Comparing Self-regulatory Processes and Achievement when
Learning for Learning versus Learning by Teaching

Cynthia Psaradellis
Department of Educational and Counselling Psychology
McGill University, Montreal
July 2014

A thesis submitted to McGill University in partial fulfillment of the requirements
of the degree of Masters of Arts in Educational Psychology

© Cynthia Psaradellis 2014
# Table of Contents

List of Appendices............................................................................................................. 4

Abstract ............................................................................................................................. 5

Résumé ............................................................................................................................... 6

Acknowledgements ........................................................................................................... 8

Chapter 1: Introduction .................................................................................................... 9
  Learning by Preparing to Teach .................................................................................... 12
  Self-regulated Learning ............................................................................................... 15
  Self-regulated Learning when Learning by Teaching .............................................. 18
  Summary ....................................................................................................................... 19

The Current Study ........................................................................................................... 20

Chapter 2: Methodology ................................................................................................. 22
  Participants ..................................................................................................................... 22
  Materials ....................................................................................................................... 22
  Procedure ....................................................................................................................... 24
  Coding Schemes ........................................................................................................... 26
  Table 1 ............................................................................................................................ 28
  Self-regulated Learning Coding Scheme for Mathematics Problem Solving .......... 28

Chapter 3: Results .......................................................................................................... 35
  Preliminary Analyses ................................................................................................... 35
  Correlations among Variables ..................................................................................... 35
  Table 2 ............................................................................................................................ 36
Zero-order Correlations ........................................................................................................................................ 36

Design .................................................................................................................................................................. 36

Students’ Understanding of the Problem Space .................................................................................................. 37

Table 3 ................................................................................................................................................................. 38

Means and Standard Deviations for each Variable as a Function of Learning Condition by
Gender (raw frequencies shown) ......................................................................................................................... 38

Self-Regulatory Processes .................................................................................................................................. 39

Mathematics Problem Solving Achievement .................................................................................................... 40

Chapter 4: Discussion ........................................................................................................................................ 42

Summary of Findings ........................................................................................................................................ 42

Theoretical Implications .................................................................................................................................... 42

Educational Implications .................................................................................................................................... 44

Limitations of the Research ................................................................................................................................. 45

Suggestions for Future Research .......................................................................................................................... 45

References ............................................................................................................................................................ 48
List of Appendices

Appendix A: *Quebec Exam in Mathematics (2009) “Start Your Engines” Problem* .................. 54

Appendix B: *Consent Form* .................................................................................................. 57

Appendix C: *Assent Form* .................................................................................................... 60

Appendix D: *Protocol for Grade 5 students* ......................................................................... 62

Appendix E: *Concept Map Marking Rubric* .......................................................................... 64

Appendix F: *Sample Concept Map* .................................................................................... 65

Appendix G: *Quebec Exam in Mathematics (2009) “Start Your Engines” Marking Rubric* ...... 66

Appendix H: *Quebec Exam in Mathematics (2009) “Start Your Engines” Sample Solution* ...... 67
Abstract

The purpose of this thesis was to develop a better understanding of why learning by preparing to teach results in better learning outcomes during complex mathematics problem solving. Seventy-eight elementary students’ conceptualizations of the problem space, self-regulatory processes, and mathematics achievement were compared across two conditions: learning by preparing to teach (referred to as learning by teaching) versus learning for learning. To measure their task definitions of the mathematics problem, students developed concept maps of the problem space. To capture students’ self-regulatory processes, students thought out loud as they solved the problem. Results revealed that students in the learning by teaching condition and girls developed a more complex concept map of the problem space compared to students in the learning for learning condition and boys. Students in the learning by teaching group also engaged in more metacognitive strategies. In addition, girls had higher frequencies of planning and goal setting, cognitive learning strategies, and metacognitive strategies. Finally, results revealed that students in the learning by teaching group and girls had higher levels of achievement. Additionally, correlational analyses revealed that students who used more cognitive and metacognitive strategies developed better concept maps and achieved higher scores in mathematics problem solving. Moreover, students who developed better concept maps had higher levels of achievement in mathematics problem solving. Consistent with theoretical considerations within learning by teaching literature, this research showed that learners organize the learning material differently and engage in more metacognitive processes during learning by teaching which results in better learning outcomes.

Keywords: concept maps, self-regulatory processes, academic achievement, learning for learning, learning by teaching
Résumé

L'objectif de cette thèse est de développer une meilleure compréhension des raisons pour lesquelles l'apprentissage en se préparant à enseigner mène à des meilleurs résultats d'apprentissage pendant la résolution d’un complexe problème mathématique. Des cartes conceptuelles, les processus d'autorégulation et la réussite de problèmes mathématiques ont été comparées pour soixante-dix-huit élèves du primaire dans deux conditions: l'apprentissage en se préparant à enseigner (aussi appelé l'apprentissage par l'enseignement) ou par rapport à l'apprentissage pour l'apprentissage. Pour mesurer leurs définitions de tâches du problème de mathématique, les élèves ont développé des cartes conceptuelles. Pour capturer les processus d'autorégulation, les étudiants pensaient à voix haute pendant qu'ils ont trouvé la solution. Les résultats ont révélé que les élèves de la condition l'apprentissage par l'enseignement et les filles ont développé une carte conceptuelle plus complexe comparativement les élèves de la condition l'apprentissage pour l'apprentissage et les garçons. Les résultats ont révélé que les élèves du groupe l'apprentissage par l’enseignement se sont engagés dans des stratégies métacognitives plus profondes. De plus, les filles ont des fréquences plus élevées de la planification et détermination des objectifs, les stratégies cognitives et métacognitives. Enfin, les résultats ont révélé que les élèves du groupe l'apprentissage par l'enseignement et les filles avaient des niveaux plus élevés de réussite. De plus, des analyses de corrélation suggèrent que les étudiants qui ont utilisé plus les stratégies cognitives et métacognitives ont développées des cartes conceptuelles plus complexes et avaient des niveaux plus élevés de réussite en mathématique. Les étudiants qui ont développées des cartes conceptuelles plus complexes avaient des niveaux plus élevés de réussite en mathématique. Cette recherche a montré que les élèves organisent les
matériaux différemment et les processus d'apprentissage plus fréquents se produisent pendant l'apprentissage par l'enseignement qui se mène à des meilleurs résultats d'apprentissage.

*Mots-clés:* des cartes conceptuelles, l’autorégulation, la réussite de problèmes, l'apprentissage pour l'apprentissage, l'apprentissage par l'enseignement
Acknowledgements

I would like to thank my supervisor, Dr. Krista Muis, whose scaffolding has helped me to further develop my academic skills such as critical thinking and problem solving. I would like to thank my parents and brother, Dimitrios, Maria, and Steve Psaradellis for their constant support, encouragement, respect, and love. I would like to thank all the members of the laboratory (Marianne Chevrier, Meredith Derian-Toth, Ivana Di Leo, Sara Hojabri, John Ranellucci, Gregory Trevors, and Melissa Duffy) for their help with data collection and data analysis. I would like to thank Dr. Susanne Lajoie and the Learning Environments Across Disciplines (LEADS) partnership for their support.
CHAPTER 1

Introduction

Imagine you get to choose how you will learn something. Would you choose to attend a lecture, read about it, or teach someone else? An ancient Chinese proverb of sixth century BC by Confucius is “I hear and I forget. I see and I remember. I do and I understand.” According to Confucius, if a person listens to a lecture, they will more likely forget that information. If a person reads information, they will only remember it. To truly understand and maximize the benefits of learning, a person must be actively involved during learning. One way that involvement may occur is when a person teaches someone else, which is known as learning by teaching (Roscoe & Chi, 2007).

Fiorella and Mayer (2013) define learning by teaching as a learning environment in which a student is given the role of the teacher and is asked to teach academic content to others for instructional purposes. Others may include peers or computer-based agents (Biswas, Jeong, Kinnebrew, Sulcer, & Roscoe, 2010; Roscoe & Chi, 2007). Four lines of research that have been conducted within the learning by teaching paradigm include learning by preparing to teach (e.g., Annis, 1983; Bargh & Schul, 1980; Fiorella & Mayer, 2013; Renkl, 1995), learning by (actually) teaching (Annis, 1983; Fiorella & Mayer, 2013; Fiorella & Mayer, 2014), learning through peer tutoring (Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001; Roscoe & Chi, 2007), and teachable agents (Biswas, Leelawong, Schwartz, & Vye, 2005; Biswas et al., 2010).

Learning by preparing to teach is when an individual completes a task and expects to teach someone else, but does not actually engage in the act of teaching (also known as teaching expectancy; Renkl, 1995; Fiorella & Mayer, 2013; Fiorella & Mayer, 2014). Learning by (actually) teaching is when an individual completes a task and then teaches someone else the
content he or she just learned (Fiorella & Mayer, 2013; Fiorella & Mayer, 2014). Peer tutoring is a combination of tutor-centered tutoring, in which the tutor teaches the content to a peer (similar to traditional lecture format), student-centered tutoring, in which the student being tutored plays a central role during the tutoring session, and interaction tutoring in which there is an equal interaction between the tutor and student (Chi et al., 2001). Finally, teachable agent learning environments consist of a student teaching a “teachable” agent what they know, which provides them with the opportunity to simultaneously learn (Biswas et al., 2010). For example, after learning the content, a student teaches the agent how to solve a problem, and the agent then completes the problem. If the student’s agent fails to solve the problem, then the student has to self-assess his or her own understanding before he or she can help the computer agent solve the problem. This helps learners learn, and teach the material, as well as self-regulate their own understanding (Biswas et al., 2010).

