Inquiry-Based Learning as a Strategy to Support Student Success

by

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Abstract

In this paper, I look at inquiry-based learning within mathematics and science in the Ontario educational system while making connections to Ontario's 21st Century Competencies foundation document. Further to this, I researched whether it might be beneficial for English Language Learners to integrate language and content through inquiry, and also review recommendations on how to best implement this approach. I endeavored to uncover what the current research says about how this pedagogical strategy might be used to support all learners in mathematics and science, and also the associated challenges with implementation of an inquiry approach. This was done through the lens of constructivist theory, with connections made to Ontario educational documents.

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Chapter 1: Introduction

Background Information

As a student in early elementary school, I remember how much I enjoyed both math and science class. We watched fun teacher demonstrations, we got to use microscopes, and we solved puzzles. In later elementary school, both science and math started to become a lot of sitting and listening, and was not as engaging as in the past. By the time I reached high school, these subjects were just a boring collection of isolated facts and procedures that needed to be memorized. Although I could do it, I did not really like it. As an engineering student in university, the material still seemed so detached from what I saw as the end goal. I am embarrassed to say that it was not until years later, as a high school physics and math teacher, that I truly began to appreciate the interconnectedness of the concepts and ideas that describe the world around us.

For me, what was missing was the why. Why were we learning this and practicing these procedures over and over? My math and science experiences were missing the spark that might have been generated through inquiry. Inquiry-based learning has a long history and many definitions (Schmid & Bogner, 2017; Thoron, Myers, & Abrams, 2011; Maaß & Artigue, 2013). Inquiry-based learning developed out of discovery learning in the 1960s as a response to traditional methods of direct instruction and memorization, and can be considered a constructivist philosophy (Barrow, 2006). Constructivist learning theories describe the learning process as one where students create knowledge and develop their own understandings through interactions between their current knowledge and new experiences (Marshall, Smart, & Sirbu, 2011). As suggested by Dewey in 1910, inquiry was recommended to be included in the science curriculum because there was too much emphasis on facts and not enough emphasis on the nature of science. Dewey thought that students should be actively involved in exploring a question while consolidating and adding to their prior knowledge. With the launching of Sputnik I in 1957, concern was generated about science education in the United States, leading the National Science Foundation (NSF) to develop recommendations for science with an emphasis on scientific thinking (Barrow, 2006). Subsequent similar recommendations were made, and in 1981, *Project Synthesis* emerged, which was a compilation of three major NSF projects. Inquiry was one of the five areas of *Project Synthesis*, out of which reasons were identified for why teachers might be hesitant to implement inquiry, including lack of time and support, too much emphasis on content, and difficulty of teaching (Barrow, 2006). Despite general consistency underlying the foundation of most inquiry definitions and agreement with the desire to include some inquiry-based instruction in educational programs, implementation remains inconsistent (Marshall et al., 2011). Most teachers were not taught science through an inquiry-based approach so it can be difficult and new to them, as might be the role of teacher as facilitator and student as active participant.

Ontario Educational Documents

The Ontario Ministry of Education (OME) has released several *Capacity Building Series* papers on inquiry, which describe inquiry as more of a pedagogical mindset than a strategy, and incorporates many best practices for instruction, including explicit and small-group instruction (OME, 2011). Students pose and re-frame questions, make predictions about possible outcomes, discuss connections between prior knowledge and new discoveries, reflect on learning, talk about observations and about their learning (OME, 2013). Further to this, curriculum documents and ministry publications point to a shift towards inquiry.

Mathematics

In Ontario, the mathematics curriculum emphasizes the importance of mathematics in our society and provides a framework for students to become individuals who are able to think critically, adapt to unfamiliar situations, solve problems, and communicate effectively. Seven process expectations to support mathematics learning have been established, and are the same for every grade level. These include problem solving, reasoning and proving, reflecting, selecting tools and computational strategies, connecting, representing, and communicating. Each grade level also has strands of learning which are broken down into overall expectations, or the big ideas, and specific expectations which describe the desired knowledge and skills in more detail. The process expectations are embedded within every strand. "Students must problem solve, communicate, reason, reflect, and so on, as they develop the knowledge, the understanding of concepts, and the skills required in all the strands in every grade" (OME, 2005, p.11). The authors of the curriculum recognize that a variety of teaching approaches are best to meet diverse student learning needs, but "research and successful classroom practice have shown that an investigative approach, with an emphasis on learning through problem solving and reasoning, best enables students to develop the conceptual foundation they need" (p.24). Learning math through inquiry does not mean that students are left on their own to figure out rules and procedures. Explicit instruction still exists, but it is paired with the discovery of ideas and the development of conceptual understanding. If students are to engage with topics and ideas and carry learning forward from one year to the next, we cannot simply teach facts to be memorized. From my experience, what is most effective is when there is a balance between direct instruction and discovery, and topics are uncovered in such a way that students make learning their own.

Science

In science, the authors of the Ontario curriculum recognize that “the impact of science on our lives will continue to grow as the twenty-first century unfolds” (OME, 2008, p.3). In Ontario, there are three goals for science education. The first is to relate science to technology, society, and the environment. The second is to develop the skills, strategies, and habits of mind for scientific inquiry. Finally, the third goal is to understand the basic concepts of science (OME, 2008, p. 4). These are challenging but necessary goals which reflect the importance of inquiry, which might be an effective way to confront misconceptions and develop critical thinking skills and habits of mind that will carry forward in many aspects of life beyond the K-12 years of education.

