive thought includes the ability to attempt to resolve challenges and issues through problem solving strategies, the opportunity to reflect on the problem solving method and the capacity to give reasons why such processes were used.”

Historical Perspective of Critical Thinking in Education

The study and research of thinking began back in ancient Greece with Socrates. In the modern era, it has been influenced by John Dewey, Jean Piaget, Richard Bloom and Paulo Freire. It is important to review the historical perspective of critical thinking developed by these prominent researchers to understand the evolution of the concept and then view how pedagogy has changed to allow the dynamic process of higher level thought to increase in the classroom.

Dewey: 1880’s- 1930’s

John Dewey was an American philosopher of education who spearheaded educational reform in its theory and practice. Dewey (as cited in Gibbon, 2007) identified four key characteristics of children: a) a wish to converse, b) a desire to construct things, c) a need to inquire, and d) a want to express themselves artistically. Dewey’s exploration of traditional educational practices and the movement towards a more progressive teaching model in his book *Experience and Education* (1963) led Dewey to believe that better learning and growth occurred through quality “experiences.” Learners, he stated, needed to be provided with certain “freedoms” in their experiences such as being active and social which was in direct contrast to the teaching style commonly used at the time. Reviewing Dewey’s work, it is possible to see how it created the outline for future educational research in the development of children's thinking process.

Piaget: 1940's- 1980's

Jean Piaget's educational research led him to develop his now renowned theory on four stages of cognitive development for children. Like Dewey, Piaget (1971) supported experience, but added the element of experimentation to support the "…spirit of discovery and active verification" (p. 12). Piaget, like Dewey, was also concerned that traditional education methods at the time merely "stock the memory" rather than provide the true aim of education which is to develop the intelligence.

Piaget's work provided educators with a structure for providing appropriate methods and materials based on the child's cognitive development. His research and theory is still explored in teacher pre-service programs and evidence of the influence of his work is found in classrooms throughout education systems.

Bloom: 1950's

Formal critical thinking in education or as some scholars refers to it as "the critical thinking movement" can be traced back to beginnings with The Taxonomy of Educational Objectives (Paul, 1990; Reece, 2002). Developed in the 1950's by a committee of university educators, the conclusions were published in two handbooks: *Cognitive Domain* (Paul, 1990) and *Affective Domain* (Paul, 1990). Today this influential work is commonly referred to as Bloom's Taxonomy (Paul, 1990; Reece, 2002) and it is still taught in many pre-service education programs and accessed by classroom teachers in their daily practice.

Bloom’s Taxonomy classifies intellectual behaviour according to levels of thinking (see Figure 1). The lower levels of the taxonomy are the basic thinking skills (knowledge, comprehension, application) and are achieved through simple recall and the reorganization of information. The highest three levels of the taxonomy (analysis, synthesis, evaluation) are the levels where learners will be engaged in critical thinking. Bloom’s Taxonomy is a succinct, organized and straightforward method of creating critical thinking in our classrooms and has influenced the teaching process for many years.

Bloom’s Taxonomy

Figure 1.

Paul (1990) values the classification of the thinking skills brought forward by Bloom and his colleagues. However, he argues that the Taxonomy is an over-simplification of the thinking process and his primary criticism is the one-way nature of Bloom’s hierarchy of thinking skills. Bloom’s Taxonomy must be followed in a sequential format. Knowledge is acquired first and then there will be understanding. Understanding must be achieved before any application can be made and so on up the Taxonomy. At the higher levels, Paul proves that true critical thinkers do not categorize their cognitive process; rather they flow freely up and down the Taxonomy utilizing various skills at each level (p. 424).

Bloom's Taxonomy has been well researched, widely publicized and has become a respected piece of work (Forehand, 2005). Historically, it was ground breaking and eye-opening for educators 60 years ago. It challenged and changed many of the existing teaching practices. However, for teaching today's students, Bloom's Taxonomy should be viewed as a classification of the cognitive thought process needed for critical thinking. Students in our classrooms are far more sophisticated, experienced and aware of their learning environment than the students of 50 or 60 years ago. Asking questions at each level of the Taxonomy does not guarantee critical thinking skills will be engaged. New methods and techniques for teaching critical thinking skills to children in the 21st century need to be explored.

Recently a group of academics led by a former student of Bloom, Lorin Anderson, revised Bloom's Taxonomy for the 21st century (Forehand, 2005). The revised taxonomy now includes: remembering, understanding, applying, analyzing, evaluating and creating. Whether the updated version becomes as popular as the original remains to be determined.

Freire: 1960's

Another major influence on thinking in education was Paulo Freire (2000). Freire's work was originally published in the book *Pedagogy of the Oppressed* in 1970. Freire characterized the educational method at the time as a "narrative" process. This consisted of the teacher being the central holder of power and knowledge, that would dispense information to the students as required. While communication existed, it was one-way. Freire also referred to this as a "banking" approach for education (p. 72). Freire acknowledged that this pedagogical model was flawed. It produced thinkers who could regurgitate facts but not successfully question or reflect on any part of their learning. During this period, education could be perceived as a dictatorship not a partnership.

Freire proposed that for critical thinking to exist, teachers must trust the students and enter a partnership with them. To do this successfully, Freire suggested a new model for education, one based on "problem-posing" (p. 79) a predecessor for today's "problem-based learning." The structure of this education model would be vertical (as opposed to the horizontal for the banking method) and open up the lines of communication between teachers and students. This dialogue is what starts critical thinking. "Only dialogue, which requires critical thinking, is also capable of generating critical thinking" (Freire, 2000, p. 92).

Freire's work has been called sexist and often considered to be concerned more with class struggle than educational reform. It has also been criticized for using academic language that builds or maintains barriers between students and teachers (Ohliger, 1995; Schugurensky, n.d.) as opposed to speaking a language more in line with Freire's intended audience: the poor, working class people.

Although reviewing Freire's *Pedagogy of the Oppressed* is like reading a handbook preparing us for revolution, thirty seven years after it was published, it is now referred to as a pioneering text. His work set in motion the examination of many pedagogical processes and influenced a new generation of teachers. For example, Freire's work laid the foundation for group and collaborative work to be viewed as an essential component of critical thinking.

Problem Based Learning: 1970's

The evolution of the study of critical thinking continued with the introduction of problem based learning at McMaster University in Hamilton, Ontario (Schugurensky, 2002). Problem based learning consists of an educator facilitating a discussion using open-ended problems with students, who usually work in small collaborative groups to solve them.

This method of pedagogy is a combination of Bloom's Taxonomy and Freire's problem-posing. It is a viable alternative educational model allowing students to achieve the higher levels of Bloom's Taxonomy while taking ownership of their learning through relevant problems as proposed by Freire.

Critical Thinking: 1980's

In 1983, *A Nation at Risk* was published in the United States. This report by the National Commission on Excellence in Education declared a lack of critical thinking skills amongst 17-year olds. Programs designed to teach higher level thinking skills became part of the curriculum. Critical thinking was instituted as a graduation requirement within the California State University system and the community college system (Paul, 1990).

Critical Thinking: 1990's to Present

The trend of implementing critical thinking into teaching methods and curriculum continued through the various levels of the education system. Where adult education was once considered the sole domain for higher level thinking, today it has infiltrated its way into elementary schools. Problem based learning is now thoroughly embedded in the Nova Scotia Learning Outcomes Framework for students in elementary, middle and high school. In the mid 1990's, the Nova Scotia Department of Education identified problem solving as an essential graduation of learning. According to the Atlantic Canada Framework for Essential Graduation Learnings in Schools (n.d.), Grade 12 graduates must be able to:

> Acquire, process, and interpret information critically to make informed decisions; use a variety of strategies and perspectives with flexibility and creativity for solving problems; formulate tentative ideas, and question their own assumptions and those of others; solve problems individually and collaboratively. (p. 10)

Furthermore, there is evidence of problem based learning found throughout the Atlantic Canada Math (1998), Science (2005), Information & Communication Technologies (ICT) (2005) and Language Arts (1997) curriculums. For example, the Grade 2 science outcome 202-9 states that students should "…identify new questions about the needs and growth patterns of other organisms" (2005, p. 63). The ability to develop new questions would begin with the students working through the first two levels of Bloom's Taxonomy (knowledge and understanding) and then applying (level three) this information to analysis (level four) to develop new questions.

Most recently, the province of New Brunswick published their new education plan: When Kids Come First. In the premier's message, New Brunswick Premier Shawn Graham acknowledges the education system "…fosters innovative critical thinkers …" ("*When Kids Come First*". 2007, p. 3).

As this historical review has shown, critical thinking pedagogy continues to evolve and develop from the research of each predeceasing era. Determining how to implement critical thinking teaching in the elementary classroom is an important next step.

How to Achieve Critical Thinking in the Elementary Classroom

The education system has embraced critical thinking by infusing it into the curriculum outcomes. Teaching these outcomes effectively so students develop increased levels of cognitive thought could be achieved through several educational processes. Educators should create a learning environment for students that include engaging, well designed problems, collaborative group work and time for practice.

Research from Hewitt (2001), van Gelder (2001, 2005) and Willingham (2007) recognizes that teaching critical thinking skills in isolation is flawed from the start. "People do not spontaneously examine assumptions that underlie their thinking, try to consider all sides of an issue, question what they know, etc" (Willingham, p. 18). Critical thought must be taught in a context (such as a subject matter) for students because this familiar framework (such as math) provides the structure for the students to experiment with their learning and assess their progress. The following learning elements transcend individual subjects and could be implemented into lessons in many areas of the elementary curriculum.

Problem Design

An important initial step to teaching critical thinking skills is to use well designed problems in lessons (Browne and Keely, 1998; Jonassen, 2000; Paul, 1990, Potts, 1994).

Incorporating a balance of well-structured and ill-structured (or open-ended) problems into the learning environment remains a challenge for educators. For example, Jonassen (2000) points out that our students are likely to encounter "…well-structured (story) problems, which are inconsistent with the nature of the problems they will need to learn to solve in their everyday lives…" (p. 2). Therefore, in order for students to be successful at problem solving they need to be exposed to a combination of well-structured (known elements, unknown solution such as 2+2=?) and ill-structured (unknown elements with multiple solutions or no known solution such as 'How do we stop the wide spread pollution being emitted from cars?') problems.

Educators traditionally have many years of experience teaching students at a particular grade level. This background knowledge of students' cognitive abilities at a given grade enables the teacher to develop appropriately designed problems. An indicator of properly designed problems is student motivation. Mayer (as cited in Jonassen, 2000) claims students will employ higher levels of thinking when they are motivated because they feel that they are able to solve the problems successfully.

One difficulty with the problem solving process recognized by Jonassen (2000) lies with the complexity of presenting problems to "novice learners" because of their inability to solve them due to a lack of basic problem solving skills (pp. 4, 7). For example, students in grade one will not be able to understand an algebra problem even if it is placed into a story context. Another issue presented by Willingham (2007) regards students having insufficient background knowledge to support their thinking. If students are to be successful at problem solving not only must they have access to properly designed problems, but the classroom teacher must offer adequate support by providing suitable content so students can comprehend what they are learning. Further to the problem solving process of critical thinking is the issue raised by Greg Meyers (as cited in Comley, 1989, p. 624) “that critical thinking begins with a problem and ends with a solution…” This is often the approach for problem solving in text books. However, if we are indeed seeking higher cognitive skills in our students then educators must present open-ended problems where the end point may be more questions, not solutions.

Questioning

Socratic questioning is a method of inquiry based on the works of Socrates, considered one of the greatest thinkers of all time. Questioning probes student thinking deeper by asking open-ended questions such as “What do you mean by…?”, “Could you give an example?” and “How do you know?” (Paul, 1990, p. 276). Socratic thinking “…allows students to develop and evaluate their thinking by making it explicit” (Paul, p. 269), an important reflective ability of critical thinking.

Utilizing Socratic questioning in the classroom is a viable and efficient method to improve thinking skills. In doing so, teachers must be willing to give up some control. They must be open to listening and learning from their students. Open-ended questions have no right or wrong answers and thus the teacher and students must realize that the conclusions reached may not be the expected answer. Educators must also be careful to follow the structure of Socratic questioning so as not to probe and question endlessly, which can confuse students.

When teachers allow students adequate “wait times” (3-5 seconds) for responses to questions, an inviting thinking atmosphere is promoted in the classroom. (Tama, 1989,

p. 2) This extra thinking time allows students time to process and encourages them to create more in-depth responses to questions (Beisser, 2005, p.13). Giving the time for students to respond also gives the impression that thinking is required (Potts, 1994). However, according to Tobin's study (as cited in Tama, 1989) extra response time will not create critical thinking. From my experience, extra response or wait time increases response rates amongst the students, but the time alone will not create better thoughts as this is directly related to the question being asked.

Collaborative Learning

Jean Piaget promoted collaborative learning because he felt that "…it is such cooperation that is most apt to encourage real exchange of thought and discussion, which is to say, all the forms of behaviour capable of developing the critical attitude of mind, objectivity, and discursive reflection" (Piaget, 1971, p. 180). Research by Brightman (n.d.), Johnson and Johnson, Totten, Sills, Digby and Russ (as cited in Gokhale, 1995), Gokhale (1995) and Potts (1994) concludes that group work assists students in achieving higher levels of thought and achievement. "…there is persuasive evidence that cooperative teams achieve at higher levels of thought and retain information longer than students who work quietly as thinkers" (Johnson et al., as cited in Gokhale, 1995, p. 22).