As previous research has shown, learning by teaching can have positive effects on learning (e.g., Biswas et al., 2010; Chi et al., 2001; Graesser, Person, & Magliano, 1995; Palinscar & Brown, 1984; Peets et al., 2009; Roscoe & Chi, 2007). For example, when learning by teaching, individuals theoretically learn content more deeply when they teach it to someone else, which results in better learning outcomes. However, the underlying reasons for this positive effect on learning remain unclear (Fiorella & Mayer, 2013; Galbraith & Winterbottom, 2011; Peets et al., 2009; Rohrbeck, Ginsburg-Block, Fantuzzo, & Miller, 2003; Roscoe & Chi, 2007). For instance, Bargh and Schul (1980) proposed that the expectation of teaching content to others results in a change in the way individuals study that material compared to normal studying for oneself (which is called learning for learning). Bargh and Schul (1980) argued that to teach, individuals must develop a good understanding of the domain knowledge and then structure that
knowledge in a way that can be presented to others. In addition, previous research has shown that when students expect to teach, they achieve a better understanding of the content compared to those who were asked to simply study the content (Benware & Deci, 1984). Moreover, Biswas, Schwartz, and Bransford (2001) proposed that students who are preparing to teach feel more motivated to gain a deeper understanding of the material. Additionally, when learning by preparing to teach, students devote more resources toward selecting the most relevant material and organizing it into meaningful representations (Bargh & Schul, 1980; Fiorella & Mayer, 2013; Fiorella & Mayer, 2014; Roscoe & Chi, 2007). As such, the initial step of learning by preparing to teach may be a critical period with regard to why learning gains may occur compared to learning for oneself. That is, during learning by preparing to teach, individuals may structure and organize their knowledge better to prepare to teach it to others.

To date, the majority of research has focused primarily on the effects of learning by teaching on learning outcomes. Few studies have been conducted to explore whether individuals structure and organize their knowledge differently when preparing to teach it to others compared to when learning for oneself. To fully understand why positive effects result when learning by preparing to teach, research is needed that explores each phase of learning as it occurs. As such, the purpose of this research was to assess whether learners organize the learning material differently, and whether they engage in more frequent learning processes during learning by preparing to teach than when compared to learning for oneself. Because preparing to teach is the first phase of learning by teaching, this thesis focuses specifically on that aspect. Prior to delineating the specific research questions and hypothesis, I first present a review of the theoretical frameworks and empirical work that guided this research.
Learning by Preparing to Teach

As previously noted, Bargh and Schul (1980) proposed that the expectation of teaching content to others results in a change in the way individuals study that material compared to normal studying for oneself. They argue that to teach, individuals must develop a good understanding of the domain knowledge and then structure that knowledge in a way that can be presented to others. When learning by preparing to teach, students arguably devote more resources toward selecting the most relevant material and organizing it into meaningful representations (Roscoe & Chi, 2007).

Research on learning by preparing to teach provides support for this hypothesis. For example, Bargh and Schul (1980) examined differences in learning outcomes with participants who were given verbal material to study with the expectation of simply being later tested on that material, or were told they would teach the material to another person. Results from their study revealed that participants who were expected to teach performed better on a retention test compared to those who just studied the material. Using a similar design, Benware and Deci (1984) found that students who expected to teach achieved a better conceptual understanding of an article on brain functioning than did students who did not expect to teach. In another study, Biswas et al. (2001) reported that students felt that the responsibility to teach encouraged them to gain a deeper understanding of the materials during preparation.

Renkl (1995) also explored students’ learning gains when expecting to teach someone else. Thirty-six German Education students were randomly assigned to one of two conditions. The teaching expectancy group was expected to complete a Calculus problem and then teach a similar Calculus problem to someone else. The control group was expected to complete a Calculus problem and solve a similar problem. Results revealed that the teaching expectancy
group who were expected to teach a Calculus problem had a deeper understanding of the material when compared to the control group who simply studied the material. According to Renkl (1995), learning by preparing to teach had positive learning gains for students.

The second type of learning by teaching is learning by (actually) teaching. In another study, Fiorella and Mayer (2013) explored the relative effects of learning by preparing to teach and actually teaching on learning outcomes. The learning by teaching group consisted of 30 American undergraduate students who studied the Doppler Effect and then developed a teaching video to be used to teach others the same content. The teaching expectancy group consisted of 32 American undergraduate students who studied the material and prepared to teach someone else, but did not actually develop the teaching video. The control group consisted of 31 undergraduate students who simply studied the material. Results revealed that for the immediate comprehension test, the learning by teaching group and the teaching expectancy group had a deeper understanding of the content when compared to the control group. On the one-week delayed comprehension test, however, the learning by teaching group had a deeper understanding when compared to the teaching expectancy and control groups. According to Fiorella and Mayer (2013), learning by preparing to teach has a positive learning effect for short-term comprehension, whereas learning by teaching has a positive learning effect on both short-term and long-term comprehension when compared to learning for learning.

In a second study, Fiorella and Mayer (2014) examined the role of preparing to teach and actually teaching on immediate and long-term comprehension. Ninety-five undergraduate students were randomly assigned to one of three groups: actual teaching, teaching expectancy, or control group. To assess whether students in the teaching expectancy and actual teaching groups organized the content better than those in a control group, Fiorella and Mayer (2014)
manipulated the quality of the presentation of the content (more disorganized versus well structured). Results revealed that those who prepared to teach outperformed the control group on an immediate comprehension test, regardless of the format of the content (no structural differences occurred). Moreover, those who actually taught outperformed those who did not teach on a delayed comprehension test. These results provide support for the added long-term benefit of actually teaching compared to preparing to teach or learning for learning.

The majority of research that has explored the effects of learning by teaching has been drawn primarily from the peer tutoring literature. From the peer tutoring literature, Roscoe and Chi (2007) propose that tutors benefit from instructing others because they must be able to explain the content to others. As previously noted, it is likely during the preparing to teach phase that learning gains occur given that tutors must organize the content in ways that allow them to effectively teach it to others. According to Biswas et al. (2010), this initial structuring of knowledge is likely fostered through self-explanations. Individuals are more likely to engage in these self-explanations to ensure they can teach the content to others. As previous research has shown, when individuals engage in more self-explanation processes, this should facilitate learning (e.g., Chi, DeLeeuw, Chiu, & LaVancher, 1994; Matthews & Rittle-Johnson, 2009) via increased metacognitive awareness (Kwon & Jonassen, 2011). Given that metacognitive monitoring and regulation play a central role in mathematics problem solving (Jacobse & Harskamp, 2012; Muis, 2008; Schoenfeld, 1994), a learning environment developed within the learning by teaching paradigm may foster greater self-regulatory behaviours and, subsequently, better performance compared to a learning environment that does not incorporate the learning by teaching paradigm (Biswas et al., 2010). I elaborate this possibility next.
Self-regulated Learning

One line of work that may help explain why learning outcomes differ when learning by preparing to teach versus learning for learning is theoretical models of self-regulated learning. According to Schunk and Ertmer (2000), self-regulated learning is defined as modified and planned self-generated thoughts, feelings, and actions that are oriented toward learning goals. Students who self-regulate their learning will plan how to approach a learning task, set goals, implement strategies to carry out the task, and evaluate progress and products throughout the learning process. Planning, implementation, and evaluation are common phases in the theoretical frameworks of Schoenfeld (1982), Muis (2007), and Greene and Azevedo (2009), which are described next. These models were chosen given their focus on mathematics problem solving (Schoenfeld, 1982), task definitions (Muis, 2007), and coding schemes that can be used to measure self-regulated learning processes as they occur during learning and problem solving (Greene & Azevedo, 2009).

Schoenfeld’s (1982) model of self-regulated learning during mathematics problem solving. Schoenfeld (1982) describes self-regulated learning as understanding, planning, monitoring and deciding what to do. During mathematics problem solving, Schoenfeld (1982) proposed that good problem solvers will move through six phases of problem solving: read, analyze, explore, plan, implement, and verify information. Reading includes reading a problem statement, considering problem conditions, rereading, and contemplating a problem. If a strategy to solve a problem is identified, an individual may begin a plan to approach the problem or may move to the implementation stage, where strategies are enacted. When a strategy is not identified after the problem is read, the next stage of problem solving is typically the analysis stage. During the analysis stage, an individual may attempt to understand a problem or select strategies that he
LEARNING BY TEACHING

or she thinks are appropriate. These processes often lead directly into the development of a plan but if a plan is not yet apparent, an individual may engage in exploration of the problem space. Exploration includes a broad tour through a problem space to search for relevant information that can be included in the analysis-plan-implementation sequence. Monitoring during implementation is a key factor in successful problem solving. If monitoring occurs to assess whether a plan is effective, that information can be used as feedback. If a plan is not successful, an individual may discontinue the plan and return to the planning stage, an earlier stage, or may quit. If a plan is successful or a solution is reached during implementation or exploration, the individual may evaluate the solution. The process of checking one’s work is the final stage of problem solving, the verification stage.

As described above, the six phases are not linear and occur in a cyclical manner (Schoenfeld, 1982). For example, in a fifteen minute time span, a learner might read for one minute then analyze the material for two minutes, plan for two minutes then implementing for one minute, and then verify for another minute (Schoenfeld, 1982). If the problem is incorrect after verification, the student may use a different approach (Schoenfeld, 1982). The learner may then cycle through another series of phases until the problem is solved. Another similar framework to Schoenfeld’s (1982) model is Muis’s (2007) model of self-regulated learning.

learner defines the task based on external conditions, such as the task context, and internal conditions such as prior knowledge and motivation.

Importantly, different task definitions will lead individuals to use different learning strategies to carry out the task (Muis, 2007; Winne & Hadwin, 2008). This variation in strategy use occurs given that the task definition phase influences the plans and goals that individuals set during the second phase. Planning includes selecting the types of learning strategies to carry out the task and identifying the type of information on which to focus during learning. A goal is modeled as a multifaceted profile of information (Butler & Winne, 1995) and each standard in the profile is used as a basis to compare the products created when carrying out the task.