Global Competencies

Inquiry-based learning is seen by many as a way to improve math and science education so that we can better compete and keep up with global demands. There exists much debate over what inquiry-based learning is and is not, and it is often conflated with other similar approaches, such as hands-on learning, problem-based learning, or student-centred learning (Engeln, Euler, & Maass, 2013). In general, inquiry-based learning is learning that follows the scientific method, where students ask questions, form hypotheses, gather and analyse data, and create evidence-based conclusions which are then discussed and refined with the larger group. Through the inquiry process, students learn to learn, and learn to work both individually and collaboratively. These skills and others have been identified as part of Ontario's renewed vision for education, *Achieving Excellence* (OME, 2014). Out of this renewed vision, the foundation document "21st Century Competencies" (2016) was developed to focus discussions about "how best to shape provincial policy to help students develop the 21st century competencies they need to succeed" (p. 3). The skills and competencies of critical thinking and problem solving, innovation, creativity and entrepreneurship, learning to learn, collaboration, communication, and global citizenship are those "most prominently featured in provincial, national, and international research and intellectual debate" (p. 3), and are intended to support learning in all curriculum areas. An important question that has guided the Ministry's investigation of 21st century competencies is "What pedagogical and assessment approaches are necessary to support teaching and learning of the competencies?" (OME, 2016, p.4). Inquiry-based learning could be an important part of that answer.

Research Problem

In this paper, I looked at inquiry-based learning within mathematics and science in the Ontario educational system while making connections to Ontario's 21st Century Competencies foundation document. In Ontario, students struggle to meet provincial math standards ("Ontario Ministry of Education", 2018). Educators are challenged to engage students in learning so they develop the skills and knowledge necessary to compete globally. Further to this, I looked at whether it might be beneficial to integrate language and content through inquiry, and also reviewed recommendations on how to best implement this approach. Here, English Language Learners (ELLs) defined as students who do not speak English as a first language. These students are tasked with learning and becoming proficient in the language of instruction at the same time as they are learning subject-specific content. With the growing number of ELLs in our school systems, it is important to develop strategies to help all students meet success. Inquiry-based learning may create an inclusive environment supportive of all learners, ELL or native English speakers.

Research Questions

Through this paper, I endeavored to answer two questions.

1) Given that inquiry-based learning has received increasing attention in recent years, what does current research say about how this pedagogical strategy might be used to support all learners, including English Language Learners, in mathematics and science?
2) What are some associated challenges with the implementation of an inquiry approach?

To answer these questions, I first provided an overview of relevant literature and discussed some of the key themes uncovered around using inquiry-based learning as a pedagogical strategy, including some of the reasons that have been identified for why this strategy can help achievement, what are some challenges and barriers to implementation and suggestions for overcoming some of those barriers.

I then looked at inquiry and the Ontario curriculum through the lens of Doll's 4Rs (Doll, 1993), looked at some connections to the Ontario math and science curriculum, and how inquiry-based learning can be used to support Ontario's 21st Century Competencies foundation document. Next, I examined some connections of inquiry to critical literacy, ELLs, and discourse, and finally I examined some factors that hinder the implementation of inquiry.

Chapter 2: Literature Search Method

To search for papers to address the research questions, several strategies were used. These included a database search with key words, a selection criteria strategy, and a hand-search. The results provided a wide range of articles that examined various aspects of inquiry-based learning.

Theoretical Framework

In exploring current research on using inquiry-based learning to support student success, my focus was on constructivist theory. This theory is centred on problem solving as a means to reflect on past and immediate experience to build meaning. The roots of constructivism lie with Piaget, Vygotsky, and Dewey where,

> Piaget contributed the idea of transformation in learning and development; Vygotsky contributed the idea that learning and development were integrally tied to communicative interactions with others; and Dewey contributed the idea that schools had to bring real world problems into the school curriculum ("Learning Theory – Constructivist Approach", n.d.).

This framework makes sense because inquiry itself involves posing questions and engaging in a shared experience to determine how it fits with prior knowledge.

Database Search

In gathering articles for this paper, I started with a database search to locate journal articles relevant to inquiry, mathematics, science, critical literacy, and English

Language Learners via the University of Windsor's Leddy Library. Searches were conducted with the following databases:

1. Education Resources Information Center (ERIC)
2. Gale Cengage Academic OneFile
3. ProQuest SciTech Premium Collection
4. Scholars Portal
5. Taylor & Francis Journals Complete
6. Google Scholar

Key Words

In searching the database, several key words were used to ensure a wide variety of articles and perspectives. The initial search terms used were:

1. inquiry based learning
2. inquiry
3. mathematics
4. science

Next, several terms were added to the search:

5. literacy
6. constructivist
7. constructivism
8. English language learner

Finally, a mix of the key words in various combinations was used. These key words resulted in many articles, some relevant and some not.

Selection Criteria

From the search results, articles were initially chosen based on the reading of the abstract. If the abstract indicated that the paper would discuss inquiry-based learning as an instructional strategy, that paper was chosen. For each article, a chart was used to summarize the purpose, key findings, major themes, and interesting quotes. The search was narrowed down further to articles that were published after 2002. Exceptions were made for two articles published before 2002 because they were appropriate for the research. After summarizing all the articles, groups were made based on similar key findings and similar themes that emerged to make connections within the data set.

Hand-Search

After reading the articles that were selected from the database search, I chose the articles with themes and quotes that resonated with me about the phenomenon being studied. From these I did a hand-search of the reference lists to locate additional papers via the Leddy Library.

Upon analysis of the selected papers, several themes emerged. There were articles that focused on constructivist teaching and learning, those that reflected a positive perspective on inquiry-based learning and provided helpful recommendations for implementation, those that questioned the effectiveness of an inquiry approach and suggested implications for practice, and articles that supported the use of inquiry to help ELLs meet success.

Chapter 3: Literature Review

Inquiry-based learning is not limited to science education, and there are many definitions of inquiry. Most of these share the common thread of building on the natural curiosity of students. Engeln et al. (2013) say that "the aim of IBL is to stimulate students to adopt a critical inquiring mind and develop an aptitude for problem solving" (p. 826). Wikipedia describes inquiry-based learning as a process where students actively engage with a question. Learning is facilitated by the teacher as students develop knowledge and construct meaning through shared experiences (Wikipedia, n.d.). Inquiry-based learning is an instructional strategy where the role of the teacher is that of facilitator. Working on an inquiry task allows students to construct new knowledge while consolidating current understanding. It also gives students the opportunity to assume responsibility for their learning and to make decisions that might normally be made by the teacher (Zafra-Gomez, Roman-Martinez, & Gomz-Miranda, 2015). Over several decades, the impact and challenges involved with implementing inquiry-based learning have been studied. This review represents a sample of articles that were relevant in evaluating the research questions.