Peer interaction encourages students to become actively engaged in their learning compared to being passive receivers of knowledge. Properly structured collaborative work allows students time to question, to develop new ideas and to evaluate their peers' comments and ideas. It also encourages metacognition while students work to solve problems together.

Collaborative group work is prevalent in the elementary classroom. It is incorporated into teaching methods such as: Literature Circles (or book clubs) where students take on roles to discuss and comprehend various forms of text; Learning Centres (or stations) where students work together to solve a problem or complete a task; and Writer's Workshop where students discuss, share ideas, question and edit peer's written work.

Time and Practice

Research by Carr (1990), Healy (1990), Jonassen (2000), Paul (1990), van Gelder (2005, 2001) and Willingham (2007) all concludes and stresses that in order for students to be successful at critical thinking, one element is essential: *time*. Time is required for students to practice and additional time is required for teachers to prepare properly. Therefore, it is necessary to model, share, instruct and integrate critical thinking lessons throughout the student's schooling.

According to van Gelder (2001), the school system has failed our students by adopting a flawed method to teach higher levels of thinking. This method is called the 'indirect approach' (p. 1), and it is a process whereby educators assume that by teaching the prescribed curriculum the ability to problem solve will be incorporated into students' thinking. This is a similar argument made by Paul (1990, p. 423) with regard to Bloom's Taxonomy. Beisser (2005) also highlights this problem "…and that the result is that most students do *not* get a coherent introduction to problem solving" (p. 9).

Van Gelder (2001) offers a solution called 'quality practice' because "…cognitive skills, like other skills, improve with practice" (p. 2). This quality practice includes:

motivated, guided, scaffolded, graduated learning activities and feedback (p. 2). While no researcher specifically states the necessary amount of time to be a master of critical thought, perhaps a good indicator would be by Anders Ericsson (and supported by Richard Bloom) whose research shows that 10 years of "deliberate practice" is a necessary minimum to achieve expertise in most fields!

Transfer Between Subjects

After students learn and practice, teaching students that logic skills and dispositions can transfer and link between subject areas and everyday life is the last step according to Reece (2002). It is also educator's biggest challenge (Harjehausen, 2004; Reece, 2002; van Gelder, 2005).

Transfer of critical thinking skills is important because students need to see that critical thought is not an isolated learning outcome, nor is it subject dependent. Critical thinking should be taught in a context (such as the subject of math) as previously described. Seeing how the process connects strengthens and extends the students knowledge of concepts. The challenge for educators remains in the inconsistency of the students. They are able to think critically in some situations but not in others (Willingham, 2007).

One method suggested by Halpern (as cited in van Gelder, 2005, p. 43) is "we must teach for transfer." This direct approach addresses the issue that transfer of critical thinking is something we must do, not something that will simply happen.

Another method to activate students' prior knowledge is through connections (Healy, 1990). Connecting current knowledge to previous learning experiences promotes long-term memory and provides students with examples of transfer between subjects. For example, a common line of questioning now occurring in the elementary classroom is for educators to ask students to make connections between the books they read. These are commonly referred to as Text to Self, Text to Text and Text to World connections. An example is a connection between a non-fiction book on electricity read during a language arts class and an electricity experiment in science class. These associations are the beginning steps for making the transfer of critical thinking by requiring students to reflect on their previous knowledge.

How to Assess Critical Thinking

Research supports the assessment of critical thinking (Bissell and Lemons, 2006, p. 67); however, when viewing critical thinking as a skill or dispositions (as previously discussed), skills are easier to assess than dispositions (Reece, 2002). Reece also mentions that typically assessment of critical thinking illustrates nothing about retention or long-term gains.

Stephen Brookfield has developed a Critical Incident Questionnaire (as cited in Adams, 2001) consisting of five open-ended questions that learners are to answer, based on the week's classes (see Appendix A). While this assessment tool is primarily aimed at the post-secondary level, there is value in adapting it to the elementary level in the form of a reflection journal or questions (see Appendix E).

Richard Paul and Gerald Nosich in their paper entitled "A Model for the National Assessment of Higher Order of Thinking" (1993), assessed and reported on a model for the national assessment of higher order thinking as commissioned by the United States

Department of Education. In this article, the authors highlight twelve commercially available critical thinking tests and quickly conclude that none are viable assessment tools because they did not provide a "comprehensive model for the elements of thought, the abilities of critical thinking or the affective dispositions." (Paul and Nosich, 1993). The alternative solution to these tests is a test based on multiple-choice questions, multiple-rating items and essay items. Paul and Nosich (1993) declare that "Legitimate use of multiple-choice items is limited" and then provide several examples of wording that would incorporate cognitive thought into multiple-choice questions. Examples are repeated for the multiple-rating questions and essay items. The authors wrap up their report by stating that the scope of the test should take place within academic subjects or interdisciplinary subjects because critical thinking needs a context.

Reviewing the Model for the National Assessment article provided a contrast in opinions. Using a standardized test to obtain critical thinking data on a nationwide scale contradicts almost everything that critical thinking represents! Assessing critical thinking on such a large scale is a massive undertaking and the results could provide more information on how not to assess students' cognitive abilities than it would provide a benchmark for thinking skills. To date, it appears that no national assessment of higher order thinking has occurred in North America.

Clearly defining the goals of the learning outcomes expected at the initial stages of the instruction is a key element for establishing successful learning and assessment of the thinking (Wiske, 2006, p. 29). This concept is also supported by Paul and Nosich (1993), but they propose it should not be used in conjunction with standardized tests but rather a tool called a 'rubric.' A rubric is a scoring guide based on a set of criteria taken from the learning goals. It is organized based on the skill level achieved for each learning goal from remedial to mastery. Each skill level provides clear examples of the specific goals. Students are able to compare, assess and reflect on their own work against the provided examples.

Rubrics have become increasingly popular in the elementary classroom over the past 5 years. They are relatively easy to use, design and implement. Rubrics are useful to assess critical thinking skills (Bissell and Lemons, 2006) because they allow the learners to analyze their own work. This tool also provides the benefit for on-going discourse on the student's cognitive performance throughout the learning process. The process of self-evaluation is in direct contrast to the traditional "end of the unit" summative evaluation (for example a written test). This type of assessment tool provides untimely feedback because the instruction, activities and practice have been completed, leaving little additional time for students to develop and master areas of concern. Summative evaluation is most likely to occur in classrooms where 'instructionism' (teacher instructs, student 'absorbs' required material) is the preferred teaching method (Papert, as cited in Jonassen, 1996).

The Changing Role of Computer Technology in the Classroom

It is important to review the historical perspective of technology to understand the evolution of computers in the classroom and to see how their influence on pedagogy has changed.

Pre-1970

Computers began their existence at higher learning institutions with the first electronic machines (named Mark 1 and ENIAC) built at Harvard University in 1944 and the University of Pennsylvania in 1946 respectively. However, it was the threat of falling behind in the 'space race' that initiated the US government to begin an investment in technology. Following the Soviet's launch of the Sputnik satellite in 1957, the United States stepped up educational reform (Cuban, 2001; Molnar, 1997). Education was no longer to be viewed as something completed at the end of high school, but it was suggested that a formal education would prepare workers for multiple career changes during their lifetime. In addition, new technologies emerging from companies such as IBM would have an influence on the new education system. However, it would take twenty years for computers to make their way into many elementary schools.

Interestingly, Piaget in his book *Science of Education and the Psychology of the Child* (1971), discussed a growing fear of the time: that teachers could be replaced by what he referred to as "machines." Piaget was quick to respond that this substitution would be beneficial for student learning only if repetition and right answers were required. While this may have allayed some of the threat of obsolescence amongst educators, Piaget also noted the high level of motivation of subjects who used machines for learning.

1970's and 1980's

During the next two decades the education system began to follow a business model (Cuban, 2001) based on the need for increasing efficiencies and obtaining higher standardized test scores (p. 14). In Canada and the US, computers were seen as a valuable link to the skills required in industry (Cuban, 2001; Hache, n.d.; Milton, n.d.; Wiske, 2006, p. 27). Computers began to find their way into classrooms and labs. However, because of the high cost associated with their implementation, the adoption process into the education system was slow.

The focus in the classroom was to learn about computers, rather than the students using computers to enhance learning (Brown, Bryan and Brown, 2005; Leinonen, 2007). This era was marked by computer assisted instruction (CAI). Computers were used for drill and practice, a low level thinking processes that reinforced concepts taught in class.

Seymour Papert examined computer use in the educational setting during this time and published his findings in the book entitled *Mindstorms* (1980). He saw "The computer's 'holding power' so feared by critics, becomes a useful educational tool" (p. 27). Papert supported the theory that learning is easier when students are given material from their surrounding environment. He also identified the need for integration not segregation of computers into the curriculum. Papert's theories are based on a constructivist learning approach whose development is largely attributed to Jean Piaget. To support his beliefs Papert created the LOGO programming language. This was a simple programming language based on math that allowed children to become programmers. The students would use LOGO to create a program that would have a 'turtle' (the onscreen character) complete a task (such as drawing a square). If the task was not completed correctly, students would have to use problem solving skills to correct their programming errors. Papert envisioned that the skills students exhibited with LOGO could be transferred to all subject areas. He saw the value in children using technology to take ownership of their learning and produce something of value. This change in the application of computers marked a new mindset for technology use within the educational system.

While Papert's LOGO programming language was met with great enthusiasm by educators, Hewitt (2001) states that LOGO failed to have any long term value in the education system. Moreover, he claims the transfer of skills between subjects did not occur and students no longer use technology for programming. However, Papert's LOGO programming language did not expire; it changed and was incorporated into the Lego Mindstorms kit.

1990's

By the early 1990's, technology had become faster through increased processing power of the computer chips. 'PC's' decreased in price and with their new graphical interfaces, they became easier to use, making technology more available and functional in the classroom and at home (Jonassen, 1996). While the tools were changing, the curriculum and instructional methods remained the same (Brown et al., 2005). Computers were used as reward time for students' good behaviour, for remedial learning and for administrative tasks. Instructional cd-roms were a major part of CAI but they were still used to deliver educational content in a linear communication format (Jonassen, 1996). Interactive, multi-media was still not possible.

The Internet was introduced to teachers and students during the middle of the 1990's. While it marked the beginning of electronic based learning (Leinonen, 2007) and communication with other users, the Internet based learning was limited by the need for even faster computers and a wired connection to a network. While the information highway was open, it was still difficult to get on because many schools were not yet wired to a network.

In classrooms that were able to use networks, Anderson and Speck (as cited in Brown et al., 2005) marked this as the beginning of a shift in learning approaches using technology. Until this point a behaviourist learning model to technology was in place (based on the structured use of technology such as drill-and-practice applications). By taking advantage of the Internet and networking a "constructivist learning environment" was created where teachers and learners were no longer only the receiver of the information but able to have some influence on their knowledge by creating content (web pages for example). While Papert's constructivist work with LOGO predates this point, the Internet was able to gain wide acceptance and was thus more successful in enhancing the learning environment than LOGO.

2000 to Present Day

Today, technology continues to become faster and more accessible. Speed is now measured not only for computers but also of networks and their ability to upload and download data. Prices continue to decrease and many people (including students) have access to numerous digital media and software in the course of their daily activities (video game terminals, cell phones, home computers, school computers, library computers, etc.). By 2004, over 99 % of all schools in Canada had computers and 90 % of all computers in schools were wired to the Internet (Report of the Pan-Canadian

Education Indicators Program, 2005). As a result of the Internet, technology has become more about interactivity, networks and connectivity and less about hardware.

In schools, Brown et al. (2005) reported that "…computers are no longer merely vehicles for drill and practice, but vehicles for problem-solving and active learning" (p. 2). With the introduction of Web 2.0 applications (such as wikis, blogs, social networking sites, virtual worlds), technology now exists that is more interactive than ever before.

This historical review of technology in the classroom has shown how ICT is rapidly changing and evolving from a "box that will teach learners" to a "networking tool that assists learners."

Critics of Technology in Education

While computers have been in the elementary education system for over thirty years, there are still critics that question why and how technology is used in schools (Cuban, 1999; Cuban, 2001; Peck, Cuban and Kirkpatrick, 2002; Ping, 2001). These authors view technology in the classroom as a failed experiment because students are taught how to use computers for low level tasks only, or they provide too much freedom and information leading to "cognitive overload" (Synder, 1997, p. 129). Certainly, their viewpoints have merit and they are important to consider. It is possible to observe students in many classrooms completing passive, rote activities on the computer. It is also feasible to recall students who are always multi-tasking, unable to focus on one item or location on their screen. Not withstanding these examples, however, technology in the classroom is a beneficial assistant that when used appropriately, stimulates the cognitive process and provides educators with new practices, more choices and motivators for today's learners.

Piaget (1971) identified an issue early on in the adoption of computers into the classroom that certainly remains true to this day: our society has an unbridled acceptance of technology. As our knowledge of technology increases, it has led to the "overloading of educational programs" (p. 96). It is possible to see how technology education has evolved and changed. While keyboarding instruction was once taught in the high school setting, students now in grade 1 are expected to know their way around the keyboard. While educational policy makers have created additional curriculum outcomes that guide our technology pedagogy, they remain reluctant to remove other 'required' outcomes, resulting in teachers that feel pressured and stressed to successfully teach all the mandated outcomes.