The third phase begins when a learner implements the learning strategies that were planned to carry out the task. Then, in the last phase, individuals evaluate the successes or failures of each phase or products created for the task, or perceptions about the self or context. Products created during learning are compared to the standards set via metacognitive monitoring. According to Muis (2007), it is important to note that metacognitive processes can occur during all four phases of self-regulated learning. That is, monitoring, control, and reaction can be ongoing throughout the learning process, and goals and plans may also change or be updated as feedback about progress becomes available. Moreover, products created across all four phases can feed into other phases, which reflect the cyclical nature of self-regulated learning in her model.

**Greene and Azevedo’s (2009) model of self-regulated learning.** Another similar framework to Muis’s (2007) model is Greene and Azevedo’s (2009) model of self-regulated learning. According to Greene and Azevedo (2009), cognitive and metacognitive processes for self-regulated learning include five macro levels which are planning, monitoring, strategy use, as
well as handling of task difficulty and demands, and interest. The first macro level—planning—consists of four micro levels, which are planning, goals, prior knowledge activation, and recycling goals in working memory. The second macro level—monitoring—comprises seven micro levels, which are judgments of learning, feelings of knowing, self-questioning, content evaluation, identifying adequacy of information, monitoring progress toward goals, and monitoring use of strategies. The third macro level—strategy use—consists of 18 micro levels, which include selecting a new informational source, coordinating informational sources, reading new paragraphs, reviewing notes, memorizing, free search, goal-directed searching, summarizing, taking notes, drawing, re-reading, making inferences, hypothesizing, knowledge elaboration, mnemonics, evaluating content as answer to goal, finding location in environment, and skipping (Greene & Azevedo, 2009). The fourth macro level—task difficulty and demands—comprises five micro levels, which include time and effort planning, help seeking behaviour, task difficulty, control of context, and expectation of adequacy of information (Greene & Azevedo, 2009). The fifth macro level—interest—consists of one micro level, which is interest statement (Greene & Azevedo, 2009).

Self-regulated Learning when Learning by Teaching

Taken together, these models, particularly Muis’s (2007), provide a theoretical explanation with regard to why differences in learning outcomes occur when learning by preparing to teach (herein referred to learning by teaching for simplicity) versus learning for learning. Specifically, from a self-regulated learning perspective, learners’ task definitions should differ when learning solely for oneself versus when given the task to teach others. The type of information that learners highlight as important should vary and may be organized differently when learning by teaching versus solely learning for learning. These differences in
task definitions should theoretically result in differences in how learners approach the learning task (Muis, 2007; Winne & Hadwin, 2008). To date, research within the learning by teaching framework has not explored this possibility. Moreover, despite the think aloud (Azevedo, 2005; Greene & Azevedo, 2009; Muis, 2008) and trace methodologies (Winne, Jamieson-Noel, & Muis, 2002) that can be used to capture self-regulatory processes within the self-regulated learning literature, research within the learning by teaching framework has not explored whether online differences occur in cognitive and metacognitive processing when learning by teaching versus solely learning for oneself. To further understand how and why learning by teaching improves learning outcomes, it is necessary to employ a think aloud approach to explore the types of learning strategies individuals adopt in preparing to teach. This research addresses these gaps in the literature.

Summary

Within the learning by teaching paradigm, research has focused primarily on learning outcomes (e.g., Biswas et al., 2010; Chi et al., 2001; Graesser et al., 1995; Palinscar & Brown, 1984; Peets et al., 2009; Roscoe & Chi, 2007) but not the processes involved. Research is needed wherein individuals’ task definitions and self-regulatory processes are traced as they occur during problem solving. For individuals’ task definitions, researchers can explore whether learners structure the information differently with the use of concept maps (Pintrich, Marx, & Boyle, 1993). Concept maps provide one method by which to assess how individuals organize and structure their knowledge within a particular domain, like mathematics (Laturno, 1994; Williams, 1998). For self-regulatory processes, researchers can explore whether learners monitor their learning more to ensure a deeper understanding of the content prior to teaching it. For these reasons, it is important to explore precisely the mechanisms responsible for increases in learning.
outcomes when learning by preparing to teach. This research addresses this gap in the literature.

**The Current Study**

The purpose of this research was to explore whether learners’ task definitions and self-regulatory processes differed when learning by teaching versus learning for learning in the context of complex mathematics problem solving. The research was conducted in an authentic classroom context during regular school time with a sample of elementary students. The research questions were as follows: (1) Do students’ task definitions differ when learning by teaching versus learning for learning? (2) Are there differences in the frequency of self-regulatory processes, such as planning and goal setting, cognitive processes and metacognitive processes, when a solving complex mathematics problem, when learning by teaching versus when learning for learning? (3) Does learning by teaching result in higher levels of mathematics problem solving achievement compared to learning for learning? To measure students’ task definitions, students completed a concept map of the problem space, and a think aloud protocol was used to capture their self-regulatory processes across all phases of problem solving. Given that previous research has found gender differences in self-regulatory processes at the elementary-school level (Zimmerman & Martinez-Pons, 1990), gender was included as a variable. Finally, prior knowledge was included as a covariate.

Based on theoretical (Bargh & Schul, 1980; Greene & Azevedo, 2009; Muis, 2007; Roscoe & Chi, 2007) and empirical considerations (Biswas et al., 2010; Chi et al., 2001; Fiorella & Mayer, 2013; Fiorella & Mayer, 2014; Renkl, 1995), I hypothesized that students in the learning by teaching group will develop more complex concept maps of the problem space, engage in more self-regulatory processes, and have higher levels of achievement compared to the learning for learning group. Moreover, I hypothesized that girls will engage in more self-
regulatory processes compared to boys (Zimmerman & Martinez-Pons, 1990). Additionally, given that girls typically outperform boys in mathematics at the elementary school level (see Hyde, Fennema, & Lamon, 1990), I further hypothesized that girls will develop better concept maps of the problem space and have a higher level of problem solving achievement compared to boys.
CHAPTER 2

Methodology

Participants

Eighty-two fifth-grade students (n = 34 girls) from two elementary schools across two classrooms in each school participated. All students were from the same Lester B. Pearson School Board. There were 42 students (n = 22 girls) from one school, and 40 (n = 14 girls) students from the other school. Students were randomly assigned to one of the two learning conditions: learning by teaching, or learning for learning. There were 21 students assigned to the learning by teaching condition and 21 students assigned to the learning for learning condition from the first school. For the second school, there were 20 students assigned to the learning by teaching condition and 20 students assigned to the learning for learning condition. The mean age of the sample was 11 years (SD = .31; same mean for each school).

Materials

Demographics. Demographic information was obtained from the parental consent forms, which included students’ age (by birth date) and gender.

Prior knowledge. Students’ standardized achievement score on the 2013 compulsory Quebec Exam in Mathematics (QEM) was used to obtain a measure of prior knowledge. The 2013 QEM was completed one week prior to the beginning of the research study (in the first week of April, which is the eighth month of the school year). Commencement of the research study was intentionally chosen to immediately follow the QEM to ensure a valid assessment of students’ prior knowledge. The exam score entailed two components: students’ achievement score on a complex mathematics problem, called a situational problem, and their achievement score on a series of multiple choice questions that assessed their knowledge of the underlying
concepts needed to solve the complex problem. Students’ QEM score was used given that students solved a similar situational problem for the purposes of this study (described in detail below).

**Complex mathematics problem.** The situational problem, *Start Your Engines*, was drawn from the 2009 compulsory QEM (see Appendix A). The objective is to have students develop a coherent solution to a situational problem that meets the following conditions: (1) the procedure required to solve the situational problem is not obvious, since it involves choosing a significant number of previously acquired mathematical concepts and processes and using them in a new way; (2) the situation focuses on obstacles to overcome, which requires various learning strategies; and, (3) the instructions do not suggest a procedure to be followed or the mathematical concepts and processes to be used (Ministère de l’éducation, du loisir et du sport, 2009). In the first phase of problem solving, students read the problem and then develop a concept map of the problem space (see next section). In the second phase, students are required to solve the problem, and show all steps and decisions made along the way.

**Concept map.** To assess students’ understanding of the problem space (i.e., their task definitions), they used the iPad application *Popplet* to create their concept map (students had been using this concept mapping tool throughout the school year). Developed by the teacher, students were provided specific criteria to create their concept map. Criteria included using four different coloured borders to represent various facets of the problem space. Students were told to use a black border to represent important information, a green border for calculations needed to solve various aspects of the problem, a red border for the first part of the question they would solve, and a blue border for the title of the problem.
**Self-regulatory processes.** A think aloud protocol was used to capture students’ self-regulatory processes as they developed their concept map and solved the complex mathematics problem. Students were instructed to state out loud whatever came to mind. According to Ericsson and Simon (1998), a concurrent think aloud, which is thinking out loud while completing a task, does not change the sequence of thoughts and does not affect performance. As such, think alouds provide a more accurate assessment of individuals’ self-regulatory processes as they occur compared to retrospective self-reports of strategies used during problem solving (see Winne et al., 2002).

**Procedure**

Parents first provided consent for their child to participate in the study, which was collected with student assent (see Appendices B and C). From one school, 100% of the parents and students agreed to participate, and only one parent and student from the other school did not consent. Once consent and assent were obtained, students at each school were then randomly assigned to the learning by teaching or learning for learning condition.

One day prior to solving the mathematics problem, students were trained to think out loud and practiced with one short mathematics problem (see Appendix D). Thinking out loud was described as, “saying out loud everything that you say to yourself silently. Just act as if you are alone in the room speaking to yourself.” The students then heard a practice think-aloud audio file that modeled what not to do followed by an appropriate think out loud example. That is, the second attempt included intermediate steps and spontaneous thoughts. Finally, students thought out loud while completing the following mathematics problem, “Kim can walk three kilometres in one hour. How far can she walk in two and a half hours?” To ensure all students were thinking out loud, five trained research assistants and the academic advisor were there to prompt students
to continue to think out loud if they were silent for more than 5 seconds (a ratio of approximately 4 students per prompter, with students sitting in a circle around a table).