Major Themes

Constructivist Teaching and Learning

Constructivism has many different interpretations (Philips, 1998, as cited by Mayer, 2004), but the underlying foundation is consistent. Constructivism considers that learning is an active, contextualized process, where learners construct knowledge and incorporate new information with what they already know in an effort to build organized knowledge (Mayer, 2004; David, 2015; Sheppard, 2008). Importantly, each learner brings with them past experience and cultural factors which impact the way they construct new learning (David, 2015). Constructivism suggests that each learner individually and socially constructs meaning through activity and reflecting on that activity. The difficulty comes in understanding how to translate a constructivist view of learning to a constructivist view of teaching (Mayer, 2004). The teacher's role in a constructivist classroom shifts from one who imparts knowledge through traditional lectures, to expert learner who facilitates and guides students in becoming active learners. Students bring with them multiple and varied experiences which they must use to make sense of new learning. Teachers also carry experience and prior knowledge which they, too, must integrate when engaging in new learning. I think that it must be the goal that students emerge changed as a result of new learning.

Positive Support of Inquiry

Zafra-Gomez et al. (2015) sought to determine the impact of inquiry-based learning on student achievement and satisfaction. The researchers analysed a total of 515 responses over four consecutive years of a university business administration course. During the first two years, the course was taught using traditional methods, but in the last two years the traditional approach was combined with inquiry-based learning. The outcomes from each sub-period were compared to determine whether or not there was real improvement on achievement, what were student perceptions of learning, and overall satisfaction with the learning experience. The results obtained suggest that the mixed teaching method improved students' academic performance as during the inquiry period, more students were successful on the exams and the average grades rose.

These are consistent with results obtained in previous studies (Dowling, Godfrey, & Gyle, 2003; Drennan & Rohde, 2002 as cited in Zafra-Gomez et al. 2015).

In other research, the challenges and opportunities with inquiry-based learning were studied across 12 European countries (Engeln et al., 2013; Dorier & Garcia, 2013), and the results can be easily compared to experiences in Ontario. Both sets of researchers believe that engaging students in inquiry-based learning is a way to improve mathematics and science education. In fact, in Europe most educational documents support an introduction of inquiry-based learning in school (Dorier & Garcia, 2013). This can be compared to the support of inquiry seen in Ontario mathematics and science curriculum and educational documents (OME, 2005; OME, 2008; OME, 2013). In the PRIMAS project, 14 schools from across 12 countries worked together to promote the implementation of inquiry-based learning in mathematics and science. As part of this project, teacher beliefs on inquiry-based learning and factors hindering its implementation were examined through the use of a questionnaire. Although both papers affirm the benefits of inquiry-based learning, the results outlining factors hindering implementation were detailed. Evidence shows that traditional teaching practice is used in most countries. Dorier and Garcia (2013) looked at this from the perspectives of society, school, pedagogy, and disciplines. At the society level, it was suggested that the succession of reforms over recent years in many countries has resulted in teachers, and even parents, rejecting change and looking to bring back traditional pedagogy and fundamental concepts. This appears to be similar to what has been happening in Ontario in 2018 with the call to return to fundamental skills in math (“Ontario Ministry of Education”, 2018). At the society level, it is suggested that many primary teachers do not view mathematics as their favourite subject which makes implementing inquiry-based learning more difficult. At the school level, the authors point to teacher training as a hindrance to implementation of an inquiry approach, since most lack a deep and broad understanding of mathematics and science. The authors claim that in-service teacher training and professional development is an important issue that may be the one to change teacher practice.

Pedagogically, many teachers do not embrace inquiry because they have never experienced inquiry as students. Engeln et al. (2013) find that despite the benefits associated with inquiry, changing teacher practice is not easy. Teachers' professional competencies are important for balancing efficient instruction and students' construction of knowledge. If a teacher is not ready to effectively implement an inquiry approach, it is not the best instructional method for that teacher. Overall, however, both papers show that teachers report a positive attitude about the idea of using an inquiry approach which is an important prerequisite to implementation.

Questioning the Effectiveness of Inquiry

Not everyone is in agreement on whether or not inquiry-based learning is the most effective instructional strategy. There is evidence to suggest that a pure discovery approach to constructivist learning is ineffective (Mayer, 2004; Kirschner, Sweller, & Clark, 2006). These authors believe that there is merit in the constructivism and knowledge construction but suggest that unguided instruction is less effective and may have negative results when students have misconceptions or incomplete knowledge. Mayer (2004) looked at studies conducted over three decades, and organized findings based on discovery of problem-solving rules, discovery of conservation strategies, and discovery of programming concepts. The results of early studies of discovery of problem-solving rules (Craig, 1956; Kittel, 1957; Gagne & Brown, 1961; Shulman & Keisler, 1966; as cited in Mayer, 2004) showed that pure discovery can be ineffective if it fails to promote the second of two criteria for active learning. The first criterion is constructing knowledge to be used to make sense of new information, and the second is integrating new information with the current knowledge base. The study suggests that students need enough freedom to become cognitively active, and enough guidance so that activity results in the construction of useful knowledge. Similarly, the studies on discovery of conservation strategies (Gelman, 1969; Beilin, 1965; Brainerd, 1972; Wallach & Sprott, 1964; as cited in Mayer, 2004) show that children learn better when they are active and when a teacher guides their activity in productive directions. Finally, studies on discovery of programming concepts (Fay and Mayer, 1994; Kalbey and Linn, 1985; Kurland & Pea, 1985; Lee and Thompson, 1997; Lehrer, Guckenberg, & Sancilio, 1988; Papert, 1980; as cited in Mayer, 2004) note the role of guidance in learning to program, and is a prerequisite for the transfer of one programming language to other domains.