Larry Cuban's study in 2001 found limited use of computers by teachers in schools. Certainly, if teachers are troubled by technology and unlikely to adopt it, they are not likely to let students use it. This resistance to change is a phenomenon called the "slow revolution" (Cuban, 2001, p. 153) and also documented by Ferris and Wilder (2007) and McCain and Jukes (2001). Change is not something that occurs very fast in the education system they argue and this is unfortunately a tradition embedded in the teaching culture. With some new leading edge technologies, schools are more apt to ban (van't Hooft, 2007) than incorporate them (such as prohibiting instant messaging instead of using it for interaction in group projects).

While the ongoing debates and discussions have advanced our understanding in this area, there are a number of limitations in the existing literature. Cuban's findings published in *Oversold and Underused* (2001) are based on the research from one school board in California and exclude elementary school data. Cuban, it could be argued, is more concerned about the "boxes" that "suddenly appear in the classroom" than the new pedagogical changes these boxes can inspire. The literature also predates many of the Web 2.0 applications that are now available to educators for implementation into the classroom. It is clear that more empirical studies are required to update the body of knowledge on new trends in educational technology.

An interesting view on the technology and education debate was put forth by Bruce (1997) when he asked:

> What should be the stance of literacy educators and researchers toward technology? Where does technology fit with respect to other concerns about reading and writing processes, learning, multiculturalism, texts, assessment, and socio-cultural contexts? Will new technologies fundamentally alter the nature of literacy or are they a passing fad? (p. 290)

Bruce then described the positions ranging from neutrality, opposition, utilitarian, skeptical, transformational and aesthetic. There is no doubt that everyone concerned with computers in schools could be classified into one or more of these categories. I (as is evident in this paper) would classify myself as some one who takes on the characteristics sympathetic to the transformational role: technology provides us with the opportunity to improve the educational environment but it will not be an easy process. Bruce would argue and I agree, that it is important to understand teachers' positions on technology in the context of their relationship with technology (for example, life experiences, gender, race, and class, social status, etc.). This provides valuable information and is more apt to tell if a teacher's distrust of computers stems from "I don't like computers because I never learned how to use them.", to "Growing up in rural Nova Scotia, I never had the opportunity to use a computer until university." There is no one correct position for an educator to be placed in and nor should there be. It is important to review opinions of those in all of the positions and chart a new path for education and technology based on these multiple viewpoints.

Bruce continues that technology should be viewed beyond the 'physical' aspect (numbers of computers, networks, routers, weight, and size) and be more concerned with the 'social relations.' When we view technology through consumers' eyes, we are more concerned with speed, looks, and cost. Bruce points out that parents are consumers when they base their child's school placement on the number of computers found in the classroom. Children, too, are primarily consumers when they want the latest high tech toy because it looks 'cool.' However, when we view digital technology as a "social" tool, education "is expressed through its technologies rather than determined by them." For example, educators should not ask "Would using technology help students learn to read?" (p. 301) but acknowledge that reading has changed, it is a social process and we now use computers to assist children in their learning of the reading process.

Viewing digital technologies based on Bruce's clarifications provides educators with more opportunities for assisting learners. Cuban's arguments could be classified as exterior issues which merely highlight the need for better teacher training. Johnson-Eilola (as cited in Synder, 1997) calls these 'surface versus depth arguments' that look at them in 'all-or-nothing' ways. Certainly, in this digital era, the likelihood of reversing technology integration in our North American society is not going to happen.

We are a culture that is infatuated with technology. However, we need to move beyond the 'physical' view and "surface" uses of technology and begin to teach "the application of these critical abilities to literacy and computers" (Synder, 1997, p. 207).

As Bruce has argued and Synder (1997, p. xxi) would support, the lines of technology and education have become blurred. If technology is indeed now part of our societal fabric, this is important information to accept when reviewing the students' needs and changing our teaching methods to meet their learning requirements. This analysis is discussed in the next section.

Understanding Today's Learners

Just as Nike would never produce a running shoe for the consumer without doing their product research and knowing their target market, educators should realize the learner of the early 21st century is not the same learner as twenty years ago. Learners think differently, they learn differently and they value technology as an essential part of their lives. Current research about the characteristics, needs and learning styles of today's students is explored in the following sections.

Today's learners can be called the 'Net Generation' or 'Net Gen' (Tapscott, 1998) and are defined by demographers as the part of the population that was born during or after 1982. These children have been surrounded by technology for their entire lives. Many of them do not know the world without the Internet and other associated digital media. This relationship with technology affects their learning style and impacts how educators teach them.

Net Gens have come to expect instant gratification as a result of technology and can become easily bored because of a decreased attention span (Barnes, Marateo and Ferris, 2007, p. 3). At the same time, they enjoy multi-tasking activities (Education Evolving, 2005; Thompson, 2007, p. 2) and technology supports this opportunity through fast processing, multimedia computers. A desire for 'interactivity' is a key characteristic of this generation (Tapscott, 1998) and the Net Gen finds it increasingly online. Based on a survey of Net Generation students by Education Evolving (2005), Net Gens want to use technology for learning and desire more access to diverse digital tools in their school to participate in active, engaging activities. They view technology as 'essential' to their learning. Glenn (as cited in Barnes, Marateo and Ferris, 2007) states that students require "self-directed learning opportunities, interactive environments, multiple forms of feedback, and assignment choices…" (p. 2) while Hay (as cited in Barnes, Marateo and Ferris, 2007) adds using "inquiry-based approaches to their learning…" (p. 2).

Baron (as cited in Barnes, Marateo and Ferris, 2007) does not support the change to the learning environment for this generation. She argues that this generation has poor literacy and critical thinking skills. Changing the environment and teaching methodology for the sake of their specific learning characteristics "…merely caters to a lack of discipline." (p. 2). This argument may have a valid point, but technology is not necessarily to blame. And, if this generation does indeed have poor literacy and poor higher level thinking skills, educators should consider incorporating technology to possibly improve these outcomes. Johnson-Eilola (1997) agrees by further adding that we cannot ignore “traditional” learning outcomes; however, holding students back to a world that no longer exists does them more harm than good. Being “open to possibilities” (p. 186) in our educational practice is a critical issue that educators must personally confront as we teach in the 21st century.

A challenge of educators teaching the Net Generation exists in the form of “digital disconnect” (Engstrom and Jewett, 2005, p. 12; Levin and Arafeh, 2002; Luke, 1996; Snyder, 1997). This is the discrepancy in skills that exists between today’s tech savvy students and their low-tech teachers. As Johnson-Eilola (as cited in Synder, 1997) puts it “Many adults are terrified of this place; many children live there happily” (p. 185).

For teachers to be successful in teaching students who have more technology skills, they must have the support of their administration (Levin and Arafeh, 2002) and opportunities for technology-related professional development. This is starting point for Johnson-Eilola’s “possibilities.” Teachers like their students, need to grow intellectually, they need to be able to leave their comfort zone and try new things. They must be prepared to relinquish some control and become better at understanding their students. “We must incorporate the technologies into our teaching if for no other reason than our students will force us to change” (Synder, 1997, p. xxxiii).

For any changes that technology creates, we must review existing learning theories and their relationship to technology. Determining the link between the two will be examined and can help to determine a course of action that fits the learning needs of our students.

Learning Theories and Technology

A learning theory provides concepts and evidence that explain the process of learning. Reviewing existing learning theories and determining a learning theory(s) that best meets the characteristics of today's learners is important. There are many different theories on learning, many with over 100 years of research behind them.

Research by Zhou (2004) explored the use of learning theories and computer technology applications in P-8 classrooms over a period of several years. The review consisted of examining existing major learning theories (behaviourism, cognitivism, humanism and constructivism), the merging of these theories and the development of new learning theories when using computer technology in the elementary classroom. Zhou confirmed that all of the major learning theories did allow for the incorporation of technology into their concepts. Based on her findings, Zhou concluded that cognitivism was the most referred to learning theory, narrowly edging constructivism.

Cognitive theory can be defined as "…how learners process inputs and outputs mentally in order to understand how people think, learn, transmit information, and solve problems" (Leonard as cited in Zhou, 2004). Information is independent from the learner and is transferred from the external world to the individual internally. This theory assumes that knowledge acquisition is a linear process. Technology is utilized in a cognitive learning environment for example by using interactive cd-roms with students who have difficulty reading. These assist learners in their comprehension while decreasing the emphasis on decoding words. Calculators could assist students in math problem solving while minimizing the stress of basic computational skills. However, cognitive theory does not account for previous knowledge acquired by the learners.

Sharing “the same theoretical and philosophical rooting” as cognitive theory and incorporating previous experience, constructivist theory is based on the learner taking an active role in their education by building new ideas based on their past experiences. Knowledge is developed internally instead of transmitted between one person and another. This is known as ‘instructionism’ (Papert as cited in Jonassen, 1996) and represents the more traditional teacher to student instruction model. Constructivism focuses on what factors influence the building of knowledge (Zhou, 2004) and allows the learner to construct and produce knowledge based on their needs.

Constructivism and technology can be incorporated and supported in a constructivist learning environment. Constructivist uses of technology are described later in this paper. Based on the literature reviewed (Education Evolving, 2005; Gahala, 2001; Jonassen, 1996; Jonassen, Carr and Yeuh, 1998; McCain and Jukes, 2001; Nova Scotia Department of Education, 2001; van’t Hooft, 2007; Zhou, 2004) and my personal instructional method that supports constructivist learning, constructivism will be the learning framework for this study.

Constructivist Learning Theory

Constructivism was influenced by prominent educational researchers such as John Dewey (Buffington, 2007; Epstein, 2002), Lev Vygotsky (Clark, 1999; Epstein, 2002) and Jean Piaget (Clark, 1999; Epstein, 2002).

Several principles of learning can be derived from constructivism (Epstein, 2002;

Jonassen, 1996):

1. Learning is an active multi-sensory process.
2. Learning involves language.
3. Learning is a social activity.
4. Learning is contextual.
5. Learning is cumulative. New knowledge is intertwined with previous knowledge.
6. Learning takes time and must be reflected upon.
7. A key component to learning is motivation.

Constructivist learning theory can be divided into two schools of thought: cognitive constructivism and social constructivism. Jean Piaget is associated with cognitive constructivism and Lev Vygotsky with social constructivism (Clark, 1999).

Piaget's cognitive constructivism is concerned with the process of how learners construct knowledge:

> How learners construct knowledge depends on what they already know, which depends on the kinds of experiences that they have had, how they have organized those experiences into knowledge structures, and the beliefs they use to interpret objects and events that they encounter in the world. (Jonassen, 1996, p. 11)

Piaget's theory of constructivism is based on the learner progressing through cognitive stages (sensorimotor, preoperational, concrete operations, formal operations). Progression through these stages occurs through "learn by doing" and builds upon learner's knowledge (Riddle, 1999). The role of the teacher is to provide stimulating learning environments that allow the learners to explore, discover and create their own interpretation of the knowledge being acquired. Cognitive constructivist theory places the accountability for learning on the student, not the instructor (Epstein, 2002).

Lev Vygotsky's theory of social constructivism, while sharing similar learning principles as cognitive constructivism, has no stages (Riddle, 1999) and places a greater emphasis on the role of the teacher and language in the learning environment (Epstein, 2002). In a social constructivist learning environment, any new knowledge acquired by the student occurs in the "zone of proximal development" (Pearson Education Canada Inc., 2006; Riddle, 1999). This is an area that exists between what students can do independently and what they can do only with assistance. The teacher's role is to guide, encourage and support the learners in this zone. This assistance is known as "scaffolding" (McCarrick and Xiaoming, 2007; Riddle, 1999) and provides temporary support and a gradual release of responsibility of the new learning from the teacher to the learner. The goal of the teacher in the social constructivist environment is to ultimately have the learner operate at higher levels of independence.

Vygotsky argued that language and learning are intertwined (Riddle, 1999). This language includes dialogue between students and peers and students and their teachers. Using language to scaffold student learning in a social constructivist environment is one example. Reciprocal teaching is another form of dialogue promoted by Vygotsky (Riddle, 1999). Students are able to support the learning of their peers in the form of peer-assisted scaffolding. Technology can also provide scaffolding support. For example, a webquest (further explored in this thesis) is an example of electronic scaffolding. Students use a familiar format such as the Internet (the 'scaffold') to support their learning while they investigate new subject material (Jonassen, 1996; Jonassen, Carr and Yeuh, 1998; McCarrick and Xiaoming, 2007; Riddle, 1999; Robinson, n.d.; van Gelder, 2001; Wheeler, Waite and Bromfield, 2002).

The important characteristics of constructivism and the role of the teacher in the learning environment are shown in Table 1.

Designing Constructivist Classroom Learning Environments

It is possible to design and implement optimal instructional methods for students by understanding the potential of current technology in the classroom, the characteristics of today's learners and the implementation of appropriate learning theories. Numerous authors support the need for change in our classroom teaching methods (*Education Evolving*, 2005; Gahala, 2001; McCain and Jukes, 2001; van't Hooft, 2007) with most of them advocating a constructivist approach to incorporating educational technology into the classroom.

As shown in Table 1, a constructivist approach incorporating technology into the learning environment changes the teacher's role from being the source of all knowledge and delivering content via lectures to an environment that is more collaborative between the student and the teacher. The new role of a teacher is that of a guide, knowledge expert, model and even learner (Kuriloff, 2005; Gahala, 2001; McCain and Jukes, 2001, p. 115-120; Sword and Leggott, 2007). In this role, teachers might not know all of the answers but will direct the students' learning by creating problem solving and learner-centered environments (Halverson, 2005) based on the interests and motivation of the learners.