Following the think aloud training session, students were assigned into their learning condition (see Appendix D). In the first condition, the learning by teaching condition, students were instructed to first solve the problem and then create a video, using Doodle Cast (an application designed for teaching a lesson), to teach others how to solve the problem. In the second condition, the learning for learning condition, students were instructed to simply solve the problem. Students in both conditions were told not to tell others about their task. Both conditions were in separate classrooms to ensure no confounding. Both conditions from the same school were conducted each day consecutively and counterbalanced across times such as late morning, or early afternoon.

Once students were told the explicit instructions for their condition, audio-recording of their think alouds began, and students read the problem out loud. Students wore Apple Ear Pods with remote and microphone to capture their voices on digital recording devices. In both conditions, students then completed the concept map using Popplet, a concept-mapping application, to construct their concept maps, and then solved the problem. All work was done during the regular class time, and time spent on task for both learning conditions was equivalent (approximately 1.5 to 2 hours each day over three to four days). Students took as much time as they needed to solve the problem. During problem solving, students recorded their calculations and notes in Noteshelf, and were provided several copies of the racetrack design on which to draw their work. Once students solved the problem, they were asked to submit all work, which was then scored for correctness. After submission of their work, students in the learning by teaching condition developed their teaching video with Doodle Cast using the same materials.
they developed for solving the problem. The videos were not used for any other purpose. To create the videos for teaching purposes, students were instructed to state the problem, describe the problem space, and to explain how to solve the problem. To thank students for their participation, each student received a $15 iTunes card.

Coding Schemes

Coding the concept map. To score the concept map, a rubric was developed that included all aspects of the problem space (see previous section and Appendices E and F). My thesis supervisor, Dr. Krista R. Muis, and I then coded 10% of the students’ concept maps to establish inter-rater agreement. Inter-rater agreement was 100%.

Coding the mathematics problem. A rubric was developed to score each student’s solution to the situational problem. This particular problem was graded based on the inclusion of all required elements of the task: create a seven-sided polygon for the racetrack design that ranges in length between 4.5 kilometres to 5 kilometres; include at least one acute angle, one obtuse angle, and one angle greater than 180 degrees; create spectator areas with 15 squares per section to seat 120,000 spectators; draw a starting line frieze pattern that is one-third white, reflected twice; and, calculate the cost of the paint for the starting line. Each element of the problem was given a particular value, and full points were awarded for successfully completing each element. Partial points were given when aspects were missing, or zero points were given if an element was completely missing or wrong. The total number of points was 50. My thesis supervisor and I then coded 10% of the students’ solutions to establish inter-rater agreement. Inter-rater agreement was 100%. I then coded all remaining solutions (see Appendices G and H for the scoring rubric of the solution).
**Coding self-regulatory processes.** Students’ think alouds were transcribed verbatim. Think alouds ranged in length from 90 minutes to four and half hours, which resulted in 1288 pages of text with 1.5 line spacing (34730 lines). Greene and Azevedo’s (2009) self-regulatory processes coding scheme as well as Schoenfeld’s (1982) and Muis’s (2007) theoretical models were used as a guide to develop a micro-macro-level coding scheme specifically for mathematics problem solving. Macro-level codes are general self-regulatory processes while micro-level codes are specific self-regulatory processes. Six macro-level processes considered from Schoenfeld’s (1982) model included reading, analyzing, exploring, planning, implement, and verifying. Greene and Azevedo’s (2009) model included five macro-level and 35 micro-level processes. The macro-level processes included planning, monitoring, strategy use, as well as handling of task difficulty and demands, and interest. From Muis’s (2007) model, I considered four macro-level processes, which reflected the four phases of her model: task definition, planning and goal setting, enactment, and evaluation.

**Original coding scheme with four macro-level and 20 micro-level self-regulatory processes codes.** Based on the codes developed from these three models, five trained research assistants and I then coded 32 single-spaced pages of transcripts to further refine the coding scheme and establish inter-rater agreement. Inter-rater agreement was established at 82%, and disagreements were resolved through discussion. Twenty micro-level codes emerged and were categorized along four macro-level codes based on Muis’s (2007) model: task definition, planning and goal setting, enactment, as well as monitoring and evaluation. Definitions of each of the macro-level and micro-level codes, along with examples drawn from the transcripts are presented in Table 1.
Table 1

**Self-regulated Learning Coding Scheme for Mathematics Problem Solving**

<table>
<thead>
<tr>
<th>Level (Macro) / Micro</th>
<th>Code abbrev</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1 – Task Definition</strong></td>
<td></td>
<td>A learner generates a perception about the task, context, and the self in relation to the task. External and internal conditions play a major role.</td>
<td>Prior knowledge activation, beliefs, motivation, and knowledge of strategies are activated during this level.</td>
</tr>
<tr>
<td>Prior Knowledge Activation</td>
<td>PKA</td>
<td>Searching for or explicitly recalling relevant prior knowledge.</td>
<td>[reading problem] “Your track must have at least one acute angle. I know what that is. It’s an angle that is less than 90 degrees.” [after reading that a reflex angle needs to be included in the diagram] “I know that means an angle that is greater than 180 degrees.” “A reflex angle. That’s more than 180 degrees.” “5 km, which is short for kilometer.”</td>
</tr>
<tr>
<td>Identifying Important Information</td>
<td>I³</td>
<td>Recognizing the usefulness of information.</td>
<td>“so that will help us figure out how many people are in each row…”</td>
</tr>
<tr>
<td><strong>Level 2 – Planning and Goal Setting</strong></td>
<td></td>
<td>The learner begins to devise a plan to solve the problem and sets goals.</td>
<td>E.g., Planning to use means-ends analysis, trying trial and error, identifying which part of the problem to solve first, solving it within a specific amount of time.</td>
</tr>
<tr>
<td>Making / Restating a Plan</td>
<td>P / RP</td>
<td>Stating what approach will be taken, what strategy will be used to solve the problem, or what part of the problem will be solved in some sequence. This includes restating plans.</td>
<td>“First, I have to figure out how many are in each row, then I can figure out how many people fit in each row to fit 120,000 people.” “Let’s just do trial and error.” “So now I’m going to draw it on paper and see if its between 4.5km and 5km.” “So I’m going to start with the track.” “Now I am going to write ‘have to draw rectangle.’”</td>
</tr>
<tr>
<td>Setting / Restating a Goal</td>
<td>G / RG</td>
<td>A goal is modeled as a multifaceted profile of information, and each standard in the profile is used as a basis to compare the products created when engaged in the activity. This includes restating goals.</td>
<td>“We have to have an acute angle, obtuse angle and one reflex angle.” “We have to label these angles too.” “I don’t want to spend too much time figuring out the track.” [time goal] “So I need 2, and then 5.” “I want to make sure my calculations are neat.” “Then I have to reflect it twice.”</td>
</tr>
</tbody>
</table>
Table 1

*Continued*

<table>
<thead>
<tr>
<th>Level (Macro) / Micro</th>
<th>Code abbrev</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 3 – Enactment</strong></td>
<td>Enactment occurs when the learner begins to work on the task by applying tactics or strategies chosen for the task.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypothesizing</td>
<td>HYP</td>
<td>Making predictions.</td>
<td>“The next one is probably going to tell us the information about the design.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>[in reference to the learner’s track being large enough] “I think it is going to be enough.”</td>
</tr>
<tr>
<td>Summarizing</td>
<td>SUM</td>
<td>Summarizing what was just read in the problem statement.</td>
<td>“Next, the spectator seating area, must be divided into sections each section must have seats for 15,000 people. So there, each section has 15,000 people.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“The starting line must be painted with a frieze pattern, this pattern is a rectangular design that has to be, that has been reflected twice, so it has to be reflected twice.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“So you need to draw circles and write down the required information.”</td>
</tr>
<tr>
<td>Help Seeking info eval</td>
<td>HS</td>
<td>Asking for help from a teacher, peer, or other source.</td>
<td>[turns to teacher and asks a question] “But what if my track isn’t exactly 5 kms?”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Help seeking for information VERSUS help seeking for evaluation.</td>
<td>“Mrs. [teacher’s name], for the reflex angle would I do it on the outside or the inside?”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“So we’re supposed to do something like this?”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“What are we supposed to do next?”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“Is this correct?”</td>
</tr>
<tr>
<td>Coordinating Informational Sources</td>
<td>CIS</td>
<td>Using other sources of information to help solve the problem.</td>
<td>“Lets go back to our popplet.” [Popplet includes the concept map, and learner is going back to the concept map he created to help solve the problem].</td>
</tr>
</tbody>
</table>
Table 1