Kirschner et al. (2006) base their work on a half century of empirical research in looking at the important relationship between working and long-term memory. They suggest that the goal of instruction is to alter long-term memory and that new information that is held in working memory must be practiced or it will be lost. When engaging in inquiry, any problem-based searching places a heavy demand on working memory and it is possible for students to work on a problem for a long time but not learn anything. They claim that we do not learn a discipline the same way we practice a discipline, and we cannot expect that students can step into the role of an expert in the field. Direct instruction involving considerable guidance results in significantly more learning than discovery (p. 79). If students develop misconceptions, unguided instruction will be ineffective. The work of both these authors leads to important implications for practice. Both speak to the idea of something in the middle and it might be ineffective to rely solely on either discovery learning or direct instruction. Students should be taught using minimally guided instruction, and inquiry can be used when students have some prerequisite knowledge and have had some previous structured experience. To improve learning, students should be provided worksheets that outline some of the steps and hints that they can use while working on a task (Kirschner et al., 2006).

Inquiry to Support ELLs

The importance of the cultural experiences students bring to the classroom is discussed in the science curriculum document. The introductory section states that,

> English language learners bring a rich diversity of background knowledge and experience to the classroom. These students' linguistic and cultural backgrounds not only support their learning in their new environment but also become a cultural asset in the classroom community. Teachers will find positive ways to incorporate this diversity into their instructional programs and into the classroom environment. (p. 34)

Further to this, the authors say that teachers must adapt their instructional approach to facilitate success for all students, including the "use of a variety of learning resources (e.g., visual material, simplified text, bilingual dictionaries, and materials that reflect cultural diversity)" (p. 35). Additionally, it is stated that "developing a deeper understanding of the big ideas requires students to understand basic concepts, develop inquiry and problem-solving skills, and connect these concepts and skills to the world beyond the classroom" (OME, 2008, p. 6). As technology advances, this world beyond the classroom begins to draw on a diversity of cultures, and thinking critically about what that means becomes increasingly important. In Ontario, ELL students may be Canadian-born, newcomers from other countries, or international students who pay tuition to attend school. According to the Ontario Ministry of Education *Capacity Building Series* (2013), over 25 per cent of students in Ontario schools are ELLs, and that number is expected to increase. The authors of that document distinguish between everyday English "which involves the ability to carry on a conversation in familiar everyday settings" (p. 2), and academic English, which "reflects an individual's access to and command of the specialized vocabulary, functions and registers of language that are characteristic of the social institution of schooling" (p. 3). Both levels of English language learning are important to be successful, but students have multiple opportunities to develop everyday English. If academic English is not learned at school, there are not many other ways to do so. It has been recommended that teachers start with explicit instruction about the cultural norms and to build skills, scaffold instruction to make transitions between cultural expectations visible, and then gradually release responsibility to students to participate in scientific inquiry (OME, 2008). The challenge of learning new concepts is magnified for students who come from culturally diverse backgrounds and who do not speak English proficiently. An inquiry approach can build on natural curiosity as students engage and dialogue with real problems. Even though reality is filtered by our conceptual frameworks and cultural experiences, inquiry can result in genuine knowledge developed in an inclusive environment.

There have been many studies on inquiry-based learning and English language learners. Amaral et al. (2002) summarized the results of a four year project in science where ELLs in grades K to six participated in inquiry-based science in California. They examined performance in the areas of science, reading, writing, and math, and the results indicated that the achievement of ELLs increased in relation to the number of years they participated in the project. It was the group dynamics of inquiry-based learning that seemed to benefit ELLs. Similarly, Stoddart et al. (2002) studied the integration of science and language development through inquiry-based learning and found that when students constructed meaning through an authentic context for language use, they were able to engage and discuss ideas in authentic interactions and communicate their ideas in a variety of ways. Additionally, Lee et al. (2008) looked at the results from the first of a five year intervention in the United States, where teachers were given professional development on implementing inquiry-based learning, and found that collaboration and discussion seemed to help ELLs develop content knowledge and language proficiency. Classroom talk is important to engage students in dialogue, which “stimulates the development not only of new conceptual understanding but linguistic understanding as well” (OME, 2013, p. 4).

The link between English Language Learners, literacy, and inquiry science was examined in two independent studies (Shaw, Lyon, Stoddart, Mosqueda, & Menon, 2014; Weinburgh, Silva, Smith, Groulx, & Nettles, 2014), and both recognize the importance of pre-service education. The Effective Science Teaching for English

Language Learners (ESTELL) project involved pre-service teachers, preparing them to promote language and literacy development with inquiry-based science for English Language Learners (Shaw et al., 2014). This project involved a pre-service science education course and professional development for cooperating teachers, and aimed to measure the impact on student learning through a pre and post assessment administered to 191 students of nine first year elementary teachers of grades three through six. In a separate study (Weinburgh et al., 2014), the change in science content knowledge and academic vocabulary for English Language Learners was examined while students engaged in inquiry-based science. This study was conducted over two years during a three week summer program with 110 grade five newcomers to a large school district in Texas. The results in both studies were varied and it should be recognized that each project occurred over a time frame that represented two to four weeks of instruction. Results might have been different if each intervention happened over the course of an entire school year. Taken as a whole, all students in the ESTELL project showed learning gains which were statistically significant. However, these gains differed across the three achievement categories of vocabulary, science writing, and science concepts. When looking across the three categories, post-test scores were lower for ELLs than English only students, but the learning gains for ELL groups were on par with English only students (Shaw et al., 2014). In the summer program project, all children did not show the same amount of change in vocabulary and conceptual understanding. However, the results did show a clear trend of growth (Weinburgh et al., 2014). Shaw et al. (2014) suggest that an emerging body of research supports the development of English language with science inquiry as a way to improve ELLs’ achievement in science (Bravo & Garcıa, 2004; Cervetti, Pearson, Barber, Hiebert, & Bravo, 2007; Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008; Ovando & Combs, 2012; Rivet & Krajcik, 2008; Rosebery & Warren, 2008 as cited by Shaw et al., 2014, p. 622). Similarly, Weinburgh et al. (2014) claim that students did construct more sophisticated understanding and use more language to communicate that knowledge, consistent with results put forth by Krashen (2013).