Table 1

A Comparison of Net Gen Learning Characteristics and a Constructivist Learning Environment Incorporating Technology

Net Gen Learning Characteristics	Constructivist Learning Environment	Teacher Role	Technology Role/Application
Multi-tasking	Active	Models	Hypermedia learning/Internet applications
Interaction	Collaborative	Guides	Group work on computers/webquests
Socialization	Conversational	Accepts dialogue as integral part of learning	Online communication/webquests, wikis, email
Engaging learning activities	Learner centered	Facilitates	Technology is part of the process/ Internet applications
Easily bored with traditional learning methods	Reflective	Creates engaging learning environments	Motivates/ Internet applications, Web 2.0, Lego Mindstorms
Curious	Authentic problems	Designs real world projects	Up to date resources/Internet applications
Diverse learners	Multiple paths of progression	Accepts flexible, customized learning	Accommodates learners of all levels/ all technology applications

Technology can be integrated into a constructivist classroom by having students complete collaborative group work and self-directed projects with the assistance of computers (see Table 1). Learning goals should be established at the beginning of the projects and students will be able to assess their own work against these outcomes. Technology assists learners in the "learning by doing" approach that constructivism supports. Students will be encouraged to use technology as a vehicle for positive, social interaction; another valuable characteristic of the constructivist learning environment.

This "new learning environment" will better equip students to develop skills required for their future. These new skills include: finding, decoding, evaluating and organizing data; processing media into new forms (such as blogs, wikis, and web pages); writing effectively; matching the message to the medium; and learning the ethics about information (Armstrong and Warlick, 2004). Other advantages of using technology in a constructivist environment include the increased motivation of the Net Gen students to learn (*Education Evolving*, 2005), higher productivity for both the students and teachers and a more progressive use of the curriculum. Authors who have focused on technology and critical thinking tend to agree that it is possible to combine the two successfully (Hopson, Simms, and Knezek, 2002; Jonassen, 1996; Jonassen, Carr and Yueh, 1998; Mauch, 2001; Papert, 1980; van Gelder, 2001; Wheeler, Waite and Bromfield, 2002).

Teachers who are likely to make the changes to include technology in their classroom are the early adopters and those who are highly motivated by digital media themselves (Becker, 2001; Cuban, 2001, p. 71). For these teachers, incorporating technology is relatively simple. In addition, many younger adults who grew up in the digital age are now entering the teaching workforce. These Net Gen educators are very likely to adopt new technologies into their teaching practice.

The challenge of technology integration into a constructivist learning environment remains with educators who are skeptical of technology. These educators are usually part of the aging workforce who have never incorporated digital media into their lives. Based on my experience, they often feel that there is not enough time in the school day to properly prepare lessons and incorporate technology into the classroom. These "barriers" to using technology in the classroom must be continually addressed by school boards. Placing computers in the classroom will not guarantee they will be used. The administration, school boards, professional organizations and teachers' peers should encourage the use of technology in the classroom. By offering educators professional development courses, appointing school technology leaders and providing time for teachers to create technology specific lesson plans, there will be more a supportive environment for all teachers who want to incorporate technology into the curriculum.

There are other challenges when using technology as a tool to teach critical thinking skills. Students may not necessarily be able to apply the lessons learned in one subject and transfer the learning between subject matters (Hewitt, 2001; van Gelder 2001, 2005). For example, technology that assists a student to solve math problems may not be effective in assisting the same student to write about their math problem. For students to be successful at transferring their knowledge, it is important for educators to demonstrate and allow students time to practice the transfer of higher cognitive skills (van Gelder, 2005, p.43) between subjects. The Nova Scotia Department of Education (2005, p. 5) also supports a connection of learning and ideas by encouraging teachers to incorporate cross-curricular teaching (i.e., learning about economics in Social Studies and incorporating math outcomes into the lessons).

Another difficulty in creating critical thinking skills in conjunction with technology is the physical layout of many existing computer labs. Labs typically promote "a one child per computer" scenario. This impedes communication amongst the learners and does not allow for proper functioning group work. Educators must be aware that this barrier exists and allow students the opportunity to move about the computer lab to engage in meaningful dialogue.

Integrating Critical Thinking Skills through Technology in an Elementary Classroom

Technology found in today's classroom can be supported by a constructivist learning theory to engage students' critical thinking skills. As shown in Table 1, many of the learning traits that exist with these technology products and applications connect to a constructivist learning theory and the learning characteristics of today's learners.

Internet Applications: Webquests, Internet Research and Website Analysis

A Webquest is defined, by Bernie Dodge, the creator of webquests, as "an inquiry-oriented activity in which some or all of the information that learners interact with comes from resources on the Internet" (Schrock, 1995). In other words, it is a modern day version of a treasure hunt with the goal to obtain information. Teachers initiate a series of questions that are problem based and the students are expected to use the Internet to guide their investigation. Information is obtained and analyzed to solve the problem(s) and typically, a webquest is completed with a group of peers. Webquests exist for all subject areas and grade levels and are easily accessible for teachers and students on the Internet.

Used in a constructivist learning environment, webquests are based on authentic, real world problems with open-ended solutions (Bradshaw, Bishop, Gens, Miller, and Rogers, 2002) and support higher level thinking (Barnes, Marateo and Ferris, 2007; Bradshaw, Bishop, Gens, Miller, and Rogers, 2002; Buffington, 2007). These characteristics are present in this example of a science based webquest for a grade 3-5 class:

> Your first task is to find the missing animals. You will have to find foods that will make the animals want to come back to the zoo. While searching for the animals you need to research the animals eating habits as well as their habitat. After getting the animals back to the zoo you will begin your second task of creating a habitat that will make the animals want to stay at the zoo because they feel safe and happy there. (Moll, n.d.)

Webquests require students to identify problems, acquire information related to the problem, organize and analyze the data for a probable solution. Modifications to their data may be necessary and the process could be repeated. As students complete the webquest, they are encouraged to analyze their solutions against their peers and reflect on their learning. This process follows the problem solving steps and strategies identified by Guffey (1998) which are important to enhance a student's ability to think critically.

Internet research occurs when students are assigned a task such as investigating information on an animal of their choice or finding a recent news article on the Internet. The task may or may not include a position to support. The research method is based on "looking something up" and can lead to data acquisition. Similar to a webquest in the information gathering process, Internet research does not usually require students to analyze the data unless specifically stated in the project outline.

Internet research and webquests can take the place of a traditional book review or study involving books. They can be linked to many areas of the curriculum depending on the subject area(s) being studied. For example, a webquest or Internet research that connects to the Nova Scotia Grade Four Language Arts Curriculum through outcome 8.1 is: “Use strategies in writing and other ways of representing to i) Formulate questions and organize ideas ii) Generate topics of personal interest and importance” (Nova Scotia Department of Education, 2000).

Website analysis is the ability to critically review the information on web pages for authenticity, applicability, authorship, bias, and usability (Schrock, 1995). Website analysis can be used in conjunction with webquests and Internet research or as a stand-alone lesson. The scrutiny of web material is also known as ‘media literacy’ and is supported throughout the Nova Scotia curriculum. For example, in the Grade Four Language Arts Curriculum, outcome 7.1 states “Use their background knowledge to question information presented in print and visual texts” (Nova Scotia Department of Education, 2000). Teachers use this application to assist in instruction of the ethical acquisition and reliability of information found on the Internet. Students are to complete an evaluation of the websites that they visit by responding to a series of questions such as: Is the website up to date? Is the author credible? Where does the data come from? Is it bias in any way? Templates for website analysis can be accessed on the Internet at Kathy Schrock’s Guide for Educators (1995).

Website analysis and Internet research in a constructivist classroom encourages the student to personalize their learning when the teacher designs an open-ended task (for example, complete a research project on a sea creature of your choice). Internet research projects and website analysis should be designed so that they are an interactive, group process. This creates communication amongst the participants, a valuable characteristic of learning which stimulates deeper understanding of the content being studied. Students should be given specific learning criteria by their teachers at the outset of their work and they can evaluate their progress against these standards throughout the course of the project through the use of a rubric.

There are a number of parameters to consider when using Internet applications in the educational setting. The webquest or Internet research assignment must be properly designed to include a problem, a position or an open-ended task. There should be a component of data analysis and reflection. If these components are not present, the project becomes focused on data acquisition. A litmus test for proper design could be, if students are able to “cut and paste” their answers then they are not becoming fully engaged with their information.

Another challenge that exists when students use the Internet for research is the possibility of becoming “navigationally disordered” (Bradshaw, Bishop, Gens, Miller, and Rogers, 2002). The vast amount of information on the Web is not sorted and organized like a library. Therefore, students may get off task without realizing it and find content that is not intended for the students. Teachers should design their Internet-based projects by providing specific websites for their students. Content and reading levels need to be considered when selecting sites. This support allows students to have a familiar component to their research and provides teachers with some content control.

Through discussions with other professional teachers, it is agreed that learners can easily find data on the Web. Everything is now just a “Google” away. However, based on personal experience, educators give less time to developing students’ skills at evaluating websites than they do to instructing students to gather data from websites. Students need to be taught to use the criteria of: authority, accuracy, objectivity, currency and coverage (Armstrong, Warlick, 2004), when reviewing Web pages. Without the proper analysis, website review is a low level thinking skill.

When students use Internet applications in any setting, they are exploring a world that expands beyond the safety of the school walls. Internet ‘surfing’ brings the possibility of children being exposed to online predators, discovering inappropriate content and being unduly influenced by advertising. While many schools utilize Web security programs, no program is 100 percent secure. And although the CRTC monitors the amount of advertising for children on television, it does not monitor the Internet.

Parents, teachers, principals, boards and education departments must be ever vigilant in protecting our children from these online threats. Methods include Internet Authorization Policies, media literacy and teaching students to become personally responsible for staying aware and away from offensive content.

Software: spreadsheets, databases and graphic organizers

Software on classroom computers can be operated by students for activities that will encourage their higher cognitive thought processes. Software applications such as spreadsheets, databases and graphic organizers can be used to promote critical thinking (Jonassen, 1996).

These software applications connect to all subject areas in the curriculum, with spreadsheets having a particular strength for math activities. An example of a Grade four math outcome that could be used with a spreadsheet is: "F1- recognize and use a variety of methods for the collection and organization of data." (Nova Scotia Department of Education, 2000). Using a spreadsheet, database and graphic organizer would replace more traditional tools such as record keeping in a journal, flowcharts and concept maps on paper such as webs and Venn diagrams.

Spreadsheets, databases and graphic organizers are widely available in most elementary classrooms. When used in a constructivist manner, they support student learning at higher levels of thought (Jonassen, 1996; Jonassen, Carr and Yueh, 1998). Spreadsheets and databases are capable of capturing large amounts of data. When spreadsheets/databases are used in a real world context such as capturing the weather statistics for a 3-month period, students are able to visualize the connection between their learning and skills required outside of the classroom. Having the students evaluate, sort, organize and manipulate the information, creates the environment for higher learning processes.

By creating "what if" scenarios for the students using the data they collected, the learners are further pressed into analyzing the information for trends and content analysis. Importing the data into a graph allows the students to visualize their information and creates the opportunity to illustrate how changes can impact various data fields. For example, if students were gathering the data on gas prices for the past year and they viewed a large increase/decrease during a certain season, they could assess what factors may have lead to these changes.

Graphic organizers (also known as concept maps or mind maps) allow students to enter their ideas into a visual format. Concepts are linked between ideas. It is the connection that requires critical thought. As Jonassen (1996) states "The process of articulating those links requires learners to search through the range of possible relationships in order to define the relationship that exists in the context in which they are studying" (p. 98). For example, if students are beginning to plan a presentation on pollution, they might begin by examining air pollution. Linking to this idea may be the realization that Nova Scotia Power's coal burning electricity plants also produce air pollution as a by-product. This concept could then be linked to the use of power at home which could then be connected to turning off the lights which will reduce air pollution.

Once again, if educators truly desire their students to engage their higher level thinking skills, they must design appropriate assignments. It is very easy for these software applications to become a format for capturing data only and promoting shallow thinking. The focus must be to use the technology to assist learning, not to use technology just for the sake of using technology.

Another challenge of this software is the ability for the younger students to use these software applications properly. Robinson (n.d.) raises the concern of "developmentally appropriate software." While graphic organizer software such as Inspiration (suitable for grades four and higher) has modified their product for lower grade levels into Kidspiration, other popular spreadsheet and database programs (such as Microsoft Excel, Microsoft Access) are designed for the business community and higher level educational institutions. If these applications are used in the classroom, teachers must modify and assist the younger students so they can be successful.

Lego Mindstorms

Lego Mindstorms is a technology tool that has been available for approximately 10 years. It combines the traditional Lego building bricks along with a 32-bit microprocessor (called the NXT) that has touch, sound, sight and audio sensors. The central processing unit controls the movement and serves as the "brain." Using the Lego bricks in conjunction with the NXT, it is possible to build numerous "robots" that can complete a number of simple purposes such as keeping time like a clock or shooting a marble in a catapult. To date there is not another commercially available product that competes with Lego Mindstorms.

Lego Mindstorms is based on constructivist theory. In fact, the name 'Mindstorms' comes from the book of the same name by Seymour Papert (1980). Papert developed the LOGO computer programming language which is a simple programming language based on math that allows children to become computer programmers. This programming language has evolved and Papert worked in conjunction with MIT and Lego to help create the Mindstorms product (Papert, n.d.).