*Continued*

<table>
<thead>
<tr>
<th>Level (Macro) / Micro</th>
<th>Code abbrev</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 3 – Enactment continued</strong></td>
<td></td>
<td>Enactment occurs when the learner begins to work on the task by applying tactics or strategies chosen for the task.</td>
<td></td>
</tr>
<tr>
<td>Highlighting / Labeling / Colouring / Drawing / Writing</td>
<td>HLC</td>
<td>Highlighting information, labeling information as part of the problem-solving process, or taking notes in reference to the problem. Making a drawing to assist learning or as part of solving the problem</td>
<td>“We can put the starting line just like right there.” [labeling] [you can hear the learner’s pencil] “So its two sides, 2 sides, 3, kind of look like a good drawing [evaluating quality of drawing], 4.” “Like that, like that and like that.” “This is a reflex angle.” “4 C-M.”</td>
</tr>
<tr>
<td>Calculating / Measuring</td>
<td>CAL</td>
<td>Solving equations, measuring, or other similar features.</td>
<td>[adding up the sides] “10 so that’s like 1 km plus 1 km and 400 meters…” “4.4 plus 3.1 plus…equals…” “I’m measuring the starting line.”</td>
</tr>
<tr>
<td>Re-Reading</td>
<td>R-R</td>
<td>Re-reading a section of the problem, word for word. Important that it is word for word, otherwise it is summarizing.</td>
<td>“I’m just going to re-read this…”</td>
</tr>
<tr>
<td>Making Inferences</td>
<td>MI</td>
<td>Making inferences based on information read or products created from solving the problem. (self-explanation) Explaining why something was done. Key word is “because.”</td>
<td>“So it doesn’t say it has to be irregular or regular.” “I'm just, I'm multiplying 18 by 6.25 [calculating] because there are 6.25 per white squares.” [self-explanation]</td>
</tr>
<tr>
<td>Goal-directed search</td>
<td>GDS</td>
<td></td>
<td>“I’m looking for another thing that might be useful.”</td>
</tr>
</tbody>
</table>
### Table 1

**Continued**

<table>
<thead>
<tr>
<th>Level (Macro) / Micro</th>
<th>Code abbrev</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 3 – Enactment continued</strong></td>
<td>Enactment occurs when the learner begins to work on the task by applying tactics or strategies chosen for the task.</td>
<td>“We can put the starting line just like right there.” [labeling] [you can hear the learner’s pencil] “So its two sides, 2 sides, 3, kind of look like a good drawing [evaluating quality of drawing], 4.” “Like that, like that and like that.” “This is a reflex angle.” “4 C-M.”</td>
<td></td>
</tr>
<tr>
<td>Highlighting / Labeling / Colouring / Drawing / (Writing)</td>
<td>HLC</td>
<td>Highlighting information, labeling information as part of the problem-solving process, or taking notes in reference to the problem. Making a drawing to assist learning or as part of solving the problem</td>
<td>[adding up the sides] “10 so that’s like 1 km plus 1 km and 400 meters…” “4.4 plus 3.1 plus…equals…” “I’m measuring the starting line.”</td>
</tr>
<tr>
<td>Calculating / Measuring</td>
<td>CAL</td>
<td>Solving equations, measuring, or other similar features.</td>
<td></td>
</tr>
<tr>
<td>Re-Reading</td>
<td>R-R</td>
<td>Re-reading a section of the problem, word for word. Important that it is word for word, otherwise it is summarizing.</td>
<td>“I’m just going to re-read this…”</td>
</tr>
<tr>
<td>Making Inferences</td>
<td>MI</td>
<td>Making inferences based on information read or products created from solving the problem. (self-explanation) Explaining why something was done. Key word is “because.”</td>
<td>“So it doesn’t say it has to be irregular or regular.” “I'm just, I'm multiplying 18 by 6.25 [calculating] because there are 6.25 per white squares.” [self-explanation]</td>
</tr>
<tr>
<td>Goal-directed search</td>
<td></td>
<td></td>
<td>I’m looking for another thing that might be useful.</td>
</tr>
</tbody>
</table>
Table 1

Continued

<table>
<thead>
<tr>
<th>Level (Macro) / Micro</th>
<th>Code abbrev</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 4 – Monitoring and Evaluation</strong></td>
<td></td>
<td>Various types of reactions and reflections are carried out to evaluate the successes or failures of each level or products created for the task, or perceptions about the self or context. Reaction and reflection also includes judgments and evaluations of performance on a task as well as the attributions for success or failure.</td>
<td>Products created are compared to the standards set via metacognitive monitoring. Monitoring and evaluation can include any facet listed above (e.g., progress, motivation, plans, goals, strategies, products like answers or drawings made).</td>
</tr>
<tr>
<td>Self-Questioning</td>
<td>SQ</td>
<td>Posing a question.</td>
<td>“But how much is that?”&lt;br&gt;“What is the most important thing?”&lt;br&gt;“So how do we turn meters into km?”</td>
</tr>
<tr>
<td>Monitoring</td>
<td>MON</td>
<td>Monitoring something relative to goals.</td>
<td>“I’m not sure there is a reflex angle in my drawing. Let me check.”&lt;br&gt;“I might forget that “each section must have seats for 15,000 people.”&lt;br&gt;[learner is counting the number of sides for the polygon] “So we have 1 side 2 side 3 side 4 side 5 side 6 side 7 sides.”</td>
</tr>
<tr>
<td>Judgment of Learning</td>
<td>JOL</td>
<td>Learner is aware that something is unknown, not fully understood, or difficult to do.</td>
<td>“That would be an acute angle, which is kind of hard to draw, this is hard to draw.”&lt;br&gt;“I don’t really understand this.”&lt;br&gt;“I’m not sure.”&lt;br&gt;“This is going to be very hard to figure out.”&lt;br&gt;“I need help with this one. I don’t understand.”&lt;br&gt;“So, I don’t know.”</td>
</tr>
</tbody>
</table>
Table 1

Continued

<table>
<thead>
<tr>
<th>Level (Macro) / Micro</th>
<th>Code abbrev</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 4 – Monitoring and Evaluation continued</strong></td>
<td></td>
<td>Various types of reactions and reflections are carried out to evaluate the successes or failures of each level or products created for the task, or perceptions about the self or context. Reaction and reflection also includes judgments and evaluations of performance on a task as well as the attributions for success or failure.</td>
<td>Products created are compared to the standards set via metacognitive monitoring. Monitoring and evaluation can include any facet listed above (e.g., progress, motivation, plans, goals, strategies, products like answers or drawings made).</td>
</tr>
</tbody>
</table>
| Self-Correcting | SC | Correcting one’s mistakes. | “Here are 4 kms. Not 4 kms. Sorry, 400 meters.”  
“So the first thing was the track had to be has to be a 4 sided [summarizing], not a 4 sided sorry a 7 sided polygon [self-correcting].”  
“Never mind, I’m not going to put that.”  
“Oops, that was actually an obtuse angle.” |
| Evaluation | EVAL | Judging whether goals have been met, whether a particular strategy is working, whether the answer is correct, whether the work is neat, etc. Judgment of all facets that fall under monitoring. | After counting the number of sides of the polygon, the learner states, “Yes, I have 7 sides. Okay, we’re good.”  
“I measured the wrong thing by accident.”  
[after adding up the sides] “3 kms, that’s way too little.”  
“That’s not very neat.” |
| Control | CON | Changing strategy when monitoring or evaluation results in a determination that goal has not been met. | [after judging that polygon was not 7-sided] “I'm just going to erase this. It has to be a 7-sided polygon so lets do a different one.” |
| Task Difficulty | TD | Statements reflecting the difficulty or easiness of a task. | “This is difficult.”  
“This is easy.” |
Modified coding scheme with three macro-level codes. The frequency with which the original four macro-level and 20 micro-level codes occurred was calculated. Codes with low frequencies were removed (e.g., averages less than three over a four hour period). The modified coding scheme consisted of three macro-level and 12 micro-level codes. The first macro-level code was labelled planning and goal setting in which two micro-level codes, plans and goals, were included. The second macro-level code was cognitive processes, which included summarizing, help seeking for information, help seeking for evaluation, calculating, colouring, and rereading. The third macro-level code was metacognition, which included monitoring, judgment of learning, evaluation, and control. The frequency with which students used each of the micro-level codes were then summed within each of the three macro-level codes, which were used in subsequent analyses.
CHAPTER 3

Results

Preliminary Analyses

Two students with learning disabilities opted out of the think aloud component, and two other students’ audio recordings failed to record properly across all days. As such, four students were removed from the analyses, for a total of 78 participants. Skewness and kurtosis values were then examined for normality for all variables. For kurtosis, all variables were within an acceptable range (using Tabachnick & Fidell’s [2013] criteria of $< |3|$). For skewness, with the exception of plans and goal setting (5.29), variables were within an acceptable range. Because the measurement of plans and goals was on a ratio scale, scores were not transformed (see Tabachnick & Fidell, 2013).

I then examined whether there were group differences in prior knowledge (to ensure random assignment to condition worked). As expected, there were no differences between the learning by teaching compared to the learning for learning group on prior knowledge ($p = 1.00$). However, gender differences were found for prior knowledge, $F (1, 76) = 4.61, p < .05, \eta^2 = .06$, wherein girls had a higher level of prior knowledge than boys. As such, prior knowledge was used as a covariate in all subsequent analyses.

Correlations among Variables

Table 2 presents the zero-order correlations for all variables: planning and goal setting, cognitive strategies, metacognitive strategies, concept map score, and mathematics problem solving achievement score. Cognitive strategies was significantly positively related to concept map score, $r (67) = 0.37, p < 0.01$ as well as with achievement score, $r (76) = 0.45, p < 0.01$. Metacognitive strategies was significantly positively related to concept map score, $r (67) = 0.40$, 
learning by teaching, \( r (76) = 0.46, p < 0.01 \). Concept map score was significantly positively related to achievement score, \( r (67) = 0.33, p < 0.01 \). These results suggest that students who used more cognitive and metacognitive strategies developed better concept maps and achieved higher scores in mathematics problem solving. Moreover, students who developed better concept maps had higher levels of achievement in mathematics problem solving.