All of these papers suggest that when students can investigate a question with a group of peers, they can engage with both the problem and the language. If a student is lacking confidence in how to express themselves, they have others in the group to lean on, learn from, and listen to, without feeling isolated or pressured to have the right answer or vocabulary to express their thinking in English. In this way, they are learning academic content, and both academic and social language. Inquiry-based learning relies heavily on social interactions and discourse among students to solve a problem. Strategies that engage students in activities that require reading and interpretation of content are shown to improve English proficiency and academic achievement among ELLs (Lee, 2004; Lee & Fradd, 1998; Snow, 2008; as cited by Ortega, Luft, & Wong, 2013). This should be given consideration when planning programs for ELL students.

Critical Literacy and Inquiry

Educational outcomes are influenced, and often determined, by the motivation of and self-regulation by the students. Students need to be active participants in their own learning, which is influenced by the environment in which they are learning. It is the teacher’s role to provide a non-threatening classroom environment, rich in interesting activities to foster curiosity, where skills can be developed through scaffolding, modelling, and feedback (Schmid & Bogner, 2017). Based on Vygotsky's "zone of proximal development", or the space between students' current knowledge and the level they can reach with the help of more knowledgeable others, scaffolding is a social process between expert and novice that helps students engage and become competent by developing understanding in stages based on prior knowledge (Meyer, 2002).

Discourse analysis is one approach to scaffolding research that looks at teacher-student interactions and classroom talk, which are both key features of inquiry. It allows exploration of social processes within the classroom that lead to the development of self-regulation (Meyer, 2002). The language that teachers use in the classroom is their discourse. A teachers' instructional discourse is a discourse of competence which refers to the *what* of education, or the content knowledge that is transmitted. It is through communicative instructional discourse that students develop self-regulation and construct knowledge. A teacher's instructional discourse cannot be one-sided, but rather should be authentic and promote interaction within the classroom (Meyer, 2002). Within a discourse based on competence, monitoring of behavior shifts to monitoring learning goals and expectations. Effective scaffolding relies on instructional discourse built on mutual respect and a shared responsibility for learning, a context that can support the development of self-regulation (Meyer, 2002).

Teaching critical thinking and critical literacy, together with inquiry-based learning, seems to be a good match. Critical literacy involves so much more than just reading and writing. Critical literacy provides a lens for learning that encourages active engagement with text, consideration of multiple perspectives and viewpoints, identification of who is silenced or who is marginalized, and the promotion of students becoming agents of social change by taking action on social justice issues (Gee, 1998). The desired skills of critical thinking, communication, and global citizenship are among those outlined in the 21st Century Competencies foundation document (OME, 2016). Critical literacy involves ways of being and is more about social practices and identity. In his work, Gee states that a discourse is an identity kit and is “a socially accepted association among ways of using language, of thinking and of acting that can be used to identify oneself as a member of a socially meaningful group or a ‘social network’” (Gee, p. 1, 1998). Gee contends that students acquire primary discourses at home and secondary discourses outside the home within social institutions, such as school. An important distinction is made between acquisition and learning. Gee says that acquisition happens subconsciously without formal teaching, while learning is conscious and happens through formal teaching. Since discourses are acquired, not learned, Gee claims that literacy should be approached in natural, meaningful settings that incorporate prior knowledge and experience, and that “teaching” literacy is not time well spent. An important approach to developing literacy pedagogies that help at risk students is critical discourse analysis. It has been noted through critical discourse research that a focus on performance and learning goals, or instructional discourse, can produce better educational outcomes for at risk students than a focus on behavior and social order, or regulative discourse.

Inquiry versus Direct Instruction

I would like to draw attention to the dispute that exists about direct instruction versus an inquiry approach. Some suggest that early learners should be provided with direct instruction on the fundamentals of a subject. This type of learning, where information, concepts, and procedures are provided and fully explained, results in a change in long-term memory and results in more effective learning. Our understanding of long-term memory has changed over the last few decades, as influenced by the work of De Groot (1945/1965) followed by Chase and Simon (1973) on chess expertise (Kirschner et al., 2006). It was shown that expert chess players are better than novices at reproducing briefly seen board configurations from real games, but not at replicating random board configurations. This was replicated in other areas (e.g., Egan & Schwartz, 1979; Jeffries, Turner, Polson, & Atwood, 1981; Sweller & Cooper, 1985; as cited by Kirschner et al., 2006). These results suggest that expert players are able to draw on their experience stored in long-term memory and the differences can help explain how we can be skilled in an area because our long-term memory is loaded with information in that area which allows us to quickly recognize, often unconsciously, what to do and when to do it (Kirschner et al., 2006). In other words, people who are good at solving problems have had a lot of experience which they can draw from. This experience is stored in their long-term memory. Through experience, they have used and mastered many strategies, tools, and procedures which they can apply to different problems. I have seen year after year where students at all levels, grades nine through twelve, struggle with problem solving and give up too easily because all their working memory appears to be used up with basic operations because they lack fundamental number sense and automaticity with math facts. If a student is holding too many ideas or numbers in their working memory, there is not enough room to solve a problem or learn something new. Kirschner et al. (2006) claim that our goal in education is to alter long-term memory and instructional strategies that do not do this or do not increase efficiency in storage or retrieval, are ineffective.