Mindstorms is a beneficial tool for implementing technology into the classroom environment. Many students have prior experience using Lego bricks. The graphical interface used for programming is user-friendly and age appropriate for students in an elementary classroom. It is easy to create problem based learning environments with the Mindstorms kit. An example of a Grade Four Science outcome that could be used in a constructivist classroom using Lego Mindstorms would be: “Carry out procedures to explore a given problem and to ensure a fair test of a proposed idea, controlling major variables.” (Nova Scotia Department of Education, 2000) Such a problem could be: “Many people in the world are colour blind. You are to develop a robot that will help them distinguish colours they are unable to distinguish.”

While designed and sold as an educational product, the empirical research completed on Mindstorms is limited. To date, only a few bodies of work using the Lego Mindstorms kit are readily available for review (Cameron, 2005; Gibbon, 2007; Mauch, 2001; Ricca et al. 2006). Further research is required in this area to see how Mindstorms could impact students’ critical thinking skills.

An impediment to this product is the cost. One kit costs over $350 and thus prohibits the quick adoption of Mindstorms into elementary classrooms across the country. Creating group tasks with a limited number of Mindstorm kits in the constructivist classroom is a challenge that teachers will have to address in their project design.

Web 2.0 Applications

One of the technological trends that has already seen growing acceptance with students is Web 2.0 applications such as wikis, blogs and social networking sites (for example, Wikipedia.com, blogger.com and Facebook.com). Web 2.0 applications are the next generation of applications available on the Internet (Thompson, 2007). Compared to most Web applications, Web 2.0 services are more interactive, allow for user input and can customize the learning experience to the demands of individual students.

Wiki (derived from a Hawaiian word for ‘quick’) for example, is “…a unique interface where information is not fixed (as in a print model) but fluid and flexible to meet the needs of the community…” (Ferris and Wilder, 2007, p. 1). Wikis are websites with “open-editing” which means that anyone can read and alter their content with security clearance. In contrast to a blog, where there is only one “user” who moderates the content and many “users” who are able to post comments chronologically but not alter any content.

Used in a constructivist teaching manner, Web 2.0 applications allow greater flexibility in student knowledge acquisition and create a collaborative learning environment for the students. Social sites such as Facebook and applications including Microsoft Instant Messenger could be incorporated into group projects by allowing students to dialogue with knowledge experts. Wikis and blogs allow for the users to provide content to web pages. Reporting on projects, changing the organization of group work and updating findings on current assignments are several ways of incorporating wikis and blogs to promote critical inquiry. From the Nova Scotia Grade Four Social Studies curriculum, a wiki could be created for students to explore the following outcome: “Identify and explain the rights and responsibilities of individual citizens in a local, national, and global context.” (Nova Scotia Department of Education, 2000) Students could then explore these concepts and add to the wiki on this topic. If new information was acquired students would have the power to make such changes to their existing body of knowledge on the wiki.

Web 2.0 applications are appealing to educators and students because they are widely available to everyone, everywhere. However, with so many users of wiki websites there exists the challenge of credibility. It is easy to modify a text entry to include inaccurate information or falsified data. Educators must ensure that students utilize their critical thinking skills when analyzing wikis websites for content. These applications are relatively new to the school environment, and therefore a school's Acceptable Use Policy (AUP's) for technology may require retooling to allow students to create Web content.

Future Trends: Gaming

Technology is continuously changing and advancing so it is important for educators to look ahead and see possible future uses with computers. One possible combination of education and technology exists in the field of gaming. Halverson (2005) reports that simulation-based games (currently beyond what is available in educational software) when introduced into the classroom "…are powerful learner-centred environments that scaffold learning content in terms of what students need to know and when they need to know it" (p. 5). These constructivist tools are highly motivating, allow for immediate assessment feedback and are richly engaging. Games can provide what has been called by Norman (as cited in Chen and McGrath, 2003) as the "optimal experience" in learning with technology: the point where the task is so all encompassing, the outside world is forgotten. If only all teachers' lessons could have this effect!

Summary

This review of the literature acknowledges four core themes: critical thinking is a valuable and necessary skill, technology is a key learning component for today's students, constructivist learning theory is the optimal learning model for incorporating technology and there exists promising methods for incorporating technology into the constructivist learning environment to promote critical thinking. The following chapter describes the methodology for the action research project that attempted to engage students' critical thinking skills using Lego Mindstorms.

Chapter 3

"Knowledge is only part of understanding. Genuine understanding comes from hands-on experience." (Seymour Papert as cited on Lego Mindstorms packaging, n.d.)

Methodology

This study investigated whether the use of the Lego Mindstorms robotic kit had any impact on grade four students' critical thinking skills. This chapter outlines the research method used to conduct the research study, the setting, participants, data collection methods, data analysis and limitations in the research approach.

Methodology

For the purpose of examining the question: *Do grade four students' critical thinking skills improve when the Lego Mindstorms kit is used as an instructional tool in a constructivist learning environment?,* qualitative action research was the research medium for the investigation. Action research according to O'Leary (2004) is, "A research strategy that pursues action and knowledge in an integrated fashion through a cyclical and participatory process. In action research, process, outcome, and application are inextricably linked" (p. 139). In addition, "Action research is often used in workplaces…where the goal is to improve professional practice" (p.139).

Action research was used for this study because I wanted to conceivably increase my knowledge and understanding of the application of critical thinking skills amongst the grade four students in my classroom using Lego Mindstorms. Action research provides

"…the goals of gaining insight, developing reflective practice, effecting positive changes in the school environment, and improving student outcomes…" (Mills as cited in Callison, 2007, p. 40). The research project took place in a constructivist learning environment, so it was necessary that the research methodology and data collection tools valued and would operate in the social aspect of constructivist learning.

Action research has been used in the field of education (Callison, 2007; Collier, Guenther, and Veerman, 2002; Mensing-Triplett, 2001; Webster, 2003) for many years. The action research method allows for full involvement of all participants (as opposed to using only a sample of the participants). It creates the opportunity for the teacher/researcher to critically reflect on the process at any point (highlighting something that may or may not be working) and permits the teacher/researcher to implement necessary changes to test both data and interpretations from earlier cycles of the investigation (Dick, 1999).

Numerous models of action research (O'Leary, 2004; Tomal, 2003) exist for examining real-life events. Action research is a cyclical process allowing for numerous cycles of examination to occur. For the purpose of this study, the steps proposed by O'Leary (2004) were the framework:

1. Observation and Data Collection
2. Reflection
3. Action Planning
4. Taking Action

Prior to the research project beginning, some pre-teaching of instructional methods and learning practices occurred. Although this pre-teaching was not a component of the research project, it helped to develop the constructivist learning environment. It provided the participants with background knowledge and experience with the process, tools, language and learning environment prior to the beginning of the actual research project. The pre-teaching included lessons and practice with:

- Group work: How to be a valuable member of a group, how to interact in a group, roles in a group, etc.
- Problem solving steps: Reread the problem, identify the problem, use a strategy(s) attempt to solve the problem, reflect and evaluate the process.
- Problem solving strategies: Trial and error, guess and check, elimination, talk about it, draw a picture, use a formula, and find a pattern.
- Reflection journals: How to use for reflection purposes.
- Rubrics: How to use rubrics for reflection purposes.
- Free exploration of the Lego Mindstorms kit.

Proceeding the first cycle, a self-refection rubric composed of traits of critical thinking was administered to determine the present level of critical thinking skills the participants possessed. The results established a 'benchmark' (Tomal, 2003, p. 20) for the level of analytical skills the participants owned. The benchmark was useful in comparing the average results for each cycle of research to illustrate any change in the student's ability to use higher level cognitive thought.

An open-ended problem was used to direct the method of inquiry for each cycle of the project. Open-ended problems are ideal for providing the opportunity for critical thinking to occur. The structure of these problems allows for variable methods and solutions to transpire. Similar to open-ended questions, there are multiple explanations to the problem with no one "right" answer. "Open-ended questions also encourage students to think and respond creatively, without fear of giving the "wrong" answer" (Potts, 1994). The problem (based on the Grade Four Science and Math curriculum) was first posed to the students and they then used Lego Mindstorms and a computer to program the robot in an attempt to find a possible solution.

During the investigation, my role as researcher was that of a candid participant (O'Leary, 2004, p.172). My participation was very limited during the planning, building, programming and subsequent trials, as my focus was primarily on observing and taking field notes on the participants. However, due to my dual role as teacher-researcher, students were free to ask me questions for clarification purposes at any point during the process. Students were also made fully aware of the nature of the research project and my dual role prior to the research beginning.

Groups of two to three were used in this study because it was identified as the ideal number in previous research (Hussain et al., 2006, p. 188) for use with Lego in the classroom.

Cycles of Action Research

The research project consisted of three phases:

Action Research Cycle 1: The participants were required to work in a group of three to program a pre-built robot to move 65 cm.

Action Research Cycle 2: The participants were required to work in a group of three to attach a sound sensor to a pre-built robot. They were then required to program the robot to start movement after a sound of 80 decibels was made, and then travel 150 cm.

Action Research Cycle 3: The participants were required to work in groups of three to create a robot that would help someone with a disability. It had to travel around the classroom and make sounds with various pitches. The participants were also required to create a plan that included: a diagram of the robot, a flowchart of the program and a paragraph outlining what the robot would do to help the disabled person.

Setting

The research for this project took place at a Primary to grade six elementary school within the Halifax Regional School Board during the months of February to May 2008.

The research project was designed with the Nova Scotia Education curriculum outcomes from the grade four science and math curriculum (Nova Scotia Department of Education, 2006) in mind. This allowed for some of the research project to take place within the assigned instructional hours of the school day. When it was not possible to complete during instructional time, the project was completed over the lunch period.

Participants

The participants for this study consisted of 22 grade four students ages 9 to 10, from a Primary to grade six, elementary school located in Halifax, Nova Scotia. Forty-three per cent of the participants were male and fifty-seven per cent were female. While previous Lego experience varied among the participants, none of the participants reported using Lego Mindstorms before this project.

Consent for participation was obtained prior to the research beginning. A letter of information and an informed consent form was sent home to each child's parent/guardian explaining the research project with the option of participation or non-participation (see Appendix B).

Data Collection

Data collection began in February and continued until the project ended in early May. Three cycles of action research were completed within the classroom, using a variety of data collection methods to increase the validity of the data through triangulation.

Observations of the participants by the teacher-researcher were completed during periods of math, science, lunch hour and free choice time(s). Records of the participants' actions, dialogue between group members, attitude towards the challenge and observations of the group's product were created. These annotations were recorded manually as field notes and then transcribed digitally at a later time. Upon conclusion of the challenge, the participants completed a series of reflection questions (see Appendix E and F) and a critical thinking self-evaluation in the form of a rubric (see Appendix C). From each group, one student was randomly selected to complete a one-on-one, semi-structured interview. Interviews initially followed a structured format of core questions for continuity and consistency but these semi-structured interviews also allowed for a non-structured component. If required, questions and issues were discussed and clarified in more detail and depth. All interviews were digitally recorded. Refer to Appendix D for a list of core interview questions.

Data Analysis

Data analysis for this project was thematic analysis. Thematic or content analysis (O'Leary, 2004, p. 199) according to Ritchie and Lewis (2006) is the way "…both the content and context of documents are analyzed: themes are identified, with the researcher focusing on the way the theme is treated or presented and the frequency of its occurrence" (p. 200). Themes can be developed from inductive analysis, review of relevant literature, prior experience of the researcher, the nature of the research question and during the data collection.

Thematic analysis was used because it presents a systematic way of analyzing qualitative data (Greenhalgh and Taylor 2005). Repetitions, patterns, keywords, differences and irregularities were coded and indexed manually into the appropriate theme/sub-themes and analyzed based on the research question. O'Leary (2004) also explains the importance of exploring concepts (p. 197) (such as gender) and non verbal cues noted by the researcher in the analysis of the information to provide a more complete understanding of the data.

Once the data was sorted, the detail and distinctions within each theme were analyzed by reviewing and considering "What is happening?" in each. These themes were then compared to the results from each of the three cycles of research.

Research Limitations

Limitations are features that may have a negative impact on the results of the research. Several limitations for this project included the prospect of researcher bias being introduced as a result of the dual teacher-researcher role. There is no way of completely eliminating this bias. I provided full disclosure of my role to the participants and tried to remain impartial at all times while collecting the data to increase the validity. Triangulation was used by collecting data from different sources as previously described, increasing the reliability of the information and the validity of the results. While it would have been beneficial to have another person code and analyze the results, this was beyond the scope of this study.

Another limitation for this research project arose when many of the participants in the class had to leave for assignments in other specialist classes. Attrition (Tomal, 2003, p. 84) is a threat to the validity of a study when there is no longer the proper sample size; however, there was an adequate student sample remaining in the class during these periods for the study to continue. While this may have increased the 'randomness' within the group context and provided students with a real-world situational problem of missing group members, it made scheduling the research times very difficult. Only one group of three could use Mindstorms at any one time (based on the fact that there was only one kit in the classroom and each group personalized the robot by building it to complete the task) and if two of three group members had to leave and were unable to continue, I felt the validity of the research data for that particular group would be compromised. While this limitation was manageable during cycle one, it resulted in a loss of research time during cycle two. To minimize the impact on cycle three, I broke the class into two groups: A (students who attended the specialist class) and B (those who did not attend the specialist class). Within these two groupings, random groups of three were then created and scheduled appropriately. According to Greenhalgh and Taylor (2005), this situation is not a threat to validity because qualitative research does not seek to have an "average" to replicate the findings on the population at large. Qualitative research should use participants who meet the research requirements (a convenience sample) and will provide insight into the issue being studied rather than be concerned with pulling from a true random sample (Marshall, 1996, p. 523).

It would have been beneficial to have more students complete the activities in each cycle to increase the sample size. As time to complete the data collection phase decreased, it became evident that having two or more Mindstorms kits in the classroom would have been beneficial However, considering the high cost of the Lego Mindstorms kit ($350), this was not feasible.

Finally, this action research project had no control group. During the dissemination of the results it is difficult to determine if any change to the student's thinking is a result of using Lego Mindstorms or other lessons in the class/school or even outside of the school environment. There would have been a benefit to having one student for each challenge complete the activity alone thus providing a comparison group for the collaborative work data. However, in qualitative research, the strength lies in the "richness" of the data. While qualitative research can be reproduced, it relies on triangulation to increase the strength of the findings.

This study provided me with the opportunity to obtain an "insider's" view of students' thinking processes. The information obtained in the Lego Mindstorms and critical thinking research project is presented in the next chapter.

Chapter 4

> "Our purpose should be…to transforming any learning environment from a place where learners 'do their time' into a place where learners actually 'want to do their best'" (Spitzer as cited in Chen and McGrath, 2003).

Results

This chapter presents the results of the thematic data analysis examining the effect Lego Mindstorms had on the critical thinking skills of students in a grade four classroom over a 12 week period. A student self-assessment rubric on critical thinking was administered on the first day prior to the start of the project.

Qualitative research methods were used. The data was triangulated through the researcher-observer field notes, student self-reflection questions, student self-assessment rubrics and interviews. Research data was gathered and guided by the question: "*Do grade four students' critical thinking skills improve when the Lego Mindstorms kit is used as an instructional tool in a constructivist learning environment?"*

For each cycle, data was grouped and indexed into themes and sub themes. The data was analysed and the findings influenced the procedures for the next cycle. The results for each of the three rounds of action research are described in the following chapter.

Cycle 1

The first cycle of research began by randomly placing students into groups of three. They were presented with an open-ended challenge using a pre-made robot. The challenge was stated as: "*You are to program a robot to travel 65 cm*." The time to complete the task was approximately 60 minutes which allowed the participants time to program the robot and test their program. Based on the distance the robot traveled, students could then modify their program and repeat the process through four to five trials. Seven groups (n=21) participated in the challenge with only two participants reporting that they successfully completed it.

After completing the challenge, students were asked to complete a self-reflection questionnaire and self-evaluation rubric. Three random students were selected to participate in an interview to complete the data collection process for the first cycle.

Cycle 1 Findings

After compiling the data from the first research cycle, several themes emerged. While some of these themes were pre-established based on the review of the literature and nature of the research question, other themes were not expected. The findings and themes from cycle one are presented in the following sections.

Collaborative Work

As the participants completed the first challenge, it became apparent how much they valued the benefits of working in a group. Some students reported completing the assigned task in a group was "easier" than working alone. The self-assessment rubric administered at the end of the cycle reported an increase in their collaborative work ability from the benchmark (see Table 2). Many students became engaged in language that included negotiation, confirmation and questioning which it appeared was necessary to successfully work in a group to answer the first challenge.

Problem Solving

The open-ended challenge using Mindstorms was a key characteristic for determining if students would engage in any form of problem solving. During the first cycle, there were several indications to support this claim. In the interviews and self-reflection questions, numerous problem solving strategies were mentioned. Trial and error, guess and check and elimination were the problem solving strategies referred to in the reflection questions. However, when comparing the cycle one rubric total for problem solving to the benchmark rubric, a net decrease in problem solving ability was reported. There are several possible reasons for this reduction. This was the students' first experience with Mindstorms and without previous background experience, only two participants reported successfully completing the challenge. It is also possible that the sample population felt that by not solving the challenge, they did not problem solve correctly.

Technology Use

Most of the participants who responded to question three of the questionnaire reported feeling the most engaged in the project when they were using the computer to program (68 %). A possible development was highlighted when slightly more females (6) reported being more involved with the programming than the boys (5). At this point, there are no conclusive reasons for this gender preference, but it is worthy to recognize and track this potential trend.

Reflection

The element of reflection is an important component of critical thinking. Although there was evidence of reflection during the interviews, self-reflection questionnaires and rubrics in cycle one there was little evidence of it in the field notes. I felt this was a key component missing because students should be reflecting during, as well as after the process. Several possibilities for the absence of reflection exist. The participants were so involved in their task that they did not have time to reflect during the process. It is possible that reflection is an internal process, apparent only when questioned.

Other: Negative Feelings

During the course of the first cycle of research, an unexpected development surfaced. There were negative feelings and a fear of failure voiced amongst several of the participants for not completing the task to their liking. While the students were noted to be “excited”, “motivated” and “on-task” for the assignment, conflicting words such as “discouraged” and “failure” began to appear in their dialogue. I wondered if this would impact their thinking and began to question along these lines during interviews. One additional question that I asked was: “Did you view this as work or play?” in anticipation that it may provide some insight into the negative feelings. The negative feelings and work or play were trends that benefited from the findings of further research cycles.

Based on the initial findings of the first cycle, there were several trends that merited additional research (programming and gender, reflection, group work, problem solving and negative feelings). For the second challenge, the programming content was increased and a building component added to compare how these variables, through scaffolded learning, impacted critical thinking.

Table 2

Self Assessment Results from Critical Thinking Rubric

Self-Assessment Critical Thinking Rubric	Collaborative Work	Problem Solving	Questioning	Reflection	Supporting Evidence	Connections	Inference
Average for Benchmark	**3.17**	**3.09**	**2.91**	**3.17**	**3.00**	**2.70**	**3.00**
Average Cycle 1	**3.63**	**3.00**	**2.95**	**3.42**	**3.00**	**2.68**	**3.11**
Average Cycle 2	**3.76**	**3.12**	**3.06**	**3.35**	**3.12**	**3.12**	**3.18**
Average Cycle 3	**3.63**	**3.13**	**2.81**	**3.38**	**3.13**	**3.50**	**3.25**

Cycle 2

Participants were randomly placed into new groups of three. They were presented with a new open-ended challenge stated as: "*Using the robot from challenge 1: add the sound sensor to it, program the robot to start with a noise of greater than 80 decibels and* *travel a distance 150 cm.*" This challenge added a building component that required the students to add a sound sensor to the pre-made robot. The time allotted was the same as the first challenge with approximately 60 minutes to build, program and complete four to five trials. Six groups (n=17) participated in the challenge with 10 participants reporting they successfully completed it.

After completing the challenge, students were then asked to complete a self-reflection questionnaire and self-evaluation rubric. Five students were randomly selected to participate in an interview.

Cycle 2 Findings

The analysis of the second research cycle continued the research into several previously discussed themes and several new themes that became more evident during this cycle.

Collaborative Work

The importance of working collaboratively in a group continued to appear in all of the data collection tools. Once again, the value of group work increased from cycle one to cycle two in the self-assessment rubric. Collaborative work was also scored the highest of all the categories. This result suggests that students feel they are good at working in groups and they recognize the value of it too. "Like working in a group really helps a lot. Because like if they have ideas, they'll share them…" (Grade 4 student, personal communication, March 2008).

A repetition in dialogue identified in both cycles was that students verbalized working with their classmates in groups as "easier" than working alone. It also was evident in several quotes including "Like, because their previous experience, they knew how to work some stuff that I didn't" (Grade 4 student, personal communication, April 2008).

Problem Solving

During the second cycle, there was a noticeable increase in evidence supporting the participants' problem solving abilities. While trial and error was the most popular problem solving strategy mentioned, elimination and guess and check were also highly ranked. An increase of 0.12 from the previous cycle on the self-assessment rubric in problem solving was also noted (see Table 2). The first self-reflection question asked the participants whether Mindstorms helped them to identify and solve the problem. There was a resounding "yes" response to this question (seven in total). These improvements all coincide with the higher success rate reported for the second challenge: 59% of the students successfully completed this challenge compared to 9.5% in the first cycle.

Data was obtained through an interview question on the possibility of transfer of critical thinking skills to different subject areas and everyday life by the participants. The question added to the interviews for the second round was "Where have you used that strategy before?" While the initial responses were positive, indicating a transfer of critical thinking skills, this question would be reviewed following the third cycle to possibly provide more conclusive results. If the transfer of higher level thinking skills were to hold true, there should be language visible that supports problem solving as captured by the data collection tools such as “I have used this strategy before at home”. There should also be an increase in the connections trait on the self-assessment rubric because connections would indicate that the students can “link” their learning from one subject to another.

An additional component during this round was the integration of a building element to the challenge to determine what problem solving techniques were employed during this phase. Based on the field notes and interviews, the participants used elimination and visual discrimination (i.e., block type A would/would not fit into block type B) to assist them when building with the Lego bricks. Building and problem solving strategies was a relevant theme to continue to monitor in the third cycle.

It also became apparent that students had difficulty describing the thinking process. This was noted by long pauses after a question then followed up with a response such as “I’m not sure”, or “I don’t know”, or even no response at all. It could be they are unfamiliar with responding to “Tell me about your thinking” questions. It could also be the discord between taking something abstract (in this case, their thought process) and articulating it into words.

Technology Use

Programming the robot using the computer provided the most engaging part of the second challenge for the participants. The results from cycle two did not highlight a significant difference in the preference for programming by gender.

However, it was noted in this phase that the physical location of the students around the laptop during the programming was repeating itself. The laptop being used could physically support only one person in front of it. While one person entered the data, the other two group members would always be on the left and the right of the lead programmer. This layout became the preferred configuration for all students to communicate their ideas and have input into the programming.

Reflection

The second cycle of research provided more insight into the participants' reflection process. During this round the teacher-researcher identified that the participants spent more time reflecting. Participants questioned why something wouldn't work, "Shouldn't we use sound to get it to start?" (Grade 4 student, personal communication, April 2008) and became more likely to review their program for errors. One group even asked to have their first cycle sheet to compare to their second cycle sheet.

However, the average score on the rubric for reflection dropped slightly (0.07) during this round. This could be attributed to the students' success at the task and possibly they felt that if they were successful, they didn't need to reflect.

Other: Negative Feelings

A notable decrease in the expression of negative feelings was exhibited during the second cycle. This could be attributed to the higher success rate achieved in the second challenge. Several participants confirmed that this was a more challenging task than the first. However, even for those participants who did not solve the challenge, the word "failure" was never mentioned. In its place a new word started to appear: "fun"!

Emerging Themes:

Gender

The gender of the participants and the success rate was not an issue during the initial research cycle. However, during the second round a possible gender disparity was noted when more boys (100%) reported successfully completing the challenge than girls (30%). The participants who did not effectively complete the challenge were all females (seven in total). Many of the female participants reported that they had no previous experience with Lego and they found it difficult to use. During the building phase, the female participants were more visibly frustrated when using the Lego pieces than the male participants. "How do you attach it?" (Grade 4 student, personal communication, April 2008) was an example of a comment made by one of the girls. Gender differences were an area that would be beneficial to investigate further in the next round.

New Problem Solving Strategies

For the participants who completed the second challenge (and if there was time remaining), additional challenges were assigned. The format for these extra tasks were:

1. Program the robot to return to its original starting point.
2. Program the robot to turn left and right and return to its original starting point.
3. Challenge yourself! (Free exploration.)

As the challenges increased in difficulty, a noteworthy increase in motivation and enjoyment was observed. Also, as the assignment increased in complexity, new problem solving strategies were employed by the participants not mentioned or observed in the first round. During the field work, it was noted by the researcher that several students tried modeling, using pictures/maps and visualization techniques.

These results were unexpected and should be explored further. The influence of more choice, more challenge and more variables would be integrated into the third cycle to see if there were indeed further findings to support the students' increased problem solving strategies and critical thinking skills.

Cycle 3

Participants were randomly placed into new groups of three. The challenge was stated as: "*You and your group are to create a robot that will help someone with a disability! It must be able to travel about their home and make sounds with various pitches. Your group is to create a plan that will include: a diagram of your robot, a flowchart of your program, a paragraph outlining what your robot will do to help the disabled person. This is a timed challenge. If your group is selected, you will have 120 minutes to build, program and present your robot!"*

This challenge introduced several new concepts. First the students had to devise a plan including a drawing of their robot and flowchart of their program. Secondly, the students had to completely build a robot to satisfy the challenge requirements. This was also a timed challenge with 120 minutes to complete the all three phases (building, programming, trials) to solve the task. Three randomly selected groups (n=8) participated in the challenge with zero groups reporting they successfully completed it. A smaller sample was used due to time constraints and scheduling requirements of the students.

After completing the challenge, students were asked to complete a self-reflection questionnaire and self-evaluation rubric. To gather additional data, the self-reflection questionnaire was revised (See Appendix F). The additional questions were similar to those asked during the interview. Two students were randomly selected to participate in an interview.

Cycle 3 Findings

The analysis of the third research cycle continued the examination into several previously discussed themes and several new themes which became more evident during this cycle. The data collected provided some insight on the impact that a challenge with few limitations would have on student thinking.

Collaborative Work

Strong support for group work continued amongst the participants in the third cycle. It was noted again in the third cycle that group work is "easier" than working alone. The participants however, began to diversify their roles in the groups during this challenge. In one case, this meant a division of the building tasks, in others it meant one member would watch the computer while the others ran the robot. The division of tasks within the group is an efficient and effective plan for completing the work but it was not reported in any of the data collection methods by the participants themselves. It was only observed in the field notes.

Problem Solving

Problem solving continued to be documented in all of the data collection. There was strong evidence of problem solving in the language used by the participants. Guess and check, trial and error and talking about the problem were the most commonly cited strategies used in the third challenge.

The transfer of problem solving skills was supported by an increase in the connections trait on the rubric (0.8 higher between the benchmark and cycle three, see Table 2) indicating that there was a possibility that students linked their problem solving skills to other subject areas.

During the building component, it was noted that the participants continued to use visual discrimination ("Oh, these are the wrong size though!" Grade 4 student, personal communication, April 2008) and trial and error for problem solving strategies. The use of problem solving strategies was transparent to the participants, who did not report the use of any problem solving strategies. These were only observed in the field notes by the teacher-researcher.

Several students had difficulty again articulating their thinking. The students also saw their problem solving skills isolated to one component, the programming, and failed to see how it might overlap into the building phase.

Technology Use

Similar results from cycle one and two were recorded with the programming aspect being the most challenging or "enjoyable". This is an interesting result for the third cycle because the programming was much more complex. It appeared that by increasing the programming requirements, there were not any adverse effects on the participants. Using the computer remained a favourite part of the task and the programs were more complex than any of the previous cycles. Many of the students indicated that the flowchart helped them when it came time to actually program because they were "better prepared".

Reflection

The third cycle continued to demonstrate support for the participants' ability to reflect in all tools of data collection. The self-reflection rubric indicated an improvement over the baseline for reflection (0.21). The participants were observed questioning and reviewing their work. "Wait! The touch sensor won't touch" (Grade 4 student, personal communication, April 2008)! In the field notes it was encouraging to see the students use their planning tools for reflection purposes as well. As one participant indicated, it helped them because they were more ready and they wasted less time.

Gender

The issue of gender was not as defined during the third round. This time all but two members of the sample (one male and one female) had experience with Lego. Some participants may have included their experience with Lego from previous challenges. It is inconclusive to say that the gender disparity would have continued if the sample size was larger and a more balanced gender sample was selected.

New Problem Solving Strategies

At the end of the second cycle, the findings indicated that an increase in the challenge level led to new problem solving strategies being employed. To determine if this would continue, the third challenge was designed to be the most difficult of all. Upon conclusion of the third cycle, it appears that there is evidence to support more difficult challenges to potentially increase student problem solving skills. Participants continued to use modeling, visualization and pictures/maps to assist in their problem solving for these advanced challenges which supports the findings from cycle two.

New problem solving strategies also emerged. Participants began to make predictions of future events while they were in the programming stage. For example, one student stated "First this will happen, then this, and then this…" (Grade 4 student, personal communication, April 2008). This is an interesting approach to use because it requires some background knowledge on the subject matter and confidence in one's thinking abilities.

Another new strategy that was introduced was the use of one group member to physically monitor the progress of the program on the computer. This enabled the group to troubleshoot more quickly and efficiently. Two groups began to run the program several times so they could observe and accurately locate their errors. Previously in the first two cycles, the participants would only execute their program once before troubleshooting. Similar to cycle two, these new strategies were not highlighted in any data collection tools other than in the researcher's field notes.

Other: Negative Feelings

At the end of cycle two, a higher level of motivation and enjoyment was noted amongst the participants who completed the additional challenges. The third challenge was modelled by using a more in-depth, complicated, multi-staged problem. Given that no one completely solved the problem, the students still used words such as "fun" and "cool" to describe their learning with Mindstorms. This enthusiasm was appropriate because they did experience some partial success by designing and creating the robot to move through the classroom. During an interview, one student reported that the third challenge was the most difficult but his favourite because of the additional time to build and program with the robot.

Once again, several incidents of negative feelings reappeared when the challenge was not solved to some students' satisfaction. When asked how it felt not to solve the problem, one participant responded that it made them "A little worried" (Grade 4 student, personal communication, April 2008). While no group completely solved this challenge, most members of the sample group reported that Mindstorms helped them to solve and understand the problem. While this does not match the results, it indicates the possibility of a growing confidence in their skills.

Summary of Findings

The findings reported in this chapter demonstrate some evidence for the inclusion of Lego Mindstorms in a grade four classroom to support curriculum outcomes in math and science. By using the robotic kit as an educational tool, it is feasible to perceive that students are engaged in critical thinking. Based on the findings from all three cycles, it is possible to conclude that students liked working in groups to solve problems involving Lego Mindstorms. They were motivated to use the technology, however, the students' were not always happy with their results. The participants were able to reflect on their learning. New learning challenges appear to increase the motivation and thinking of the participants. There was not a clear pattern of gender differences across the three cycles, suggesting it is not a factor.

The following chapter will explore and analyze collaborative work, problem solving, technology, reflection, previous experience and gender in the context of using Lego Mindstorms to support critical thinking amongst grade four students.

Chapter 5

Analysis and Discussion of the Themes

This study's intent was to add to the growing body of knowledge on Lego Mindstorms and children's cognitive development. It was not meant to be a definitive report on inclusion for or against Lego Mindstorms in the elementary classroom. This chapter attempts to account for the overall findings of the study and the analysis is completed in the context of the research question. Questions for further research are also considered.

Collaborative Work

In a properly structured constructivist learning environment, Lego Mindstorms supports and can enhance group work. The positive role of Lego Mindstorms on collaborative group work as reported in this study has also been researched by Hussain et al. (2006) and found similar results verifying the role Lego can play in the classroom. Placing students into groups will not guarantee that the students will practice critical thinking. However, when provided with a properly designed problem, group work provides a vehicle for collaboration and a positive environment for critical thinking to occur.

In the typical constructivist classroom environment, the results and findings from each group would have been shared after the completion of each challenge. This would have increased the participant's background knowledge and enabled them to "scaffold" their learning by being truly collaborative. This was not done because it would have possibly skewed the results. The grade four participants may have viewed the problem solving techniques and product created by the previous group as the best and/or perhaps 'only' method for completing the challenge. By not having the groups share their results and findings, it ensured that originality and creativity for attempting each challenge was maintained for each group.

Technology

Throughout the programming component, the communication between the participants was noted by the researcher for questioning, negotiation and confirmation. As previously stated, this type of language was necessary for participants as they attempted to solve the challenge. During each of the three tasks, there was evidence that the participants were highly motivated and involved with their programming. There were no incidents of off-task behaviour noted. When programming, the lead programmer would be in a position in front of the computer with the two additional members on the sides. This layout provided the medium for the language, reflection and social interaction to take place at the computer and supports a constructivist learning environment. The computer is also used as a "social tool" as previously described by Bruce (1997) and helps with the redefinition of technology in the classroom. That is, learning environments have changed, learning is a social process and technology assists in their learning.

Research by Dillenbourg, Baker, Blaye, and O'Malley (1996) and Inkpen, Booth, Klawe, and Upitis (1995) support the findings that collaborative use of technology is beneficial. "Children playing together on one machine solved significantly more puzzles than children playing alone on one machine" (Inkpen et al., 1995, p. 1). This may also explain why participants reported group work being "easier" than working alone because it allows them to achieve more than they usually would. In essence, the students provide the scaffold to support each other's learning.

Problem Solving: Strategies

The results of this study demonstrate that Lego Mindstorms could possibly support problem solving in an elementary classroom. Upon conclusion of all three cycles, it was encouraging to see the diversity of problem solving strategies being employed by the participants. In total, six strategies were mentioned in the interviews and reflection journals (guess and check, trial and error, elimination, talk about it, use a pattern and use a formula) and four were noted and observed (visual discrimination, drawing pictures/maps, modeling and prediction) in the field notes. These findings are consistent with Cameron (2005), Gibbon (2007) and Mauch (2001) who also support cognitive development with Lego Mindstorms. However, the findings from this research project contradict the results of Hussain et al. (2006) who concluded "For the problem solving, there is no significant improvement either" (p. 192). There are several possible reasons for this discrepancy. Hussain et al. conducted a large scale project involving qualitative and quantitative research methods and they utilized a Lego product (Dacta) that pre-dates Mindstorms in order to replicate another study.

As the cycles progressed, the participants had more input into their design and the movement of the robot. The study provided the participants with an open-ended problem that allowed for multiple methods for solving the challenges. For cycles two and three, the variety of robots differed greatly and allowed the students to create original designs. Hussain et al. (2006) reported the students learned Lego Dacta by using "trial and error" (p. 188) which was also the most popular problem solving strategy used by the sample population observed. This strategy was likely used most frequently because the participants had prior knowledge, experience and practice while studying the grade four math curriculums. This also explains why other problem solving methods such as "visualization" or "modeling" were not mentioned by the participants even though they were used. The sample population did not have as extensive background knowledge and experience with these decision making strategies and therefore could not name and articulate them. The issue of prior experience within the context is supported by Willingham (2007), for without sufficient background knowledge, comprehension is compromised.

Problem Solving: Transfer

The transfer of problem solving skills from one subject to another became an evident theme when the question "Where have you used that strategy before?" was asked. Ten of the participants reported using a problem solving strategy from the Mindstorms challenge in another subject area at home and at school (most notably, math). There may have been a tendency for the students to state math because this process was taught in the course of problem solving in mathematics. It is also the subject area where they have experienced the most practice time. Regardless, it is encouraging to see that students, at the very least, acknowledge the connection of problem solving between subjects and their every day life. This finding is supported by Willingham (2007) who writes that familiarity with how to use and solve a problem transfers well with repeated practice and experience. The "new" problem solving strategies that appeared in the third cycle (visualization, modeling, picture making and mapping) were not named and recognized by the participants because of their lack of repeated exposure to these problem types (Willingham, 2007).

Problem Solving: Language

Several participants originally had difficulty articulating their thoughts about their thinking process. Responses to questions such as "Did your thinking improve?" were generally met with a long pause or "I don't know." Students are not familiar with being asked this type of question because reflection questions that ask you to assess your thinking are difficult to answer (Reece, 2002). Yet, the assessment questions based on skills "What problem solving strategy did you use and did it work?" were answered considerably better. The pre-teaching and practice of the problem solving strategies was beneficial because it gave the students the language to use. In essence, the language is now part of the 'scaffold'. Without adequate exposure and practice with the problem solving strategies, the participants could not or did not realize they were using them. As previously noted in the second and third round, the students used modeling, visualization and pictures to help them. Because they have not used these strategies in class or discussed them to a large degree, the students failed to mention their use.

Reflection

There was evidence of reflection in all cycles of the research project but it became more prevalent in the second and third cycles when students' experience and background knowledge with the Mindstorms kit increased. The "depth of reflection" (Tarlow and Spangler, 2001) made by the participants needs to be examined because it is possible to reflect improperly resulting in a re-evaluation of the learning experience that leads to failure. It could be argued that several students failed to reflect deeply enough to solve the challenge. One group in particular when reflecting on the problem encountered with their robot and program simply stated "The program doesn't work" (Grade four student, personal communication, May 2008) when in actual fact, they failed to see their design was too heavy for the robot to operate properly. What causes students to be so off-base in their reflection process? In an era of immediate feedback and a generation of students that expect instant results, Tarlow and Spangler state "With new technologies, the time element that promotes such cognitive activity is definitely missing" (p. 26). This is supported by Dillenbourg et al. (1996), who write "…immediate feedback may prevent fruitful exchanges between human co-learners…" (p. 14). These students became too involved in their technology related task and as a result they did not take the time to properly consider other possibilities that would generate more success in their endeavours. As a result, this may be a negative side effect of technology, higher involvement levels but decreased metacognition.

Based on the observations from this research, Lego Mindstorms supported reflection because the course of action of build, program and then complete a trial incorporated time to cognitively reflect between the actual trials and the programming. It was not possible to complete one aspect (run the robot) without the other (programming).

This situation of "cause and effect" is highly beneficial for engaging students in the process of reflection.

Previous Experience

Prior to the beginning of the research study, the students did not acknowledge that they had previous experience with Lego Mindstorms. However, two types of personal experience became apparent during the second and third cycles of action research that impacted the sample population's ability to solve the challenges: previous experience with Lego and previous experience (from the cycles of research) with Mindstorms.

Following the second cycle, three participants reported previous experience with Lego and all three successfully completed the challenge. Two had not used Lego before and both reported they did not complete the task. Based on this trend, it appears that there may be some benefit to previous experience with Lego bricks. As Gibbon (2007) states, "Participants who regularly used Lego's may have brought with them a set of prerequisite skills and understandings that increased their level of readiness to benefit from the experience" (p. 96). This research project was not looking specifically for the benefit or lack there of with previous Lego experience on the results. Therefore, it was not possible to completely isolate the conditions to review this possible trend in the third cycle. It would be beneficial to study this perceived element of "Lego experience" in further research.

The advantage of using Lego Mindstorms over the 12 week period was evident when reviewing the actions not the success rate, of the participants in cycles two and three. Their actions were noted by their "eagerness", "confidence" and "efficiency." This background knowledge provides increased their comprehension and efficiency (Willingham, 2007).

Feelings

Overall, the participants were overwhelmingly supportive of Lego Mindstorms. This is in sharp contrast to the Hussain et al. (2006) research which reported a downward trend in the attitude towards Lego in their sample. This difference could be attributed to the novelty factor. None of the sample population in this study had used Lego Mindstorms before and the sample population in the other project was using a less technologically advanced product.

During portions of the project, participants reported negative feelings when discussing their failure to complete the task. Yet the students contradicted their own feelings by reporting they enjoyed working on the challenge. This is aptly called “joyful stress” by Hussain et al. (2006) and coincides with Lev Vygotsky’s Zone of Proximal Development. This area of cognitive development takes the learners’ beyond their “comfort level” through scaffolding and therefore they feel some stress; yet, they are able to still able to work on the task assigned and in some cases experience partial success. This is the area, according to Vygotsky, of intellectual growth. The first round and the third round were noted for negative feelings. I believe these are the two rounds that the participants demonstrated the largest increase in their learning. The first cycle was a completely new experience for them. The second cycle scaffolded their learning by assimilating their previous experiences and extending their new knowledge. The third round essentially provided additional information and understanding (both old and new) for the participants that caused them to evaluate, extend and apply new knowledge to the challenges they were facing.

Gender

The gender differences with Lego were an unexpected finding in the study. During the second research cycle 11 female participants were involved. Four girls reported successfully completing the challenge, while seven did not. Did their previous Lego experience help or hinder their performance? The previous experience of the boys was known for only two of the seven male participants (both positive) and all boys reported successfully completing the challenge. Two female participants reported having no previous experience with Lego and these two participants did not effectively complete the challenge. Of the two female participants who did report that they had played with Lego outside of the school setting, only one successfully completed the challenge. The previous experience of the remaining five female participants was unknown. Unfortunately, this theme evolved during the second research cycle and not the first. The random sample population for the third cycle resulted in an unbalanced gender sample and the results did not add to the theme of gender.

The issue of gender and technology and Lego has been studied (Beisser, 2005; Lloyd, 1989; Inkpen, 1995; Upitis, 2001) and indicates that there is indeed a difference between females and males when it comes to using computers and Lego for learning. Specifically for problem solving, both Gibbon (2007) and Hussain, et al. (2006) reported that there was no significant gender disparity when using Lego Mindstorms or Lego Dacta. Based on my results, there may be some difference between the girls and boys.

However, with the small sample it is difficult to generalize and base conclusive results on it.

Personal Reflections

At the conclusion of the thesis, it is valuable to reflect on the impact that the action research study has had on me, my teaching practices and how the students learn.

This study has succeeded in presenting me with new methods of teaching curriculum outcomes that are engaging for my students. It has allowed me to explore and implement innovative adaptations of curriculum based outcomes using technology. The emphasis on Mindstorms began as a novelty for the students but quickly demonstrated its value as a tool for stimulating their critical thinking to the teacher. And, in turn, the changes to my pedagogical practice prompted the students to be more creative and engaged in their learning activities.

In addition, the experience of this study has provided me with an increased understanding and awareness of the importance of the relationship between critical thinking and constructivism as it relates to student learning. I expect to be more inclusive of these concepts when designing lessons and activities for the elementary students. In many cases, I will modify existing programs to better accommodate the requirements of the constructivist classroom. I will also use more open-ended questions, allow more time for student practice and reflection and integrate collaborative group work within the learning environment wherever possible.

It is my intent to continue to use Lego Mindstorms in the classroom and expand on its potential. I plan to initiate a Robotics Club with the possibility of entering a First

Robotics League competition. This would extend the students' current knowledge base and capitalize on the high level of motivation experienced with Mindstorms in the study. Having seen the power of scaffolding student knowledge in the classroom using Mindstorms, I feel that the students will take more ownership over their projects and integrate more creativity into their inventions.

Conclusions and Suggestions for Future Study

This research study investigated the effects of Lego Mindstorms on the critical thinking abilities of grade four students. During the 12 week investigation, the challenges created using the Mindstorms robotic kit demonstrated support for several key components of critical thinking including collaborative work, problem solving skills and reflection. While this study has limitations, the possibility of improving children's cognitive abilities with Mindstorms in an elementary classroom is encouraging. Willingham warns that "substantial improvement requires a great deal of practice" (2007, p. 13), therefore it would be recommended that a long term project with Mindstorms be developed to see the longitudinal effects on students problem solving after they did receive more practice with the kit. There are several other areas for further investigation.

As previously mentioned, the role of gender on previous experience with Lego Mindstorms is worthy of further study. While there has been research on gender differences in learning with technology, the issue of robotics, females and learning appears to be uncharted territory.

Lego Mindstorms allows children to be creative thinkers as demonstrated by the multiple versions of the robots and programs they created while attempting to solve the challenges in this research project. It would be beneficial to investigate the possible link between critical and creative thinking for elementary school students.

During the second round, additional challenges were presented to the participants who successfully finished the challenge. For the groups that worked on these extra tasks, they were noted to be highly motivated and they used new problem solving strategies. The third round of action research results provided some information that the participants liked the most difficult challenges the best. Willingham (2007) has researched the literature and determined that the most beneficial method of teaching problem solving is to utilize more complex knowledge bases. The challenge in the third round is an example of this type of knowledge base. It was necessary for students to utilize many different types of troubleshooting in order to determine a course of action. Potential future studies could examine how these more complex types of Lego Mindstorms challenges impact the participant's logical abilities.

Finally, much of this research project addresses the current cognitive abilities of a population of students. However, what about the long term retention of these skills and dispositions? It would be interesting to investigate how long these skills are used and if they strengthen over time or diminish and are replaced by new skills.

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Appendices

Appendix A: Critical Incident Questionnaire

The Classroom Critical Incident Questionnaire (developed by Stephen Brookfield)

Please take about five minutes to respond to each of the questions below about this week's class(es). Don't put your name on the form – your responses are anonymous. At the start of next week's class I will be sharing the group's responses with all of you. Thanks for taking the time to do this. What you write will help me make the class more responsive to your concerns.

At what moment in class this week did you feel most engaged with what was happening?

At what moment in class this week did you feel most distanced from what was happening?

What action that anyone (teacher or student) took in class this week did you find most affirming or helpful?

What action that anyone (teacher or student) took in class this week did you find most puzzling or confusing?

What about the class this week surprised you the most? (This could be something about your own reactions to what went on, or something that someone did, or anything else that occurs to you).

Appendix B: Letter of Information for Participation and Informed Consent Form

MOUNT SAINT VINCENT UNIVERSITY

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Information Letter

February 7, 2008

Dear Parents/Guardians,

I am currently completing the research component of my Masters of Arts in Elementary Education at Mount Saint Vincent University (MSVU) and I am inviting your child to participate in the exploration of the use of Lego Mindstorms and critical thinking in the classroom.

This study will be conducted by myself (Chris Cocek) and will take place in our grade four classroom. For the past several years I have focused my studies on the use of computer technology in the elementary classroom and the development of children's critical thinking skills. The research question for the purpose of this investigation is:

> Do Grade Four students' critical thinking skills improve when the Lego Mindstorms kit is used as an instructional tool in a constructivist learning environment?

The research for this project focuses on the integration of the Lego Mindstorms robotics kit into the Grade Four Science and Math Curriculum. Lego Mindstorms is a combination of common Lego pieces built on a Central Processing Unit which is programmable using a computer. Students will be using Mindstorms in a collaborative environment to solve problems based on math and science curriculum outcomes in our Light and Sound unit (approximately February to March 2008).

The benefit to this project is to see if any improvements to your child's critical thinking skills (ie., questioning, reasoning, problem solving, reflection) occur when they use the Lego Mindstorms kit. To measure the results of any changes in their critical thinking skills, it is necessary to provide students with self-reflection questionnaires, self-assessment rubrics and ask them questions through interviews. Interviews would be recorded through video and audio recordings so they could be transcribed. Some interviews may be necessary to complete outside of regular school hours and would occur between 3:30 and 3:45 in the classroom. You would be made aware of this in advance if necessary.

Student's identities will remain anonymous and pseudonyms (false name) for all names and places will be used to protect the privacy of all participants. Neither your name nor your child's name will appear in any reports of this research. Results will be published using these pseudonyms. The research material that contains the identities of the participants will be destroyed after the analysis of the research. All electronic files will be password protected. You have a right to review a copy of any survey, questionnaire, checklist, etc. being administered to your child.

Participation in this project is voluntary and involves no unusual risks to you or your child. You may rescind your permission for your child to participate in this research at any time with no negative consequences. If you and your child agree to participate, please indicate your decision on the following page and **return it to Mr. Cocek by Tuesday, February 12**.

To respect and protect the rights (privacy, dignity, and minimizing harm) of the participants, prior to the start of this research project, it was presented to and received approval from the University Research Ethics Board (UREB) at Mount Saint Vincent University and the Halifax Regional School Board. If you have any questions about how this study is being conducted and wish to speak with someone who is not directly involved in the study, you may contact the Chair of the University Research Ethics Board (UREB) c/o MSVU Research and International Office, at 457-6350 or via e-mail at research@msvu.ca.

Sincerely,

Chris Cocek
Westmount School
493-5164
ccocek@staff.ednet.ns.ca

MOUNT SAINT VINCENT UNIVERSITY

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Participant Consent Form

I have read and understood the information contained in the information letter for participants. I have had the opportunity to ask questions and receive additional information. I understand that my child's participation is completely voluntary and they may withdraw from the study at any time without consequences.

I have indicated below my decisions regarding the various parts of the **Lego Mindstorms and Critical Thinking** research project:

I give my permission for the items checked "Yes" below:

Yes	No	
☐	☐	I give permission for my son/daughter to participate in the research project.
☐	☐	I approve of my child's participation and permit my child to be interviewed.
☐	☐	I agree to the audio taping of the interviews.
☐	☐	I agree to the videotaping of the interviews.

______________________________ ______________________________

Child's Name | Name and Signature of Parent/Guardian

______________________________ ______________________________

Signature of Participant | Date

Appendix C: Critical Thinking Rubric

Please complete the self assessment rubric based on your performance with the Lego Mindstorms activity. Think carefully and be honest. Thanks!

Critical Thinking Self Assessment Rubric	**4** **Awesome!**	**3** **Great!**	**2** **Good.**	**1** **Needs Improvement**
Collaborative Work	Working in the group helped me understand more. I learned from my group members.	Working in the group was good. I learned something new because of it.	Working in the group did not result in me learning anything new.	I do not try to solve problems or help others solve problems. I let others do the work.
Problem Solving	I tried several different problem solving strategies. I could solve the problems.	I tried a problem solving strategy and solved a problem.	I tried problem solving strategies but nothing worked.	I did not try any problem solving strategies.
Questioning	I created several high level questions. I frequently made predictions throughout the project.	I created a high level question. I made some predictions during the project.	I have difficulty making high level questions. I sometimes make predictions.	I cannot make any high level questions. I do not make any predictions.
Reflection	I always think about what I have learned. I make changes when needed.	I regularly think about what I have learned. I usually make some changes.	I, from time to time, think about what I have learned. I sometimes make changes.	I never reflect on my thinking. I don't make changes.
Supporting evidence	I can identify problems and solutions and back up my answers with details/diagrams and examples.	I usually identify problems and solutions. I can back up my answers.	I have difficulty identifying problems and solutions. I can sometimes back up my answers.	I cannot identify problems or solutions. I cannot back up my answers.
Connections	I can see how my learning, experiences and ideas connect to the real world in many ways.	I generally can relate my learning, experiences and ideas to new connections.	I sometimes make connections from my learning.	I am not able to make any connections.
Inference	I infer and can support it with details and examples.	I usually can infer and provide some details to support it.	I sometimes infer.	I am unable to infer.

Appendix D: Semi-structured Interview Schedule

1. Did Lego Mindstorms help you understand and solve the problem? If so how?
2. At what point in the problem solving process did you feel the most involved?
3. Were there any changes to your thinking during the process? How?
4. Were there any improvements to your thinking during the process? How?
5. What was something that surprised you while you were completing the task?
6. What was the most challenging aspect of this project?
7. If you could change something during the completion of the task you took part in, what would that be?
8. What did you learn from working in the group?
9. What questions did this science task raise for you?
10. Is there anything else you would like to tell me?

Appendix E: Self Reflection Questions

1. Did Lego Mindstorms help you understand and solve the problem? If so how?

2. What were some of the problem solving strategies that you tried?

3. At what point in the problem solving process did you feel the most involved?

4. Were there any changes or improvements to your thinking during the process? How?

5. What was something that surprised you while you were completing the task?

6. If you could change something during the completion of the task you took part in, what would that be?

7. What did you learn from working in the group?

8. A question(s) from the project I developed was…

9. Based on this project I would like to learn more about…

Appendix F: Revised Self Reflection Questions

1. Did Lego Mindstorms help you understand and solve the problem? If so how?

2. What were some of the problem solving strategies that you tried? Did they work? Have you used these strategies anywhere else?

3. At what point in the problem solving process did you feel the most involved? During the planning, building, programming, trials or some other point? Why?

4. Were there any changes or improvements to your thinking during the process? How or how not?

5. What was something that surprised you while you were completing the task? Why?

6. If you could change something during the completion of the task you took part in, what would that be? Why?

7. What did you learn from working in the group?

8. A question(s) from the project I developed was…

9. Based on this project I would like to learn more about…

10. Completing this challenge was like (circle one) work or play. Why?

11. I have used Lego before. (circle one) Yes No

12. I like using Mindstorms. Yes No

13. Completing challenges 1 and 2 helped me with this challenge: Yes No. How or how not?

14. We successfully completed this challenge. Yes No. How did you feel about that?