Table 2

*Zero-order Correlations*

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Planning and Goal Setting</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Cognitive Strategies</td>
<td>.39**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Metacognitive Strategies</td>
<td>.48**</td>
<td>.58**</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Concept Map</td>
<td>.14</td>
<td>.37**</td>
<td>.40**</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>(5) Achievement</td>
<td>.21</td>
<td>.45**</td>
<td>.46**</td>
<td>.33**</td>
<td>1</td>
</tr>
</tbody>
</table>

**p < .01

Design

To answer the first research question, whether students’ task definitions differed when learning by teaching versus learning for learning, a two-way analysis of covariance (ANCOVA) was used. The two independent variables included the learning condition (learning by teaching versus learning for learning) and gender (boy or girl). The dependent variable was students’ score on the concept map. For the second research question, whether there are differences in the
frequency of self-regulatory processes when learning by teaching versus when learning for learning, a two-way MANCOVA was used. The two independent variables were learning environment (learning by teaching versus learning for learning) and gender (boy or girl). The dependent variables were planning and goal setting, cognitive learning strategies as well as metacognitive strategies. For the third research question, whether students in the learning by teaching condition attained higher levels of mathematics problem solving achievement compared to students in the learning for learning condition, a two-way ANCOVA was used. The two independent variables were learning environment (learning by teaching versus learning for learning) and gender (boy or girl). The dependent variable was students’ total score on the situational problem. For all analyses, the covariate was students’ prior knowledge.

**Students’ Understanding of the Problem Space**

Table 3 presents the means and standard deviations for both conditions as a function of gender for all variables. The first research question addressed whether there were differences in students’ understanding of the problem space as a function of learning condition. To assess this, students developed a concept map of the problem space. Analyses of students’ concept map scores revealed a main effect for learning condition, $F (1,63) = 4.30, p = 0.042, \eta^2 = .064$, a main effect for gender, $F (1,63) = 6.03, p = 0.017, \eta^2 = .087$, but no condition by gender interaction $F (1,63) = .30, p > 0.05$. Specifically, students in the learning by teaching group developed more complex and detailed concept maps of the problem space compared to students in the learning for learning group, and girls developed a more complex concept map than boys.
Table 3

*Means and Standard Deviations for each Variable as a Function of Learning Condition by Gender (raw frequencies shown)*

<table>
<thead>
<tr>
<th></th>
<th>Learning by Teaching</th>
<th></th>
<th>Learning for Learning</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation</td>
<td>Mean</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Planning and Goal Setting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>74.59</td>
<td>47.68</td>
<td>80.38</td>
<td>55.06</td>
</tr>
<tr>
<td>Boys</td>
<td>30.41</td>
<td>22.40</td>
<td>29.77</td>
<td>25.02</td>
</tr>
<tr>
<td>Total</td>
<td>49.67</td>
<td>41.56</td>
<td>51.08</td>
<td>47.18</td>
</tr>
<tr>
<td>Cognitive Strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>114.65</td>
<td>41.99</td>
<td>115.50</td>
<td>56.21</td>
</tr>
<tr>
<td>Boys</td>
<td>76.32</td>
<td>56.31</td>
<td>61.00</td>
<td>31.27</td>
</tr>
<tr>
<td>Total</td>
<td>93.03</td>
<td>53.53</td>
<td>83.95</td>
<td>50.79</td>
</tr>
<tr>
<td>Metacognitive Strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>81.94</td>
<td>35.64</td>
<td>60.25</td>
<td>26.04</td>
</tr>
<tr>
<td>Boys</td>
<td>51.50</td>
<td>28.13</td>
<td>42.14</td>
<td>23.46</td>
</tr>
<tr>
<td>Total</td>
<td>64.77</td>
<td>34.73</td>
<td>49.76</td>
<td>25.88</td>
</tr>
</tbody>
</table>
Table 3

Continued

<table>
<thead>
<tr>
<th></th>
<th>Learning by Teaching</th>
<th>Learning for Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td><strong>Concept Map</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>49.13</td>
<td>21.76</td>
</tr>
<tr>
<td>Boys</td>
<td>40.55</td>
<td>14.53</td>
</tr>
<tr>
<td>Total</td>
<td>44.23</td>
<td>18.21</td>
</tr>
<tr>
<td><strong>Achievement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Girls</td>
<td>91.72</td>
<td>6.22</td>
</tr>
<tr>
<td>Boys</td>
<td>85.89</td>
<td>10.96</td>
</tr>
<tr>
<td>Total</td>
<td>88.43</td>
<td>9.55</td>
</tr>
</tbody>
</table>

**Self-Regulatory Processes**

The second research question addressed whether there are differences in the frequency of self-regulatory processes when solving complex mathematics problems as a function of learning condition. A two-way MANCOVA was used, with learning condition (learning by teaching versus learning for learning) and gender (girls versus boys) as the two independent variables, and planning and goal setting, cognitive strategies, and metacognitive strategies as the dependent
variables. Prior knowledge in mathematics was used as the covariate. The omnibus multivariate test was significant, $F(3, 72) = 54.19, p < .001, \eta^2 = .70$. Analyses of students’ planning and goal setting revealed a main effect for gender, $F(1, 72) = 26.53, p < 0.001, \eta^2 = .27$, but no learning condition effect, $F(1, 72) = .12, p > 0.05$ and no condition by gender interaction $F(1, 72) = .060, p > 0.05$. Specifically, girls had higher frequencies of planning and goal setting than boys.

Analyses of students’ cognitive learning strategies revealed a main effect for gender, $F(1, 72) = 16.03, p < 0.001, \eta^2 = .18$, but no condition effect $F(1, 72) = .43, p > 0.05$, and no learning condition by gender interaction, $F(1, 72) = .47, p > 0.05$. Specifically, girls had higher frequencies of cognitive learning strategies than boys. Finally, analyses of students’ metacognitive strategies revealed a main effect for learning condition, $F(1, 72) = 5.93, p = 0.017, \eta^2 = .076$, a main effect for gender, $F(1, 72) = 11.46, p < 0.001, \eta^2 = .14$, but no condition by gender interaction, $F(1, 72) = 1.16, p > 0.05$. Specifically, students in the learning by teaching group had higher frequencies of metacognitive strategies and girls had higher frequencies of metacognitive strategies than boys.

Mathematics Problem Solving Achievement

The third question addressed whether students in the learning by teaching condition obtained higher levels of mathematics problem solving achievement compared to students in the learning for learning condition. A two-way ANCOVA was used, with learning condition (learning by teaching versus learning for learning) and gender (boys versus girls) as the two independent variables, and score on the situational problem as the dependent variable. Prior knowledge in mathematics was used as the covariate. Analyses of students’ situational problem scores revealed a main effect for learning condition, $F(1, 72) = 9.37, p = 0.003, \eta^2 = .12$, a main
effect for gender, $F(1, 72) = 8.73, p = 0.004, \eta^2 = .11$, but no condition by gender interaction $F(1, 72) = .60, p > 0.05$. Specifically, students in the learning by teaching group had higher levels of achievement compared to students in the learning for learning group, and girls had higher levels of achievement than boys. I discuss the theoretical and practical implications of these results next.
CHAPTER 4

Discussion

Summary of Findings

The purpose of this research was to develop a better understanding of why students typically attain better learning outcomes when learning by preparing to teach compared to solely learning for learning. To explore the mechanisms involved, models of self-regulated learning were used to develop specific testable hypotheses. I predicted that learners’ task definitions and self-regulatory processes would differ across these two conditions. Concept maps, self-regulatory processes and mathematics problem solving achievement were compared for 78 elementary students who were randomly assigned to one of the two learning conditions.

Results from the correlational analyses revealed that students who developed better concept maps had higher levels of achievement in mathematics problem solving. In addition, students who used more cognitive and metacognitive strategies developed better concept maps and achieved higher scores in mathematics problem solving. Group analyses revealed that students in the learning by teaching group developed more complex and detailed concept maps of the problem space, had higher frequencies of metacognitive strategies, and higher levels of achievement compared to students in the learning for learning group. In addition, girls developed a more complex concept map, had higher frequencies of planning and goal setting, cognitive learning strategies, and metacognitive strategies as well as higher levels of achievement than boys.

Theoretical Implications

To date, the majority of previous research within the learning by teaching paradigm has focused on the effects of learning by teaching on learning outcomes (Biswas et al., 2010; Chi et
al., 2001; Graesser et al., 1995; Palinscar & Brown, 1984; Peets et al., 2009; Roscoe & Chi, 2007). Although some studies have explored whether learners organize and structure the content differently when learning by teaching, interpretations of these differences were based on learners’ retrospective self-reports, on transfer tasks that required a better organizational structure of the content for greater performance, or on delayed performance tests (see Fiorella & Mayer, 2013). To better understand why learning by preparing to teach can benefit learners, a direct test of learners’ organizational structure of the content is necessary. My research addressed this gap in the literature. Importantly, results from this research provide convincing evidence that learners do indeed organize and structure content better when learning by preparing to teach versus when solely learning for oneself.

Previous research has also theorized that when learning by preparing to teach, individuals may engage in more monitoring of their progress to ensure a deeper understanding of the content (Bargh & Schul, 1980; Fiorella & Mayer, 2013; Fiorella & Mayer, 2014; Roscoe & Chi, 2007). Consistent with theoretical predictions, results from this study revealed that students in the learning by preparing to teach condition monitored and evaluated their progress more compared to students in the learning for learning condition. Additionally, students who organized and understood the problem space better, and monitored and evaluated their progress more, achieved better learning outcomes. As such, this study provides empirical evidence that the expectation of teaching changes the way individuals engage in learning (Bargh & Schul, 1980; Roscoe & Chi, 2007). Learners in the learning by preparing to teach group organized the learning material differently as demonstrated in the more complex and detailed concept maps. In other words, these results support theoretical predictions that differences in task definitions result in differences in how a task is approached (Muis, 2007).
My research also adds to the current literature on self-regulated learning. Learners in the learning by teaching group engaged in more frequent metacognitive processes, likely due to the differences in task definitions. As Muis (2007) suggests, differences in task definitions lead to differences in the ways that individuals approach a learning task. These results provide empirical evidence of this proposition and advances understanding of how learning by preparing to teach improves learning outcomes by examining the specific processes involved.