Factors that Hinder Implementation of Inquiry

Although inquiry-based learning appears to be an effective pedagogical strategy, it is not widely implemented in practice. According to Engeln et al. (2013), teacher beliefs are critical to the implementation of inquiry-based learning. In their studies of inquiry-based learning in twelve European countries, Engeln et al. (2013), and Dorier and Garcia (2013) identified similar challenges which include large class sizes, classroom management issues that arise with group work as well as equitable distribution of work within a group, and the simple fact that many students are not used to this type of learning so they resist an inquiry approach. Additionally, the curriculum has so much content that teachers feel pressure to cover all the expectations so that students are not at a disadvantage in subsequent courses. Engeln et al. (2013) identified three main factors as anticipated problems with implementing inquiry-based learning: system restrictions (professional development and training, size of curriculum), classroom management, and resources. Similarly, Dorier and Garcia (2013) found that most teachers use traditional methods of instruction because they were not taught through an inquiry-based approach so it is new to them, as is the new role of teacher as facilitator and student as active participant.

Most classroom structures remain authoritative, and lack the key ideas of true student choice, activity, and inquiry. Discourse is created by those who are in control, and those who are in positions of power select and organize knowledge (Pitsoe, Letseka, 2013). In this sense, a teacher with more of a focus on regulative discourse controls what happens in the classroom and when, who speaks and who does not.

Lefstein (2002) discuss how Foucault outlines the control mechanisms of power within social institutions. Foucault saw managing people within limited spaces as a major problem and felt that schools, for example, need to separate students into manageable groups, control their activity, and maintain surveillance. Students must be judged against an established “norm”, and as such can be threatened with failure. Disruption is seen as a control problem and disciplinary structures represent school power relationships. Based on Foucault’s theory, teachers who focus on instructional discourse may have difficulty coping with power and control. However, when students are controlled based on a pre-determined ideal of “normal behavior”, they are denied the opportunity to develop self-regulation of their own learning (Lefstein, 2002). In my experience, loss of control of a classroom is a concern for many teachers and can be a reason why inquiry-based learning has not been implemented in many classrooms.

To have successful implementation of inquiry-based learning, it has been suggested that inquiry needs to play a dominant role in the professional development of in-service and pre-service educators, and should include observation of teachers practicing inquiry along with debrief time (Barrow, 2006; Ortega et al., 2013). Most teachers were taught traditionally, where they were often passive consumers of information. It is not realistic to expect them to suddenly become facilitators of activity and reflective discourse, where students are producers of their own knowledge and understanding. There have been many recommendations that teachers need more training and professional development, and more time. Barrow (2006) advocates for professional development that models inquiry and provides opportunities for teachers to leave a session feeling comfortable with doing inquiry. He also advises that assistance from a consultant be provided to teachers implementing inquiry. This is reflected in the study summarized by Amaral et al. (2002). The authors noted that teachers received at least 100 hours of professional development over the four years of the project, where training was in the same manner as their students would receive content. Teachers were given the opportunity to experience and understand the activities, and with instructional implementation strategies. They also received in-class support from consultants, and were given time to meet with grade-level teachers to deconstruct and reflect on student work.

Similarly, Klingner et al. (2006) suggest the importance of "…making sure that teachers know a variety of research based instructional approaches specifically designed for ELLs who show early signs of struggling to learn" (p.124). Finally, Lee et al. (2008) say that teachers need to engage in science inquiry to be able to facilitate inquiry. They say that "teachers need to learn how to enable students to share and negotiate ideas and construct collective meanings about science" (p. 33). In the five year professional development intervention studied by Lee et al. (2008), teachers participated in workshops that included inquiry tasks and discussions on implementation. Together, they worked on lessons and activities which were then presented to the group, and they focused on how to incorporate English language and literacy into science lessons. Teachers also participated in classroom observations twice in the first year. This approach proved effective as the students in these classes showed a statistically significant increase in science and math achievement, and the achievement gap narrowed for ELL students.

Ontario is committed to helping students become successful, global citizens able to face complex challenges now and in the future (OME, 2016). Following the 2013 study of inquiry-based learning in twelve European countries, it was noted that “there is a generally accepted consensus that a lack of basic competencies and interest in mathematics and science subjects will hinder young people in becoming active citizens and contributing adequately to the development of society” (Engeln et al., 823). In addition to the challenges of implementation discussed, Barrow (2006) suggests that teachers are confused about what inquiry really is, and that professional development and time are major barriers to implementing this model. Many teachers believe task oriented, visual instruction falls short, and believe that if all learning is inquiry-based, there will not enough time left for practice and reinforcement of skills. What this interpretation lacks is the combination of rich, open tasks with direct instruction when needed. Rigor is built into the classroom environment as students construct meaningful understanding before moving to develop procedural fluency. To have successful implementation of inquiry-based learning, there are repeated recommendations that teachers need more training and professional development, and more time. More time becomes an institutional factor because of the immense content in each curriculum, but also to be considered is the longer learning time required for students who bring with them a wide range of prior knowledge.

Based on my own experiences with professional development, the only way to make a difference in the classroom is to actively engage teachers in the learning, and have opportunities to visit other classrooms where professionals can learn from and with their peers. The similar approaches and suggestions made in this body of research seem to be an effective model to implement inquiry-based learning.

Chapter 4: Analysis of Curriculum from a Perspective of Inquiry

Inquiry through the Lens of Doll's 4Rs

William Doll Jr. is an educator and curriculum theorist who draws on ideas from chaos theory, which emphasizes sensitivity to initial conditions and the importance of constant feedback loops, as well as Dewey's focus on hands-on experiential learning and Piaget's constructivist theory of knowing ("William E. Doll Jr", n.d.). In his book, *A Post-modern Approach to Curriculum* (1993), Doll theorizes a post-modern curriculum and its development, as compared to the modern perspective taken by Ralph Tyler, who in 1949 published *Basic Principles of Curriculum and Instruction*. The Tyler rationale is based on a structure for delivering and evaluating curriculum, and involves educational purpose, selecting learning experiences to meet that purpose, organizing learning experiences, and evaluating the effectiveness of the learning experiences. In looking at the Tyler rationale, Doll disapproves of experiences that are pre-determined and rigid, and evaluations that are strictly based on pre-set goals, making time and schedules a factor in the learning. He also dislikes the three Rs of "Readin", "Ritin", and "Rithmetic" from the late 19th and early 20th century. Doll suggests that the quality of curriculum within a post-modern framework be evaluated using the four Rs of Richness, Recursion, Relations, and Rigor. The modern approach to curriculum was very prescribed and specific and was geared towards students becoming functional members of the developing industrial society. Today, "the primary goal of the province's education system is to enable students to develop the knowledge, skills, and characteristics that will lead them to become personally successful, economically productive, and actively engaged citizens" (OME, 2016, p. 3). There exist parallels between Doll's ideas and the strategies being promoted through research and by the Ontario Ministry of Education.

Inquiry, Global Competencies, and the Ontario Mathematics Curriculum

Doll suggests four Rs to replace "Readin", "Ritin", and "Rithmetic". Richness speaks to the multiple interpretations and possibilities within a curriculum. Students bring with them a range of prior knowledge and abilities. In math, when we rush to the algorithm without giving consideration to this current knowledge and before developing conceptual understanding, we deny students the opportunity to engage in productive struggle that is so important to learning and to merging new and current knowledge. In the Ministry of Education (2011) publication "Paying Attention to Mathematics Education", one of the seven foundational principles outlined is "focus on mathematics". It states that focusing on mathematics involves teachers helping students explore and make sense of patterns and relationships between and among the strands, enabling students to develop a deep understanding of mathematical concepts, skills, and processes, engaging students as co-learners in the development, refinement and expression of mathematics, including multiple representations of mathematical concepts, and encouraging multiple approaches for learning and actively doing mathematics (Ontario Ministry of Education, 2011, p.4). As students engage in *doing* mathematics through inquiry, they learn to fit new understanding with their prior knowledge. This idea of recursion (Doll, 1993) is critical to the construction of knowledge. In his paper, Barrow (2006) speaks to Dewey's 1938 idea that "problems to be studied must be related to students' experiences and within their intellectual capability; therefore, the students are to be active learners in their searching for answers" (p. 266). Recursion supports learning and is a reflective process that develops competence. This is emphasized in the 21st Century Competencies foundation document (OME, 2016), which states that "learning the process of learning must become the core purpose of education in the 21st century" (p.16). Further to doing and reflecting-on-doing, students must have time and space to uncover the interconnectedness of ideas relationships between concepts. Support of the concept of relations in curriculum can be found in Research Monograph #59, "Making Space for Students to Think Mathematically" (OME, 2015). Math talks which are based on a rich inquiry-based task that has multiple layers, as well as a low floor and high ceiling to provide all students an entry point, along with providing a safe space for taking risks, allowing for exploration, and encouraging high-quality student interaction are presented as a way to foster mathematical understanding. Students work collaboratively to solve problems and make connections. "Changing economic, technological, and social contexts in the 21st century mean that interpersonal and intrapersonal competencies have become much more important than in the past" (OME, 2015, p. 10). Other important components of inquiry are rigor and persistence. An inquiry can be considered complete when we "know something we did not know before we started. Even when our investigation fails to find the answer, at least the inquiry should have yielded a greater understanding of factors that are involved in the solution" (Barrow, p. 265). A program with rigor provides opportunities for students to search for hidden assumptions, and students are encouraged to seek out alternatives and connections. It does not mean the questions are harder or that students are given more worksheets and more homework. It is important to note that in my experience, consolidation of concepts and practice are still needed at the end of an inquiry task, but are not a stand-alone feature.

Inquiry, Discovery, and the Ontario Science Curriculum

Over time, science seems to have become a collection of isolated facts. But it is not, and it is not only for the smart kids. *The Next Generation of Science Standards* (2013) is doing a good job in its attempt to move science education in the right direction. The progression of concepts from kindergarten to grade 12 addresses how learning is recursive. Even though the underlying core idea is the same, students enter each year with new skills and experiences, so understanding deepens and matures. Students are led to recognize the connections within and between fields, and to develop a genuine interest in science, engineering, and math, which they need to meet success in the future, and which we need to compete globally.

When students are not given the opportunity to help construct, reflect on, and evaluate knowledge, they often do not acquire conceptual understanding. The old, and too often current, model of science education gives students a distorted view of science and the process of inquiry and discovery. In his paper “Discovery Simulated Teaching Approach: Theory and Example” (2003), Zhou discusses the importance of also teaching students the history of science. As students move through the discovery process of constructing their own knowledge, they learn that scientific ideas are born out of inquiry and experimentation, and “…can clearly see the success, failure, sadness, excitement, value, and bias of scientists…” (p. 4). Zhou looks at the parallels between knowledge acquisition in the history of science and the way students construct knowledge. Students are naturally curious. Science education should endeavor to build upon and work with this curiosity. Science is a way of knowing, but it is often taught as a body of knowledge and a set of facts that must be memorized. Laboratory exercises are usually performed as a way to verify someone else's hypothesis, following steps like a recipe. Too often, students are offered little engagement with the process of science. Although curiosity is natural, critical thinking is not. Students need scaffolding and guidance in developing the skills and habits of mind of inquiry. Science education should be authentic and focused on *doing* science. Students can learn that there are patterns in nature, and that certain core ideas are stable but, as seen throughout the history of science, can slowly evolve and change. Students begin to understand science and learning as a process. They see that making mistakes is an important part of learning. With every new discovery, there were many failures that came before it. When students become active scientists in the classroom they learn to learn, and learn to communicate and work collaboratively by developing and considering alternative hypotheses. By doing science, students develop better questioning and critical thinking skills which are important in all aspects of life. If our goal in education is to produce students with the critical thinking skills needed to meet success in the future, an important step is to have students do, reflect upon, and argue about science, and experience science as a scientist. More teachers are moving towards an inquiry-based approach, where students become scientists. They pose questions, form hypotheses, and evaluate ideas. They are immersed in observation and collection of data and are led to think critically about current and new theories. It is through this process that students can begin to fit new knowledge into their existing framework of understanding and life experiences. As in the mathematics curriculum, the science curriculum also states that “research and successful classroom practice have shown that an inquiry approach…best enables students to develop the conceptual foundation they need” and, as with Doll’s Recursion, that programs need to “actively engage students in inquiries that honour the ideas and skills student bring to them…” (OME, 2008, p.30).