Results from this research are also consistent with previous research (Zimmerman & Martinez-Pons, 1990) with regard to differences found between girls and boys in their use of learning strategies, and on mathematics problem solving performance (Hyde et al., 1990). Specifically, girls used more learning strategies compared to boys, and outperformed boys on understanding the problem space and on achievement outcomes. Additionally, this research is unique in that it was carried out in an authentic classroom situation, and measured students’ learning strategies as they occurred in real time.

**Educational Implications**

These results are important from an educational perspective as teachers can readily integrate this approach into their daily classrooms. In addition, these finding are useful because children in the learning by teaching condition improved their self-regulatory processes and had higher problem solving achievement. Parents may also continue to provide students with learning environments that support learning at home. Furthermore, in the long term, students can create learning by teaching environments, which support learning while sharing their knowledge with others.
**Limitations of the Research**

One of the limitations of the study is that think alouds can place additional cognitive load on individuals. This research focused on concurrent thinking out loud, which is thinking out loud while completing the task. Ericsson and Simon (1998) stated that concurrent thinking out loud does not change the sequence of thoughts and does not change performance. After conducting this study, I believe that some students may have had additional cognitive load while thinking out loud, particularly students with learning disabilities. As such, it may have been more challenging for a few students to simultaneously think out loud while solving the complex mathematics problem.

Another limitation is that the sample was small. Although there were 82 participants from two elementary schools, there were only 41 students per group. Given this small sample size per group, standard deviations for the frequency with which students planned and set goals, and used cognitive and metacognitive strategies was high. Larger samples are needed to reduce the standard errors within each group. It is likely the case that differences would also result between groups on use of cognitive strategies.

**Suggestions for Future Research**

Learning by (actually) teaching. Future research is needed to test the additional effects of actually teaching on student learning. As discussed earlier, four lines of research that have been conducted within the learning by teaching paradigm include learning by preparing to teach (e.g., Annis, 1983; Bargh & Schul, 1980; Fiorella & Mayer, 2013; Renkl, 1995), learning by (actually) teaching (Annis, 1983; Fiorella & Mayer, 2013; Fiorella & Mayer, 2014), learning through peer tutoring (Chi et al., 2001; Roscoe & Chi, 2007), and teachable agents (Biswas et al., 2005; Biswas et al., 2010). This study focused on learning by preparing to teach. Within the
learning by teaching literature, few studies have systematically explored the effects of learning by preparing to teach versus actually teaching (Annis, 1983; Fiorella & Mayer, 2013; Fiorella & Mayer, 2014). Actual teaching includes both components of teaching which are preparing to teach and explaining content to others. These studies found that actually teaching provided additional benefits with regard to learning gains, but much more work is necessary to systemically explore why these gains are achieved. Future research should include a learning by (actually) teaching group, which will allow students to develop additional teachable self-regulatory skills and an even deeper understanding of the content (Fiorella & Mayer, 2013; Fiorella & Mayer, 2014). This is important since previous research has shown that elementary school students are poor at regulating their learning in the context of mathematics problem solving (Schunk & Zimmerman, 1997; Schoenfeld, 1994).

Content area. Other content areas can be tested as well to establish whether improved understanding and use of learning strategies differs across conditions. This study focuses on complex mathematics problem solving. Future studies can focus on other content areas such as science, English, and history.

Emotions and motivation. Future studies can assess whether there are motivational and emotional implications in the learning by teaching condition. According to Pekrun’s (2006) control-value theory of emotions, high value for a specific task and high perceived control will lead to enjoyment and an increase in learning (Pekrun, 2006; Johnson & Sinatra, 2013). On the other hand, low task value will lead to boredom and a decrease in learning (Pekrun, 2006). In addition, high value and low perceived control results in anxiety (Pekrun, 2006). Future studies can assess students’ emotions during learning when preparing to teach and assess whether they
value learning more when they are expected to teach the content. If the expectation of teaching increases value, this may have additional motivational benefits (Pekrun, 2006).

**Teachable agent learning environment.** Future studies can also explore how technology-rich learning environments (TRE) can foster the development of self-regulatory skills, which are essential for learning and problem solving. Teachable agents can be developed as a type of TRE. Students can teach their agent, reflect on their agent’s performance, and receive metacognitive prompts from their agent (Biswas et al., 2010). TREs may help students become more knowledgeable of and responsible for their own cognition and reasoning in the context of mathematics problem solving (Bransford & Schwartz, 1999; Schwartz & Martin, 2004).

**Conclusion**

The purpose of this thesis was to explore whether learners’ task definitions and self-regulatory processes differed when learning by teaching versus learning for learning during complex mathematics problem solving. Previous research has focused on the learning outcomes of learning by teaching. This research advances understanding of how learning by preparing to teach improves learning outcomes by exploring the specific mechanisms involved. These results provide empirical evidence of theoretical predictions that learners in the learning by teaching group will engage in more frequent metacognitive processes, likely due to the differences in task definitions (Muis, 2007). Twenty-seven centuries later, I agree with Confucius that learning by teaching maximizes the benefits of learning. Throughout our lives learning is a cyclical process in which we must continue to learn in order to teach and teach in order to further learn.
References


Jacobse, A. E., & Harskamp, E. G. (2012). Towards efficient measurement of metacognition in


Peets, A. D., Coderre, S., Wright, B., Jenkins, D., Burak, K., Leskosky, S., & McLaughlin, K.
Involvement in teaching improves learning in medical students: A randomized cross-over study. *BMC Medical Education, 9*, 55.


*Journal of Educational Psychology, 82*(1), 51-59.
Appendix A

Quebec Exam in Mathematics (2009) “Start Your Engines” Problem

REFERENCE DOCUMENT

Name: ________________________________
522-510

June 2009
Dear Student,

Congratulations! You have been selected to join the Start Your Engines Construction Company, which has been hired to build a new Formula One racetrack.

Formula One, often called F1, is the highest class of open-wheel auto racing. The F1 world championship season consists of a series of races, known as the Grand Prix races, most of which are held on specially built circuits.

Here is the job you are asked to do:

- Design the new racetrack, including a starting line.
- Plan the spectator area.
- Calculate the cost of painting the starting line.

You must keep in mind the specific criteria set by the Formula One Racing Program. These criteria are provided in this reference document.

On behalf of the Start Your Engines Construction Company, welcome to the team!

Mark Getsetgo,
Construction Manager
Guidelines and Criteria for completing the

Start Your Engines Construction Plan

- The outline of the track must be drawn inside the central rectangle of your plan. (Appendix 1: Plan for the Formula 1 Racetrack and Seating Area)
  - Your track has to be a 7-sided polygon.
  - The length of the outside perimeter of your track must measure between 4.5 km and 5 km. The measure of each line segment must be clearly indicated.
  - Your track has to have at least 1 acute angle, 1 obtuse angle and 1 angle that measures more than 180° (You must clearly identify the angles by name on the plan.)
  - The starting line on your track should be identified with an “S”.

- The spectator area surrounds the track. This area must be able to seat 120 000 people.
  - The spectator seating area must be divided into sections. Each section must have seats for 15 000 people.
  - Each section must be clearly outlined in the spectator area of your plan and identified by a letter.

- The starting line must be painted with a frieze pattern. This pattern is a rectangular design that has been reflected twice.
  - The rectangular design must be black and white. White must cover $\frac{1}{3}$ of the design.

- The company that was hired to paint the white section of the frieze pattern charges $6.25 per square metre.
  - The starting line measures 18 m by 3 m.
Appendix B

Consent Form

Dear Parent/Legal Tutor,

We are professors in the Department of Educational and Counselling Psychology at McGill University. Our areas of expertise include learning and motivation across the lifespan. We are conducting a study in collaboration with the math teacher, and we would like to ask your permission to have your child participate. The purpose of this study is to gain knowledge about the use of iPads in the classrooms. In particular, we are interested in increasing our understanding of whether different approaches to learning using the iPad are effective for developing mathematics problem solving skills.

The specific purpose of this research is to explore whether these different approaches alter learning by increasing students’ learning processes (like monitoring their understanding). The outcomes of this study will be highly valuable for teachers and parents/legal tutor. For teachers, the information that we gather from this study may help to inform instruction designed to better meet the needs of all students. For parents/legal tutor with access to these tablets, this study may provide information with regard to whether these applications help students improve these skills, which they could practice at home.

What would my child have to do?

To examine the effectiveness of these approaches in the classroom, your child will be randomly assigned to one of two conditions (both of equal benefit). He or she will be given the iPad to complete a complex mathematics problem (one used in the regular curriculum). Each day for one week, your child will work on the mathematics problem during regular class time and their thought processes will be audio-recorded on the iPad. Performance on the mathematics problem will also be measured. These sessions will occur during regularly scheduled class activities.

Other Important Information

First, in all cases, your child’s responses will be kept confidential. Confidentiality is protected by assigning a random identification number to each participant. This number will be stored in a file separate from the data used to analyze the results. The audio-recording of your child’s thought processes while completing each problem will be heard only by the trained research assistant. All data and audio files will be kept in a locked room that is accessible only by the research team.

Participation in this study is completely voluntary on the part of your child. We expect that students who participate in this study will benefit given that they will have the opportunity to further develop their numeracy skills through practice. Moreover, to compensate your child for his or her time, and to ensure there are no out-of-pocket expenses for you, all students will receive an iTunes gift card for $15, which will be used to purchase Popplet or Doodle Cast (both costs less than $5 each).
Your child may withdraw from the study at any time for any reason. Moreover, participating (or not participating) in this study will not in any way affect his or her regular classroom activities and will not influence his or her grades. Given that this study will be conducted during regularly scheduled activities, the students who do not consent will be doing the same thing as those who do consent. We will simply not use their data for the study. Risks to your child are minimal and should be no greater than those associated with everyday classroom activities. The students will be informed of all aspects of the study before they participate, as described here in the consent form. We will gladly answer any questions and address any concerns they may have. We plan to publish the results of the study in journals designed for teachers and researchers. No reference will be made to the school or to your child in written or oral materials that could link them to this study. All records will be stored in a locked facility at McGill University for at least five years after the completion of the study. After this time, all information gathered will be destroyed.