Chapter 5: Conclusion and Recommendations

Conclusion

In this paper, I attempted to explore what the current research says about inquiry-based learning in order to answer two questions.

1) Given that inquiry-based learning has received increasing attention in recent years, what does current research say about how this pedagogical strategy might be used to support all learners in mathematics and science?

The analysis was done through the lens of constructivist theory, which emphasizes problem solving and active reflection on prior and new learning as a way to construct knowledge. As such, the teacher becomes the facilitator who guides students in building meaning. Inquiry has been shown to be supported by the Ontario Ministry of Education, which recognizes the importance of students developing deep understanding of the big ideas and promotes inquiry as a means of doing this. The Ministry also recognizes the importance of the cultural experiences students bring to the classroom, and emphasizes that teachers adapt their instructional approach to facilitate success for all students. In the body of research that was analyzed, it seemed evident that inquiry-based learning has had a positive impact on the achievement of mathematics and science learners, particularly due to the group dynamics and communicative aspects involved with inquiry.

2) What are some associated challenges with the implementation of an inquiry approach?

Looking across most of the research analysed, some common barriers to implantation of inquiry-based learning in classrooms emerged. Although the theory of constructing knowledge is good, the implementation has failed. Some challenges cited in the research include lack of time, lack of proper pre-service and in-service training, lack of adequate content knowledge, and resistance to change combined with the weight of dominant teacher practice.

Recommendations

Along with identifying challenges to implementing inquiry-based learning, several research studies have suggested recommendations to promote this strategy. One of the strongest recommendations involves professional development. It has been suggested that professional development follow the same structure as an inquiry classroom so teachers can experience what their students will experience. By participating in inquiry themselves, teachers can become comfortable with implementing inquiry in their own classrooms. Along with workshops, it has been suggested that teachers have follow-up support from consultants, as well as release time to discuss best practices and for observing other teachers.

In my experience, if the goal is to have teachers pedagogically transformed as a result of professional development, then modeling the student experience is the most effective approach. I, myself, have sat through countless hours of PD which present good ideas but do not provide support for their implementation. I found success in changing teacher practice with using manipulatives in the classroom by facilitating workshops where teachers took on the role of students as I led them through lessons using algebra tiles. Algebra tiles are mathematical manipulatives that help students build conceptual understanding of topics in algebra. They consist of small squares that represent integers, rectangles that represent the variable x, and large squares that represent the variable x^2. These teachers held prior understanding of the math content, and integrated that knowledge with the immediate experience of using the manipulatives. Teachers engaged with the problem of how to implement manipulatives in their lessons, and many left the workshop changed as a result of the experience.

I think that if workshops on inquiry-based learning followed a hands-on, inquiry approach, then more teachers would feel comfortable with implementing this strategy in their classrooms. We have been aware of the benefits of a problem-based approach for more than 100 years, and now we see that inquiry can benefit many of our learners. Among the skills described as important for our students in preparing for the ever-changing demands in their future are critical thinking and problem solving, collaboration, communication, and learning to learn. Doll (1993) suggests a move to Richness, Recursion, Relations, and Rigor as a way to develop deeper understanding, reflect on learning, and making connections (p. 253 – 259). This approach applies in many ways to both mathematics and science education, which both rely on conceptual understanding, making connections, and strong adaptive reasoning. To develop the skills of critical thinking, problem solving, and collaboration, students need to actively participate in doing math tasks, and experience science as a scientist. The ideas presented by Doll offer a possible framework in which to approach the development of key skills and competencies.

Critical literacy involves more than just reading and writing. It requires learners to engage in text within a social context, “Therefore, to study classroom literacy practices, one must examine the discourses that permeate classroom life. Classroom discourse involves more than just language. It includes all social and semiotic practices that shape classroom life." (p. 200 Van Sluys, 2006). Every interaction that occurs within a classroom shapes the learning that can, or cannot, happen. Discourse analysis allows us to understand the identities taken on during conversations and the power relationships within the classroom. From this, we can begin to identify and shape classroom practices that may make a difference. It seems clear that effective pedagogy includes ideas such as focusing on curriculum rather than behavior, scaffolding instruction to support learning, and promoting a non-threatening learning environment with entry points for all learners.

For inquiry to truly be implemented across the province, it seems that the curriculum needs to be minimized to a core set of key concepts. This way, students can move from surface learning to deep conceptual understanding. Learning can then move forward and students will have constructed knowledge through experiences both within and outside the classroom. In this way, education will become recursive, in that each year students come to class with a solid understanding of concepts, and through new experiences they will build upon and perhaps modify their body of knowledge. It is this new body of knowledge that is both the same and different which they will then bring to the next class and the cycle will continue.

Students will always come to us with years of life experiences and hold pre- and misconceptions that are resistant to change. Through inquiry, students are presented with a problem, predict results or interpret phenomena, and are faced with results that may differ from what they expected. Inquiry-based activities then lead students to construct, defend, and evaluate their own explanations and are an effective way to confront misconceptions and develop critical thinking skills and habits of mind that will carry forward in many aspects of life and beyond the elementary and secondary years of education. In must be noted, however, that learning which is all one side or the other is not effective. In my experience, instruction of fundamentals followed by inquiry to consolidate, extend, communicate, and connect new learning is most effective.

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