In the event that you have any questions or concerns about this research, you may contact Dr. Krista Muis at (514) 398-3445. If you have any concerns regarding ethics, please contact the Ethics Officer, Lynda McNeil at (514) 398-6831.

Thank you for your co-operation,

Krista R. Muis, PhD
Associate Professor
Faculty of Education
McGill University

Susanna Lajoie, PhD
Professor, Canada Research Chair Tier I
Faculty of Education
McGill University
Yes. I, _______________________________ (Parent/ Legal Tutor), give permission for my child _______________________ (name of child) to participate in all research aspects as described above.

I give permission to audio-record the child while completing the tasks. □ yes □ no

Signature of Parent/Legal Tutor: _______________________________

Date: _____/_________/_________

Day     Month     Year

Birth date of child: _____/_________/_________

Day     Month     Year

No. I, _______________________________ (Parent/ Legal Tutor), do NOT give my child _______________________ (name of child) permission to participate in this research.
Dear Student,

We are professors at McGill University and are doing a project with your teacher. We would like to learn more about how you solve math problems and the feelings you have about math. We would also like to learn more about how iPads may help you to learn math.

What will you do?

You will work on one math problem. We will ask you to talk out loud to tell us what you are thinking as you answer the problems. The problem will take about three to five days to solve (one hour each day), and we will record your voice as you try to solve the math problems.

Other Important Information

Your information and audio-recording will be private. I will not tell your teacher or your parent/legal tutor what you say and write.

You can quit this study any time you want. You can say yes or no if you want to take part in the study. This will not affect your school grades. If you do not want to be part of this study, you will be doing the same work as the other students in your class.

If you take part, you will receive an iTunes gift card for $15. Your parent/legal tutor will buy Doodle Cast for you to use for this study, which costs less than $5. If you have questions you can call me (Dr. Krista Muis) at (514) 398-3445. Thank you for reading this letter and for your help,

Krista R. Muis, PhD  
Susanna Lajoie, PhD
Associate Professor  
Professor, Canada Research Chair Tier I
Faculty of Education  
Faculty of Education
McGill University  
McGill University
Yes. I ________________________ (name of child) agree to take part in this study.

I give my permission to audio-record me while I complete the tasks.  □ yes    □ no

I am taking part of this project because I want to. I have been told that I can stop at any time.

____________________________
(child’s signature)

-----------------

No. I ________________________ (name of child) DO NOT agree to take part in this study.

____________________________
(child’s signature)
Appendix D

Protocol for Grade 5 Students

Day 1: Introduce Session and Think-Aloud Protocol – training for ALL students

- We are researchers at McGill University and we are doing a project with your teacher. We would like to learn more about how you solve math problems. Next week, we will give you the “Start your Engines” math problem to solve. You will spend about 90 minutes each day for 2 to 3 days. We will not tell your teacher or your parent/legal tutor what you say and write.

  a. We will ask you to ‘think out loud’ while you solve the math problem. As you answer the problem, we will ask you to talk out loud to tell us what you are thinking. We will be here to help you if you need it.

  b. To think out loud, we want you to say out loud everything that you say to yourself silently. Just act as if you are alone in the room speaking to yourself. Begin by reading the math problem out loud. This is a good way to start. If you are silent for too long, we will remind you to keep talking out loud. Please remember that it is very important to say everything that you are thinking while you are working on this math problem. Do you understand?

  c. Now we are going to present you an audio file of an example of how to think out loud. After that, you will practice thinking out loud with one simple math problem.

Script of the Practice Think-Aloud Audio file:

Researcher: “Please think aloud as you estimate the number of fifth graders at this school.”

Participant: “5 times 5 is 25. (pause 3 seconds) Double that. (pause 3 seconds) 50.”

Researcher: “Try again. Remember to say out loud everything that you say to yourself silently.”

Participant: "I need to estimate the number of fifth graders at this school. Hmmmmmm. So, let me start by estimating the number of students in this class. Let's see. There are...12345...5 tables in this class, right? There are 5 students at each table. So, that makes 25 students in this class since 5 times 5 is 25. Okay, now I have to figure out how many fifth grade students there are at this school. There are 2 classes at each grade level, right? If I add 25 students to 25 students, I get 50 students. So there are about 50 students in fifth grade at this school.”

Sample Math Problem:

“Kim can walk 3 kilometers in 1 hour. How far can she walk in 2.5 hours?”

Allow the students to solve the math problem.
i. Once the participant begins solving the problem, do not reinforce specific responses during this task – verbally or nonverbally. Direct your eye-gaze elsewhere while listening and ensure that you are out of the participant’s line of sight. If s/he asks for feedback, say: **I am only interested in what you are thinking as you solve the problem.**

ii. If s/he does not speak for 3 seconds, say: **Please keep talking.**

**INSTRUCTIONS FOR EACH CONDITION:**

**Learning by Teaching:**

- *We are going to give you the “Start Your Engines” math problem. Please begin to record your voice as you are solving the problem. You can use Popplet and Noteshelf on the iPad to solve the problem. Save all of your work.*

- *After you finish solving the problem, you will be asked to create a video where you will teach other students how to solve the problem. Specifically, you will use Doodle Cast to create a video that explains how to solve the problem. You can use the materials that you developed in Popplet and Noteshelf as part of the video in Doodle Cast.*

**Learning by Learning:**

- *We are going to give you the “Start Your Engines” math problem. Please begin Evernote to record your voice as you are solving the problem. You can use Popplet and Noteshelf on the iPad to solve the problem. Save all of your work.*

- *Once you have solved the problem, you can hand in your solution.*
## Appendix E

### Concept Map Marking Rubric

<table>
<thead>
<tr>
<th></th>
<th>Your Mark</th>
<th>Total Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blue Border Start Your Engines Title [1]</strong></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Red Border (multiple answers 1 out of 6) [1]</strong></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>7-sided, perimeter, angles, # sections, # squares spectator, # squares line</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Please write red choice: _________________</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Racetrack design: [6 = 2+4]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green borders centimeters to metres conversion</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>perimeter addition</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Black borders Identifies the starting line with an &quot;S&quot;</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7-sided polygon</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>perimeter between 4.5 km and 5 km</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>At least 1 acute angle, 1 obtuse angle, and reflex (180°- 360°)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Spectator area: [5= 2+3]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green borders Number of sections</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Number squares per section</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Black borders Total: 120 000 people</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>15 000 people per section</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>letter identification for each section</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Starting line frieze pattern: [4= 2+2]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green borders Total number squares starting line</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Number white squares starting line</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Black borders Reflected twice</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>One third white</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Starting line painting: [3= 1+2]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green borders Cost of paint</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Black borders 6.25 $ per square metre</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Starting line 18 m by 3 m</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal:</strong></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>-0.5 for each bubble wrong colour</td>
<td>( ___ X -0.5)</td>
<td>- __</td>
</tr>
<tr>
<td>Bonus: _____________________________</td>
<td>+ __</td>
<td></td>
</tr>
<tr>
<td><strong>Final New Total:</strong></td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

### Qualitative Notes:
Appendix F

Sample Concept Map

Research Question: Do students’ task definitions, defined as the mathematics problem space, differ when learning by teaching versus learning for learning?
Appendix G

Quebec Exam in Mathematics (2009) “Start Your Engines” Marking Rubric

<table>
<thead>
<tr>
<th>Racetrack design:</th>
<th>Your Mark</th>
<th>Total Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-sided polygon</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>perimeter between 4.5 km and 5 km</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>measures of each line segment (with ruler &amp; Label)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1 acute angle, 1 obtuse angle, and reflex (180° - 360°) [Have &amp; Label]</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Identifies the starting line with an “S”</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spectator area:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8 sections</td>
<td>1</td>
</tr>
<tr>
<td>letter identification for each section</td>
<td>1</td>
</tr>
<tr>
<td>15 squares per section</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Starting line frieze pattern:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>rectangular design measuring 6 squares by 3 squares, reflected twice</td>
<td>3</td>
</tr>
<tr>
<td>[ \frac{1}{3} \text{ white and } \frac{2}{3} \text{ black or } \frac{1}{3} \text{ black and } \frac{2}{3} \text{ white} ]</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Starting line painting:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>costs 112.50 $</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculations:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>50 cm represents 5 000 m</td>
<td>3</td>
</tr>
<tr>
<td>6 cm + 5 cm + 4 cm + 9 cm + 5 cm + 10 cm + 10 cm = 49 cm</td>
<td>3</td>
</tr>
<tr>
<td>15 000 \div 1000 = 15 squares</td>
<td>3</td>
</tr>
<tr>
<td>120 000 \div 15 000 = 8 sections</td>
<td>3</td>
</tr>
<tr>
<td>( (18 \text{ m} \times 3 \text{ m} = 54 \text{ m}^2) \times \frac{1}{3} \times 54 \text{ m}^2 = 18 \text{ m}^2 )</td>
<td>3</td>
</tr>
<tr>
<td>( \frac{1}{3} ) white squares, 6 squares white, 18 white squares total</td>
<td></td>
</tr>
<tr>
<td>6.25 $/\text{m}^2 \times 18 \text{ m}^2 = 112.50 $</td>
<td>3</td>
</tr>
</tbody>
</table>

| Total: | 50 |
| Percent: | |

Comments:
Appendix H

Quebec Exam in Mathematics (2009) “Start Your Engines” Sample Solution

Possible racetrack design and seating area:

Possible starting line frieze pattern: