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Investigating the Transfer of Metacognition to Domains Distinct From Mathematics

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By

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ABSTRACT

The purpose of the present research was to investigate the transfer of metacognition from mathematics to other domains for a post-secondary population. A systematic literature review revealed potential transferability for metacognitive strategic knowledge, metacognitive planning, monitoring, and debugging. Mevarech and Kramarksi's (1997) IMPROVE model was modified to incorporate the explicit instruction of transfer and then used as the metacognitive intervention for a beginner-level calculus course at the University of Windsor. This occurred over a period of five weeks with n = 90 participants for each of the experimental and control groups.

A concurrent, triangulated mixed-method research design was employed to assess metacognition and self-regulated learning: metacognition was assessed quantitatively using Schraw and Dennison's (1994) Metacognitive Awareness Inventory; recordings of participants' conversations (i.e., "in-course data") and recordings of post-intervention interviews with select participants (i.e., "interview data") constituted the qualitative data. In-course data employed the use of quantitative (i.e., frequency-counting and graphical presentation of the data) and qualitative (i.e., thematic) analyses; interview data employed the use of thematic analysis. Data were collected and analysed separately before being integrated during the interpretation of data.

Transfer of metacognitive strategic knowledge, self-regulation, general learning, and metacognitive regulation (i.e., planning, monitoring, and debugging) into near, far, immediate, and some delayed contexts was affirmed. Analysis of the evidence identified the necessity of novel, difficult contexts to facilitate advanced metacognitive behaviours. The necessary incorporation of metacognition into routine learning experiences was affirmed to facilitate transfer into delayed contexts. The interview, intended as an instrument of metacognition, also operated as an intervention itself. Recommendations for future study are included.

DEDICATION

This work is dedicated to my faith. As a manifestation of the Universe experiencing itself, I dedicate my work to its source: the gifts, signs, and omens left for me; the choices I made; the family, friends, and mentors who supported me through all the journeys which led me here; the cosmos who supports all of us; and the connection which binds us all together.

"And the Little Blue Engine smiled and seemed to say as she puffed steadily down the mountain, 'I thought I could. I thought I could. I thought I could. I thought I could. I thought I could' " (Piper, W., 1930, pp. 19-20).

~The Little Engine That Could

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Although many others have supported me throughout this journey, I am forever grateful to my partner, companion, best-friend, and entangled soul mate, Mia Grybas, without whose tireless support I would be lost (sometimes quite literally!). She nourished my mind, body and spirit; I thank her for her patience, love, and encouragement. Her dedication to the completion of this thesis strengthened my own resolve.

On reflection, my mother taught me many self-regulated learning strategies; instilled the metacognitive framework I used to succeed in education; encouraged me to pursue learning with life-long curiosity; and, was vigilantly persistent to keep me on-track throughout completing this thesis. I was sculpted through her continued support along each step of my educational journey from listening to my stresses, to providing me with grammatical edits. For these reasons and many more, I acknowledge my mother, Mary Teeuwen; she was my first educator.

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CHAPTER ONE: INTRODUCTION

Rationale and Statement of the Problem

Metacognition was first described by Flavell (1979). Researchers showed that metacognition, more commonly known as "thinking about thinking", impacts many areas within education such as academic achievement and achievement beyond school (e.g., Boekaerts & Cascallar, 2006; Sangers-Jokic & Whitebread, 2011). Wang, Haertel and Walberg (1990) described metacognition as a "most powerful predictor of learning" (p. 3). Radmehr and Drake (2017) noted instruction of metacognitive knowledge as an important objective, confirming the model presented by Anderson and Krathwohl (2001) in their revision of Bloom's taxonomy of educational objectives. Examination of the literature identified the positive effects of metacognitive interventions on mathematics achievement (e.g., Mevarech & Kramarski, 1997; Özcan & Ertkin, 2015; Pannequin, Sorel, Nanty, & Fontaine, 2010). One such intervention, Mevarech and Kramarski's (1997) IMPROVE model, examined this effect in detail (e.g., Mevarech, Terkieltaub, Vinberger, & Nevet, 2010; Mevarech & Kramarski, 2014). Despite such detail, the IMPROVE intervention has yet to be assessed for its impact on general metacognitive ability (Mevarech & Kramarski, 2014).

The literature has revealed conflicting evidence over the past four decades concerning the domain-general (e.g., Schraw, 2001; Veenman, Van hout-Wolters, & Afflerbach, 2006) or domain-specific (e.g., Kelemen, Frost, & Weaver, 2000) nature of metacognition. Schraw and Dennison's (1994) model for metacognition was employed: metacognitive knowledge was subdivided into person, task, and strategic knowledge; metacognitive regulation was subdivided into planning, monitoring, information managing, debugging, and evaluating. A mixed-studies systematic literature review was conducted, according to the recommendations of Pluye, Hong, and Vedel (2016), to investigate the effect and amount of transfer of domain-general metacognition from mathematics into a different domain.

A total of 2729 articles were discovered using the search terms, of which nine matched the inclusion criterion. No studies were identified which measured a significant effect of the transfer of metacognitive knowledge and metacognitive regulation to a domain distinct from mathematics in post-secondary students. As a result of the findings from this systematic literature review, it was concluded that the transfer of metacognition (i.e., metacognitive strategic knowledge, metacognitive planning, monitoring, and debugging components of metacognitive regulation) may be possible to other domains from mathematics. The findings of the literature review revealed recommendations for interventions supporting the transfer of components of metacognition.

Analysis of the results of the literature search also showed the need for a study examining potential transference of metacognitive strategic knowledge and metacognitive regulation (i.e., planning, monitoring, and debugging) to other domains from mathematics. A study exploring this would add to the literature on metacognition and mathematics. Considering the reasonable debate on the generality of metacognition and which components are domain-general, a study exploring transfer would also contribute to the validation (or contestation) of the generality of metacognition, and consequently its transferability into other domains. Based on the findings of the systematic literature review, the domain-general components to be explored include metacognitive strategic knowledge, metacognitive planning, monitoring, and debugging. Finally, the results of the present research will contribute to the literature regarding the potential impact of the IMPROVE model on general metacognitive ability (Mevarech & Kramarski, 2014).

Purpose and Research Question

The purpose of this dissertation research is to investigate the transfer of metacognition to other domains from mathematics, with two intended outcomes:

1. identifying and describing the transference of metacognitive strategic knowledge and regulation to other domains from mathematics; *and*
2. validating (or calling into question) the generality of metacognition and its transferability into other domains

for a post-secondary student population for interventions beginning in mathematics. Therefore, the following research questions arose:

1. What is the impact of an intervention program, designed for the explicit development of metacognition in the domain of mathematics and its potential transfer to other domains, on post-secondary students' perceptions of their metacognition in a) domain-general contexts (i.e., far-transfer) for b) immediate and delayed effects and for c) routine and novel situations?
2. What is the effect of an intervention program, designed for the explicit development of metacognition in the domain of mathematics and its potential transfer to other domains, on post-secondary students' experiences of their metacognitive processes in a) mathematics (i.e., near-transfer) and domains distinct from mathematics (i.e., far-transfer) for b) immediate and delayed effects and for c) routine and novel situations?

Definition of Common Terms

Common terminologies used throughout the present research are included in this section in alphabetical order for ease-of-reference. A summary of the common terms, key content, and sources, is included in Table *1* (p. 8).

Advanced/Novice. Metacognitive components are identified as novice or advanced based on experience with using metacognition. Metacognitive knowledge is considered a novice component (e.g., Kramarski & Dudai, 2009; Mevarech & Amrany, 2008). Specifically, metacognitive strategic knowledge (i.e., self-regulated learning strategies) did not differ greatly between novice and advanced individuals (Mevarech & Amrany, 2008). Self-regulated learning strategies, particularly study habits, organization, and communication, are considered to contain information management strategies (e.g., Özsoy, Memis, & Temur, 2009). Since self-regulated learning strategies are also demonstrated to be consistent between novice and advanced learners (e.g., Mevarech & Amrany, 2008), information managing is considered a novice component. Metacognitive debugging (e.g., Kramarski & Friedman, 2014) and evaluating (e.g., Erickson & Heit, 2015; Gutierrez, Schraw, Kuch, & Richmond, 2016; Hessels-Schlatter, Hessels, Godin, & Spillmann-Rojas, 2017; Kramarski & Dudai, 2009) are also considered novice components. Previous researchers identified that metacognitive planning (e.g., Hessels-Schlatter et al., 2017; Kramarski, Weiss, & Sharon, 2013; Kramarski & Friedman, 2014) and monitoring (e.g., Hessels-Schlatter et al., 2017; Kramarski & Dudai, 2009; Mevarech & Amrany, 2008) required time for development. Consequently, metacognitive planning and monitoring are considered as advanced metacognitive components.

Domain. Based on the distinctions between learning and transfer (Salomon & Perkins, 1989), "domain" in the present research referred to contexts (e.g., Mathematics, Science, English, personal life, professional life, etc.). The term domain-specific identified a metacognitive component which was learned and expressed within the same context (i.e., introduced in mathematics, and expressed only in mathematics). The term domain-general identified a metacognitive component which was learned in one context, and expressed in a distinct context (e.g., introduced in mathematics, and expressed in Science, English, and/or personal life contexts).

GKLP. GKLP is an abbreviation of "general knowledge of the learning process" and was explored by van Velzen (2016). The researcher argued that students could be explicitly taught domain-general metacognitive knowledge (i.e., person, task, and strategy) as learners, which would exist alongside domain-specific counterparts.

IMPROVE. "IMPROVE" is an acronym which stands for the various stages used in Mevarech and Kramarski's (1997) problem-solving model:

- Introducing new material;
- Metacognitive self-directed questions;
- Practicing the metacognitive questioning;
- Reviewing new materials;
- Obtaining mastery in higher/lower cognitive processes;
- Verifying the correct use of new skills based on feedback; *and*
- Enriching with additional activities.

The acronym was used in place of the expanded form.

Learning. "Learning" was identified as applying knowledge or skills into a situation equivalent to the context of instruction (Salomon & Perkins, 1989).

Metacognition. Introduced by Flavell (1979), metacognition was defined by Brown as "one's knowledge and control of [one's] own cognitive system" (Brown, 1987, p. 66). Schraw and Dennison's (1994) model of metacognition was employed for the present research. Metacognition was subdivided into metacognitive knowledge and metacognitive regulation.

Metacognitive knowledge. Knowledge of cognition was differentiated into three components by Flavell (1987): person, task, and strategy. Schraw and Dennison (1994) divided knowledge of cognition similarly: declarative knowledge (i.e., knowledge of the self as a learner and what affects learning, identified in this thesis as *metacognitive personal knowledge*); procedural knowledge (i.e., knowledge of procedures and heuristics for given tasks, identified in this thesis as *metacognitive task knowledge*) and conditional knowledge (i.e., understanding when and why to use a particular strategy, identified in this thesis as *metacognitive strategic knowledge*).

Metacognitive regulation. Regulation of cognition included five components under Schraw and Dennison's (1994) model: planning (i.e., cognition focused on prioritizing future tasks), monitoring (i.e., cognition focused on awareness of cognition), debugging (i.e., cognition focused on troubleshooting a given task), information managing (i.e., cognition focused on organizing and recalling data related to a task), and evaluating (i.e., cognition focused on judging accuracy and precision).

Self-regulation. Founded on Bandura's (1986) social cognitive perspective, self-regulation was defined by Zimmerman (2000) as the "interaction of personal, behavioural and environmental…processes" (p. 13). Zimmerman (2000) referred to thoughts, behaviours and feelings, generated by the self and associated with goal achievement, collectively as self-regulation. This was defined as a cyclical process formed through iterations based on feedback from the environment, with an individual moving through three phases: performance/volition control, self-reflection, and forethought (Schunk & Zimmerman, 1998). Self-regulation was not included in the present investigation due to its inclusion alongside metacognition in self-regulated learning.

Self-regulated learning (SRL). Zimmerman and Campillo (2003) operationalized self-regulation towards academic learning which also included three phases: performance, reflection, and forethought.

Metacognition, self-regulation, and self-regulated learning. Metacognition, self-regulation, and self-regulated learning were identified as interrelated constructs (Dinsmore, Alexander, & Loughlin, 2008). Kaplan (2008) asserted that these were “three concepts under one conceptual abstract umbrella” (p. 479).

Transfer. “Transfer” was identified as the application of knowledge or skills into a situation whose context was considered as “different” from the context of instruction (Salomon & Perkins, 1989). Transfer was divided into amount and distance of transfer. Amount of transfer was determined through observed differences in performance. Distance of transfer was subdivided into three categories: *time* (i.e., immediate and delayed use); *context* (i.e., *near*, or similar/related, and *far*, or distant); and *exposure* (i.e., *routine*, or familiar, and *novel*). Salomon and Perkins (1989) recognized the subjectivity in determining similarity and relatedness, which was defined in the present research based on comparison of the domain to that of mathematics. Consequently, domains were considered as near-transfer if the new context was the course of study (i.e., the calculus course) or a context which was fundamentally mathematical or problem-solving in nature. Domains were considered as far-transfer if the new context was distinct from the course of study (i.e., it was not mathematical or problem-solving in nature).

Table 1
Summary of Common Terms, Key Content, and Sources

Term		Key Content	Sources
Domain		*Domain-specific:* within the same context *Domain-general*: learned in one context, expressed in a distinct context	Salomon and Perkins (1989)
Advanced		Planning.	Hessels-Schlatter et al. (2017) Kramarski et al. (2013) Kramarski and Friedman (2014)
		Monitoring.	Hessels-Schlatter et al. (2017) Kramarski and Dudai (2009) Mevarech and Amrany (2008)
Novice		Metacognitive knowledge.	Kramarski and Dudai (2009) Mevarech and Amrany (2008)
		Strategic knowledge.	Mevarech and Amrany (2008)
		Information managing.	Mevarech and Amrany (2008)
		Debugging.	Kramarski & Friedman (2014)
		Evaluating.	Erickson and Heit, 2015 Gutierrez et al., 2016 Hessels-Schlatter et al., 2017 Kramarski and Dudai, 2009
GKLP		General knowledge of the learning process.	van Velzen (2016)
IMPROVE		An acronym for the various stages of a problem-solving model by the authors.	Mevarech and Kramarski (1997)
Learning		Applying knowledge or skills into the same context as that of instruction.	Salomon and Perkins (1989)
Metacognition		Subdivided into metacognitive knowledge and regulation.	Flavell (1979) Schraw and Dennison (1994)
Metacognitive Knowledge		Three components: Metacognitive personal, task, and strategic knowledge	Flavell (1987) Schraw and Dennison (1994)
Metacognitive Regulation		Five components: planning, monitoring, debugging, information managing, and evaluating.	Schraw and Dennison (1994)
Self-regulation		Thoughts, behaviours, and feelings, generated by the self and associated with goal achievement.	Zimmerman (2000) Schunk and Zimmerman (1998)
Self-regulated learning (SRL)		Self-regulation operationalized to academic learning, with three phases: performance, reflection, and forethought.	Zimmerman and Campillo (2003)
Transfer		The application of knowledge or skills into a context distinct from instruction. *Time:* immediate and delayed use *Context:* near (i.e., similar) and far (i.e., distant) *Exposure:* routine (i.e., familiar) and novel	Salomon and Perkins (1989)

CHAPTER TWO: LITERATURE REVIEW

Theoretical Background

Metacognition. Flavell introduced metacognition (1979). Metacognition was defined as "one's knowledge and control of [one's] own cognitive system" (Brown, 1987, p. 66). During metacognition, thinking operates as both action and object. For example, if one thought, "What is the next best task?" during problem-solving, further consideration may include descriptions of the particular problem, possible actions to solving the problem, and evaluations regarding performance.

For metacognition, or "knowledge and cognition about cognitive phenomena" (Flavell, 1979, p. 906), the term, "meta", was incorporated to emphasize the sense of depth or to go beyond simple cognition (Mevarech & Kramarski, 2014). Therefore, metacognition was identified in the present study as a type of higher-thinking process which has control over other cognitive processes.

Metacognition model by Schraw and Dennison (1994). Knowledge of cognition was differentiated into three components by Flavell (1987): person, task, and strategy. Schraw and Dennison (1994) divided knowledge of cognition similarly: declarative knowledge (i.e., knowledge of the self as a learner and what affects learning, identified in this thesis as *metacognitive personal knowledge*); procedural knowledge (i.e., knowledge of procedures and heuristics for given tasks, identified in this thesis as *metacognitive task knowledge*); and conditional knowledge (i.e., understanding when and why to use a particular strategy, identified in this thesis as *metacognitive strategic knowledge*).

An example of metacognitive personal knowledge is a learners' self-identified set of learning preferences (such as auditory learning) for a given subject. A metacognitive task knowledge example is knowing how to isolate for a variable in an algebraic expression. An example of metacognitive strategic knowledge is knowing when and why to substitute an expression from an equation to assist with simplifying or knowing when and why to search through course notes when seeking support.

Expanding on Brown's (1987) model of metacognition, regulation of cognition included five components under Schraw and Dennison's (1994) model: planning (i.e., cognition focused on prioritizing future tasks), monitoring (i.e., cognitive awareness or mindfulness as defined by Kabat-Zinn, 1990), debugging (i.e., cognition focused on troubleshooting a given task), information managing (i.e., cognition focused on organizing and regulating the flow of data related to a task), and evaluating (i.e., cognition focused on judging performance or benefit of present or past work).

An example of metacognitive planning is a learner taking time to understand the components of a particular word problem before prioritizing necessary steps to solving the problem. Monitoring examples include a learner consciously attending to progress while working on a problem or a learner recognizing a loss of focus in the present moment. An example of debugging is a learner recognizing struggle with the identification of a strategic approach to a problem and reading through course notes to identify possible approaches. A learner taking time to write down known and unknown variables during problem solving is an example of information management. Examples of evaluating include a learners' judgment that a solution is accurate (or inaccurate) prior to validation by an external source or a learners' assessment that a particular strategy is beneficial to desired goals.

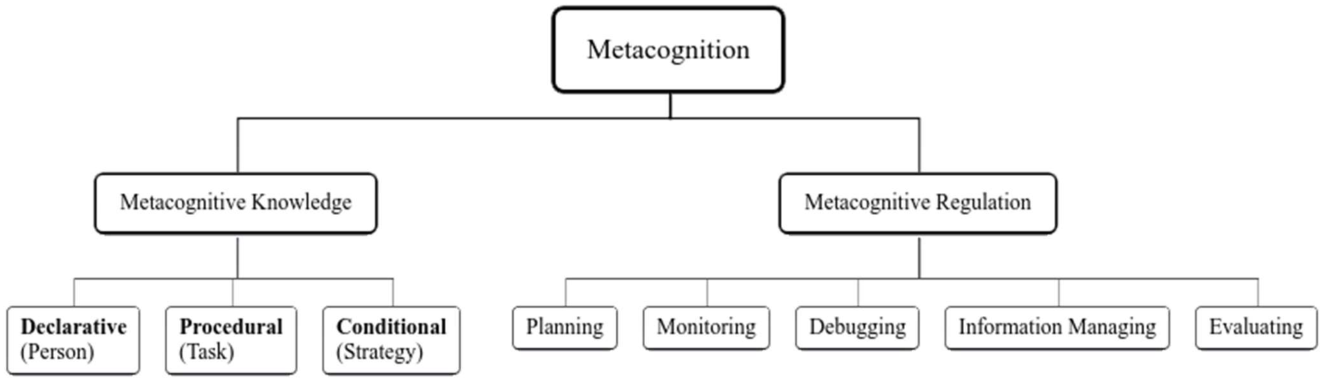


Figure 1. Schraw and Dennison's (1994) model of metacognition (adapted).

A comprehensive and often-cited model for self-regulated learning, Schraw and Dennison's (1994) model of metacognition (represented *above* in *Figure 1*) was used as the basis for understanding self-regulated learning in the literature search unless indicated otherwise by the authors of investigated studies. Zimmerman (2008) viewed metacognitive regulation as a cycle. In light of the components added by Schraw and Dennison (1994), as a process the metacognitive components may be described as interrelated (See *Figure 2* below).

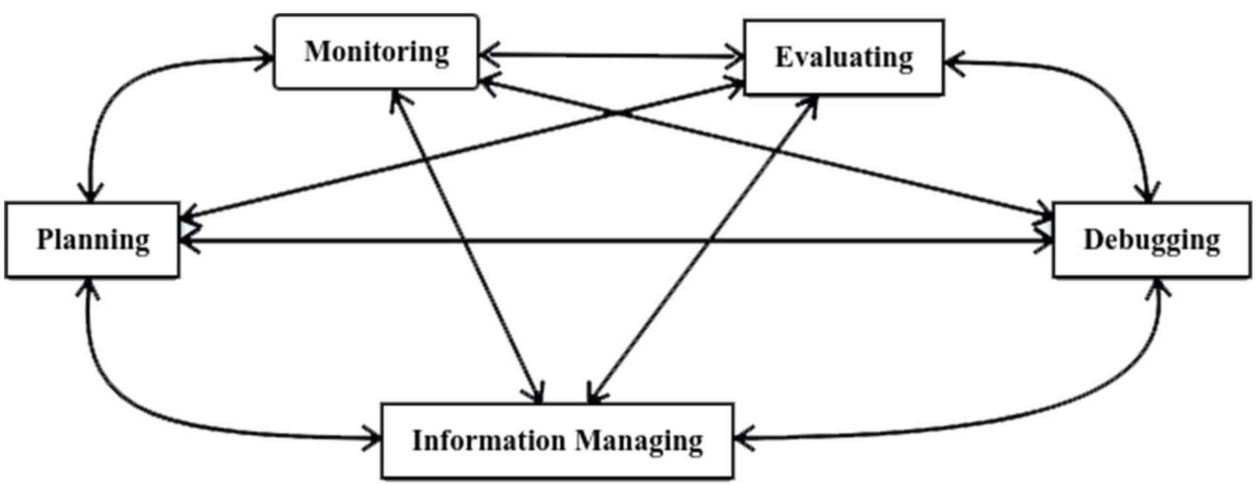


Figure 2. Interrelatedness of all components of metacognitive regulation as a process.

Notice that the components of metacognitive knowledge (i.e., person, task, and strategy) were not included in the diagram. This was intentional, as all components of metacognitive knowledge may be needed during any component of metacognitive regulation. For example, while monitoring, a learner may develop an awareness that the self is not strong with fractions (person); one may reflect on the present action one is completing in relation to a goal (task); or one may be paying attention to personal use of a particular strategy (strategy). Any of the components of metacognitive regulation may employ any of the components of knowledge, thereby showing how interrelated the components are with each other. This aligned with what was identified as advanced use of metacognition (e.g., Mevarech & Kramarski, 2014).

Learning mathematics. Modern research viewed mathematics as a human, social, and cultural activity, formulated outside of any individual school of thought (Dossey, 1992; Radford, 2014). Schoenfeld (1992) was a major proponent of advocating this modern perspective of math as a human, social and cultural activity:

> Mathematics is an inherently social activity, in which a community of trained practitioners (mathematical scientists) engages in the science of patterns … The tools of mathematics are abstraction, symbolic representation, and symbolic manipulation…Learning to think mathematically means (a) developing a mathematical point of view – valuing the processes of mathematization and abstraction and having the predilection to apply them, and (b) developing competence with the tools of the trade, and using those tools in the service of the goal of understanding structure – mathematical sense-making. (Schoenfeld, 1994, p. 60)

Schoenfeld (1992) purported that students identified as mathematically powerful were analytical, flexible thinkers. Schoenfeld (1992) argued that mathematicians' efforts to solve problems centered on those identified as "perplexing or difficult" (p. 339). According to Schoenfeld, problem-solving is at the heart of mathematics. Schoenfeld expanded on Pólya's (1945) asserted view regarding the entangled relationship between mathematical epistemology and pedagogy; for Schoenfeld, mathematical learning is done in a manner that is social, cultural, and interactive

(Schoenfeld, 1992).

Schoenfeld (1992) also established a framework for teaching mathematical cognition: (a) *knowledge base* of the various mathematics skills needed; (b) *problem-solving strategies* (i.e., the various heuristics made available to students); (c) *monitoring and control* (i.e., teaching students how to regulate their thinking); (d) *beliefs and affects* (i.e., of conscious and subconscious attitudes); (e) *beliefs and emotional responses* in respect to mathematics; and (f) *practices* regarding the "habit" of sense-making through conversation, argumentation, and conjectures (Schoenfeld, 1992).

Mayer (1998) showed that problem-solving has cognitive, metacognitive, and motivational components (Mayer, 1998). Since Flavell's (1979) introduction to metacognition and problem-solving, extensive research illustrated the benefits of using explicit metacognition to improve problem-solving ability (e.g., Desoete, Roeyers, & Buysse, 2001; Mevarech et al., 2010; Pannequin et al., 2010; Schoenfeld, 1985). Singapore's dramatic improvements in mathematics globally since implementing metacognition into their mathematics curriculum illustrate the potential benefits of incorporating metacognition explicitly into a curriculum (OECD, 2010).

The IMPROVE model in mathematics. Several models were constructed over the past century with respect to mathematical problem-solving (e.g., Lianghou & Yan, 2007; Mevarech & Kramarski, 1997; Pólya, 1945; Schoenfeld, 1985; Verschaffel, 1999). Pólya's (1945) famous model is still utilized around the world, an example of which is in the Ontario curriculum, featuring the familiar four-step procedure: "understand the problem; devise a plan; carry out the plan; look back" (Ministry of Education, 2005, p. 12).

Pólya's (1945) model lacked detail for people to properly implement it, prompting Schoenfeld (1985) to develop an instructional model with the following stages: 1) analysis; 2) design of a global solution plan; 3) exploration of the problem; 4) implementation of the plan; and 5) verification. Schoenfeld's (1985) model identified consecutive stages. Both Pólya's (1945) and Schoenfeld's (1985) systems were adapted to younger students who required explicit guidance in their implementation.

While several problem-solving models exist, comprehensive data was collected (e.g., Mevarech & Fridkin, 2006; Mevarech & Kramarski, 2014) using Mevarech and Kramarski's (1997) "IMPROVE" model, an acronym which has the following stages: **I**ntroducing new material, **M**etacognitive self-directed questions, **Practicing** the metacognitive questioning, **R**eviewing new materials, **O**btaining mastery in higher/lower cognitive processes, **V**erifying the correct use of new skills based on feedback and **E**nriching with additional activities. This model was unique in that it could be utilized outside of a single problem, allowing it to be used in multiple systems, particularly complex, unfamiliar, and non-routine problems (Mevarech & Kramarski, 2014). Mevarech et al. (2010) showed that metacognition impacted learners' solutions of complex, unfamiliar and non-routine problems singularly, as these often require various use of metacognitive regulation.

The IMPROVE model relied significantly on the inclusion of co-operative and explicit learning (Mevarech & Kramarski, 2014). The researchers defined cooperative learning, based on the research of Artzt and Newman (1990), as the completion of common tasks or problems while learners work together in small groups. Because of the inclusion of co-operative learning, the learning models of both Piaget and Vygostky were combined in the implementation of the IMPROVE program (Mevarech & Kramarski, 2014).

According to Piaget (1975/1985), cognitive development (i.e., learning) happened through the equilibrium a student finds when resolving the "cognitive conflict" caused by the contrasting facts. He argued that such conflicts arise more frequently when presented in group learning because of the potential for contrast in individuals' unique contributions. Vygotsky (1978) however, defined teaching and learning as social processes; this was illustrated by the "zone of proximal development", defined as the distance between individual learning and that which was learned with more capable peers. Vygotsky emphasized the interplay between the cultural and personal thoughts developed during discussions. By design, group work was included in the model to provide opportunities for students to reason critically to reach mutual understanding (Mevarech & Kramarski, 1997).

Researchers showed that metacognitive training benefitted from explicit instruction, followed with intense practice (e.g., Dignath & Buettner, 2008; Dignath, Buettner, & Langfeldt, 2008). Explicit labelling of strategies showed students how to use, practice, and retain a large selection of strategies for solving future problems (Veenman et al., 2006). King (1998) and Webb (2008) identified that cooperative learning results in greater articulation in mutual thinking when metacognitive regulation is scaffolded. Therefore, the IMPROVE model necessarily included co-operative learning and explicit instruction of metacognition (Mevarech & Kramarski, 1997).

Effects of metacognition. Previous researchers identified metacognition as supporting various areas within education:

- achievement beyond school and academic achievement (e.g., Boekaerts & Cascallar, 2006; Sangers-Jokic & Whitebread, 2011);
- academic risk-taking (e.g., Clifford, Chou, Mao, Yun Lan, & Kuo, 1990);

- problem-solving (e.g., Mayer, 1998; Desoete et al., 2001);
- creative thinking (e.g., Sternberg & Williams 1996);
- self-regulation (e.g., Pressley & Afflerbach, 1995);
- self-regulated learning (e.g., Özcan, 2015);
- self-efficacy (e.g., Jaafar & Ayub, 2010; Cera, Mancini, & Antonietti, 2013);
- math anxiety (e.g., Legg & Locker, 2009; Kramarski, Weiss, & Kololshi-Minsker, 2010);
- mathematics attitudes (e.g., Afamasaga-Fuata'i & Sooaemalelagi, 2014);
- study habits and attitudes (e.g., Özsoy et al., 2009); and
- was identified as a "most powerful predictor of learning" (e.g., Wang et al., 1990, p. 3)

Numerous studies were conducted linking the positive effect of metacognition on mathematics achievement (e.g., Mevarech & Kramarski, 1997; Özcan & Ertkin, 2015; Pannequin et al., 2010). Particular benefits were found for problem-solving using the IMPROVE model (e.g., Mevarech et al., 2010). Further, research on Mevarech and Kramarski's (1997) IMPROVE model showed enhancements in mathematics creativity, metacognition, self-regulation, self-efficacy, judgement-of-learning, math reasoning, math anxiety, and math attitudes (Mevarech & Kramarski, 2014).

Previous researchers showed that metacognition benefits multiple domains, including literacy (e.g., Amzil, 2014); reading, and studying (e.g., Baker & Brown, 1984); mathematics (e.g., Özcan, 2015); physics (e.g., Veenman & Verheij, 2001); and science (e.g., Veenman, 2012). An extensive body of research exists on the integration of explicit metacognitive instruction in mathematics and problem-solving ability (Pólya, 1945; Schoenfeld, 1985; Mevarech & Kramarski, 1997; Verschaffel, 1999; OECD, 2010). However, Mevarech and

Kramarski's (1997) IMPROVE intervention has yet to be assessed for its impact on general metacognitive ability (Mevarech & Kramarski, 2014).

Delineating between novice and advanced metacognition. Metacognitive components were identified as novice or advanced based on experience with using metacognition. Kramarksi and Dudai (2009) reported high use of metacognitive knowledge and evaluating among novice learners. Mevarech and Amrany (2008) cited minimal differences in metacognitive knowledge between novice and advanced learners. In particular, metacognitive strategic knowledge (i.e., self-regulated learning strategies) did not differ greatly between novice and advanced individuals. Mevarech and Amrany showed that knowledge of cognition did not necessarily ensure learners' regulation of cognition. Therefore, metacognitive knowledge was considered a novice component.

Self-regulated learning strategies, particularly study habits, organization and communication, were considered to contain information management strategies (e.g., Özsoy et al., 2009). Since self-regulated learning strategies were also demonstrated to be consistent between novice and advanced learners (e.g., Mevarech & Amrany, 2008), information managing was considered a novice component. Metacognitive debugging was identified by Kramarski & Friedman (2014) as occurring more frequently with participants who had no exposure to prompts or had control over their exposure to metacognitive prompts, when compared with individuals who received unsolicited prompts. Several researchers indicated that novice evaluations were not always accurate (Erickson & Heit, 2015; Gutierrez et al., 2016; Hessels-Schlatter et al., 2017; Kramarski & Dudai, 2009). Therefore, metacognitive debugging and evaluating were also considered novice components.

Previous researchers identified that metacognitive planning (Hessels-Schlatter et al., 2017; Kramarski et al., 2013; Kramarski & Friedman, 2014) and monitoring (Hessels-Schlatter et al., 2017; Kramarski & Dudai, 2009; Mevarech & Amrany, 2008) required time for development. Consequently, metacognitive planning and monitoring were considered as advanced metacognitive components.

Self-regulation and self-regulated learning.Over the past thirty years, two additional, related constructs emerged which support student learning: self-regulation (Bandura, 1986; Zimmerman, 2000) and self-regulated learning (Zimmerman & Campillo, 2003).

Self-regulation. Thoughts, behaviours, and feelings generated by the self and associated with goal achievement, are collectively referred to as self-regulation (Zimmerman, 2000). Founded on Bandura's (1986) social cognitive perspective, self-regulation is defined as the "interaction of personal, behavioural and environmental… processes" (Zimmerman, 2000, p. 13). It is a cyclical process that is formed through iterations based on feedback from the environment, where the individual moves through the phases of performance/volition control, self-reflection, and forethought (Schunk & Zimmerman, 1998). Self-regulation was assumed to be a domain-general process (Pintrich, Wolters & Baxter, 2000).

***Self-regulated learning*.** Similar to self-regulation, but operationalized toward academic learning, Zimmerman & Campillo (2003) constructed a three-phase cyclical model of self-regulated learning (SRL): performance, reflection, and forethought. Zimmerman (2008) updated the model, shown in *Figure 3* below. Intervention programs focused on the development of self-regulated learning skills positively impacted performance (Dignath & Buettner, 2008; Dignath et al., 2008).

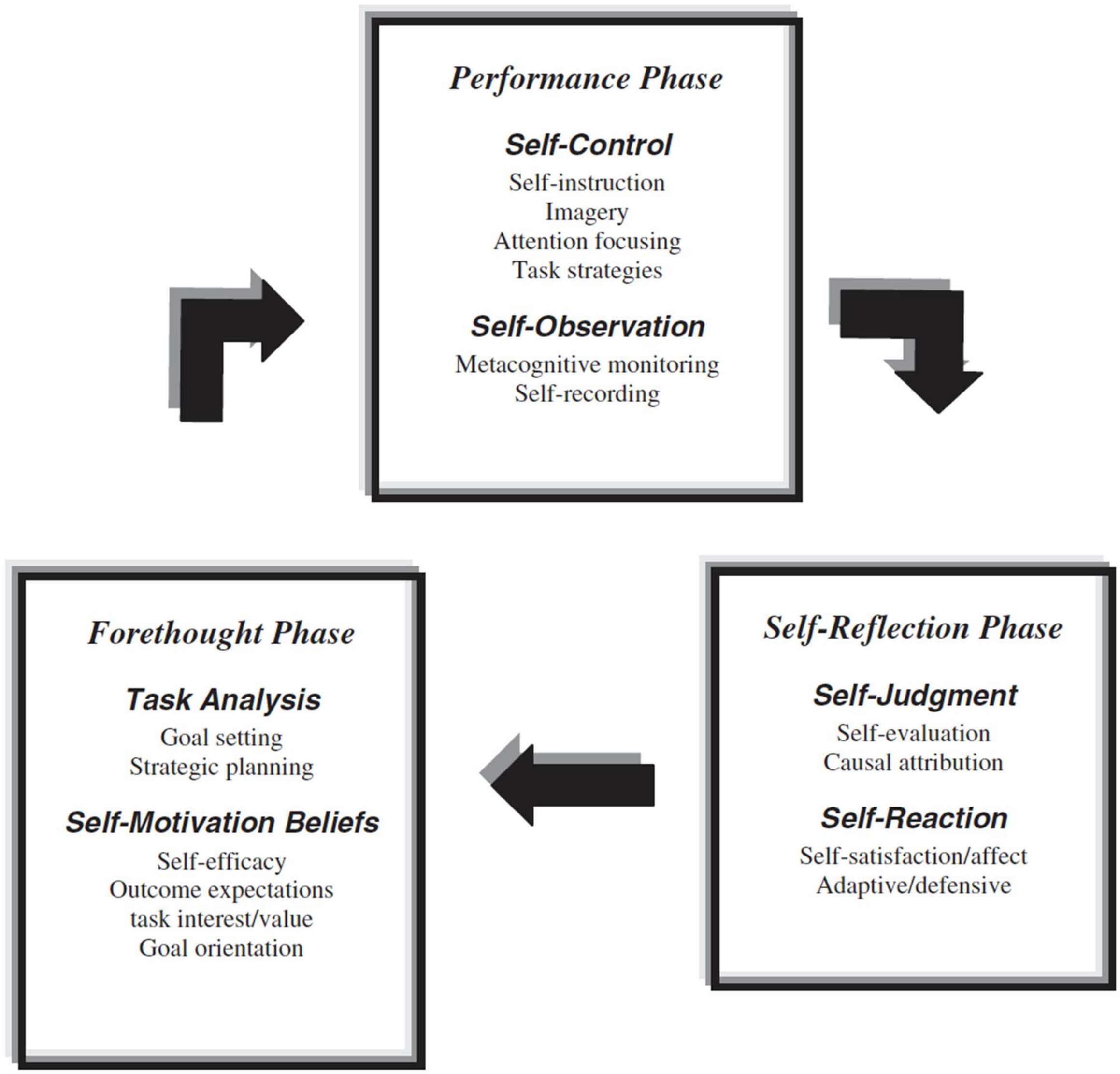


Figure 3. Zimmerman's (2008) cyclical phases of self-regulation and self-regulated learning. From "Investigating self-regulation and motivation: Historical background, methodological developments, and future projects," by B. J. Zimmerman, 2008, *American Educational Research Journal*, 45(1), p. 178. Copyright 2008 by AERA.

Metacognition, self-regulation, and self-regulated learning.

***Theoretical frameworks*.** Fox and Riconscente (2008) compared the interrelated constructs of metacognition and self-regulation in relation to the theoretical frameworks of Piaget (1959/2002; 1976), Vygotsky (1981; 1986) and James (1992). Fox and Riconscente (2008) declared that viewing metacognition and self-regulation through these complementary theoretical perspectives creates an integrated picture of otherwise entangled (i.e., interrelated) constructs. Constructing their framework around the relationship between subject and object, the authors demonstrated the following alignment shown in Table *2*:

Table 2
Alignment of Theorists for Metacognition and Self-Regulation

	Interpretive Framework		
Metacognition:	Knower	Medium	Object of Knowledge
Self-regulation:	Actor	Agency	Object of Action
Theorist:	James	Vygotsky	Piaget
Orientation:	Self	Language	Other/Object

Note. From "Metacognition and Self-Regulation in James, Piaget, and Vygotsky," by Fox. E, and Riconscente, M, 2008, *Educational Psychology Review*, p. 374. Copyright 2008 Springer Science.

***Towards the inclusion of self-regulated learning*.** The combination of these theoretical frameworks revealed the full power of each construct individually and together; therefore, a thorough assessment of metacognitive ability would include both metacognition and self-regulation. It is through the incorporation of metacognition and self-regulation that self-regulated learning emerges as a related construct (Dinsmore et al., 2008).

***Distinguishing metacognition, self-regulation, and self-regulated learning*.** Dinsmore et al. (2008) distinguished these terms in their analysis of the literature. Metacognition, self-regulation, and self-regulated learning each are constructs which “continue to move and take shape over time” (Dinsmore et al., 2008, pp. 404–405). While they have different domains of origin and are not synonymous with each other, over time they have become entangled (i.e., interrelated). Based on analysis from Dinsmore et al. (2008), a summary of the distinctions were included in Table *3* below:

Table 3
Comparison of Metacognition, Self-Regulation, and Self-Regulated Learning

Construct	Primary (original) Domain	Secondary (Entangled) Domain
Metacognition	Cognitive	Behavioural
Self-Regulation	Behavioural	Cognitive
Self-Regulated Learning	Academic	Behavioural-Cognitive

Note. Based on work from Dinsmore et al. (2008).

Metacognition (Flavell, 1979) had its roots in developmental psychology, making its domain primarily cognitive, while self-regulation (Bandura, 1986) had an emphasis on the interaction between person and environment (Dinsmore et al., 2008). Dinsmore et al. (2008) showed that, over time, metacognition research moved into the domain of behaviour while self-regulation research looked at the cognitive domain. Self-regulated learning research began in academic domains but shifted towards behavioural-cognitive domains.

At the core of metacognition, self-regulation, and self-regulated learning, Dinsmore et al. (2008) denoted a central theme of ideas, mainly, “that individuals make efforts to monitor their thoughts and actions and to act accordingly to gain some control over them,” (p. 404). Kaplan (2008) asserted that metacognition, self-regulation, and self-regulated learning may be “three concepts under one conceptual abstract umbrella” (p. 479). Therefore, the framework used in the present research encompassed these three perspectives.

Because self-regulation and metacognition are both assessed in self-regulated learning, self-regulation was not included in the investigation. Consequently, only self-regulated learning and metacognition were included for this study for assessing overall metacognitive ability. Collectively, these constructs measure metacognition from different vantage points, thus creating a more complete picture of the process of metacognition. This view was summarized in *Figure 4* below.

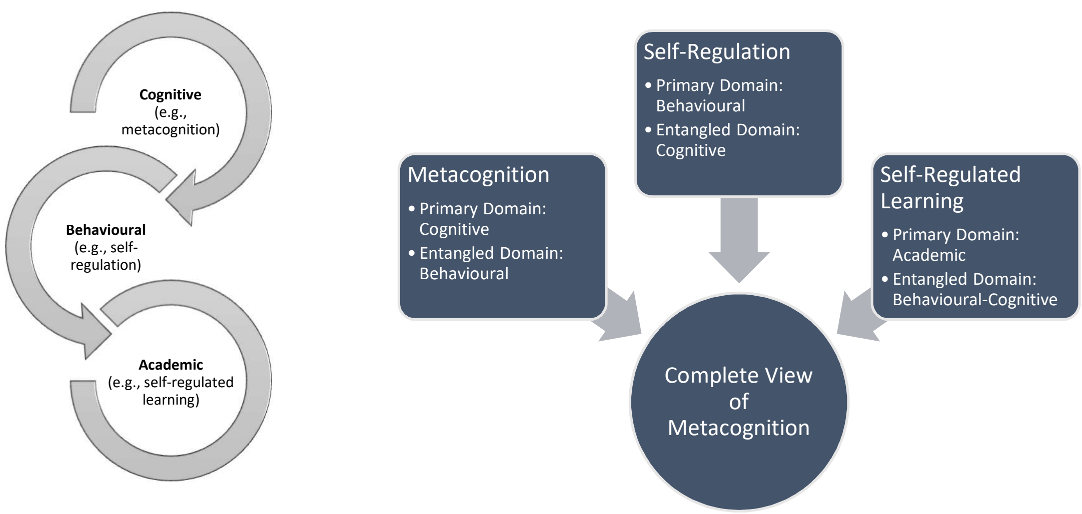


Figure 4. Interrelated domains of metacognition (Left) converge into a complete view (Right).

Pedagogy of Metacognition Instruction. Previous research recommended that metacognition instruction be explicit, dialogic, and systematic (Teeuwen & Salinitri, 2019). Considering the purpose of the present research (i.e., assessing potential transfer of metacognition), pedagogical choices enhancing the transfer of metacognition were selected. Metacognition was instructed through: the use of metacognitive prompts for explicit instruction; the inclusion of dialogic, reflective practice; the adaptation of the IMPROVE model to include explicit prompts for transfer; and a systematically scaffolded instruction to reduce cognitive load. Each instructional element is justified individually below.

Explicit. According to previous research, the explicit use of metacognitive prompts benefits all components of metacognition (e.g., Dignath & Buettner, 2008; Gutierrez et al., 2016; Mevarech & Amrany, 2008) and self-regulated learning (Pelton, 2014; Kistner et al., 2010). Therefore, metacognitive prompts were used to explicitly address each component of metacognition, specifically an adaptation of Mevarech and Kramarski's (1997) IMPROVE model.

Dialogic. Kramarski and Dudai (2009) demonstrated the positive impact of a social context on transfer when compared with an individual context. Teeuwen and Salinitri (2019) illustrated the importance of meaningful discourse: explicit use of prompts must be necessarily answered by the learner. Voluntary responses demonstrated learners' choice to procrastinate or engage in other self-regulatory behaviours (Belenky & Nokes, 2009; Teeuwen & Salinitri, 2019). Therefore, metacognition was instructed through a dialogic practice between participants, and with their instructor, to facilitate increased development and transfer.

Metacognitive prompts. The IMPROVE (Mevarech & Kramarski, 1997) model involves instructing students in the importance, utility, and executed uses of metacognitive prompts in assisting with problem-solving. Four categories of questions are used, which were demonstrated and modeled by instructors:

- Comprehension: *What is the problem/task?*
- Connection: *What is the difference/similarity between the tasks/procedures? or How do you justify your conclusion?*
- Strategy: *What is the strategy? How and when should I select/implement the strategy? Why? What other strategies are available?*

- Reflection: *Does the solution make sense? Can the solution be presented otherwise? Am I satisfied with how I faced the task? Can the task be solved otherwise? How can I solve it in another way? Am I stuck? Why?*

For the purpose of the present study, an additional question category was added to explicitly facilitate the transfer of metacognition into other domains:

- Transfer: *Where else could these strategies/this process be used? What have you learned from solving this problem that is useful in your other courses? or What have you learned about your learning process?*

Teeuwen and Salinitri (2019) inspected the above prompts to illustrate broad connections between the categories of the prompts and the metacognitive component it targets, as explained in Table *4* below:

Table 4
Connections Between Metacognitive Prompts and Metacognitive Component

Prompt Category	**Description**	**Emphasized Metacognitive Component**
Comprehension	Prompts address the students' attention to a particular task or problem.	Metacognitive Knowledge (Person, Task, and/or Strategy)
Connection	Prompts address comparison, analysis, and justification of conclusions.	Planning
Strategy	Prompts address a particular strategy, its use, and alternatives.	Monitoring
Reflection (Debugging)	Prompts address challenges regarding students' thinking for the purpose of analysis.	Debugging
Reflection (Evaluating)	Prompts address challenges regarding judgments made during students' reflections.	Evaluating
Transfer	Prompts emphasize explicit use of learned concepts and processes outside of the course of study, particularly in their general teaching practice.	Transfer

Note. Adapted from: Transmitting Metacognitive Pedagogy to Math Pre-Service Educators (p. 417) by J. Teeuwen and G. Salinitiri, 2019, in G. Mariano and F. Figliano (Eds.), *Handbook of Research on Critical Thinking Strategies in Pre-Service Learning Environments*. IGI Global. Copyright 2019 by IGI Global.

Systematic instruction. Kolb and Kolb (2009) argued the importance of individuals learning metacognitive strategies prior to commencing learning experiences, and to focus on the development of metacognitive monitoring and control (i.e., regulation) in individuals to facilitate learning about learning. Reductions in cognitive load, through focusing learning into one skill at a time, are beneficial when developing metacognition (Wedelin, Adawi, Jahan, & Andersson, 2015; Van der Stel & Veenman, 2014). Therefore, metacognition was scaffolded systematically, "first developing metacognitive knowledge, evaluat[ing], planning, monitoring, and debugging, and lastly, transfer" (Teeuwen & Salinitri, 2019, p. 429).

Teeuwen and Salinitri (2019) argued for instruction of metacognitive knowledge components to follow "the order of person, task, and strategy" (p. 429). The researchers illustrated through their study that personal and task knowledge were readily present in their population of teacher candidates. These components in turn were argued to support the development of strategic knowledge, which facilitates transfer (Hessels-Schlatter et al., 2017).

Due to the nature of the research question, metacognitive personal and task knowledge were not included in the instructional process. For the present study, metacognitive strategic knowledge was instructed first while students developed individual language for the strategies employed. Metacognitive evaluating, planning, monitoring, and debugging, were scaffolded subsequently in order. Notice that, with the exception of metacognitive debugging, each component was taught in increasing order from novice towards advanced performance (See *Delineating between novice and advanced metacognition,* p. 17) Metacognitive components were identified as novice or advanced based on experience with using metacognition. Kramarksi and Dudai (2009) reported high use of metacognitive knowledge and evaluating among novice learners. Mevarech and Amrany (2008) cited minimal differences in metacognitive knowledge between novice and advanced learners. In particular, metacognitive strategic knowledge (i.e., self-regulated learning strategies) did not differ greatly between novice and advanced individuals. The researchers showed that knowledge of cognition did not necessarily ensure learners' regulation of cognition. Therefore, metacognitive knowledge was considered a novice component (See p. 17).

Novice learners in particular show signs of flawed performance in evaluating (e.g., Erickson & Heit, 2015; Teeuwen & Salinitri, 2019); accurate evaluating would be necessary for the implementation of effective planning and monitoring. Metacognitive planning was chosen next for its support in the efficient use of cognitive resources (Kramarski & Friedman, 2014; Teeuwen & Salinitri, 2019). Considering the demand of metacognitive monitoring as an advanced skill (e.g., Hessel-Schlatter et al., 2017), such efficiency reduces cognitive load during the development of monitoring (e.g., Teeuwen & Salinitri, 2019). Metacognitive debugging requires metacognitive monitoring (Schraw & Dennison, 1994), consequently debugging was scaffolded alongside metacognitive monitoring. Finally, with metacognition sufficiently developed through the previous scaffolding, individuals are prepared to potentially transfer metacognitive strategies and metacognitive regulation (i.e., planning, monitoring, and debugging) into other domains (Veenman et al., 2006). Burger (2009) showed that a metacognitive intervention which was reflective in nature facilitates transfer. Therefore, the transfer of metacognition, being the focal point of the students' final attention, is poised for the most optimal (i.e., far/delayed/novel) transfer of strategic knowledge and of the planning, monitoring, and debugging components of metacognitive regulation.

The conclusions of Teeuwen and Salinitri (2019) were adapted to the present study; metacognition was instructed in five stages:

1. developing metacognitive strategic knowledge through dialogic discussions with peers and instructors;
2. calibrating metacognitive evaluating through personal use of metacognitive prompts;
3. developing all components of metacognition through the reception of metacognitive prompts from others;
4. developing monitoring through use of prompts for personal and peer development;
5. extending metacognitive practice to new contexts during recurrent transfer reflections throughout the process.

This method employs a dialogic practice and each activity explicitly focuses learners' attention to the aforementioned metacognitive components through an instructors' use of corresponding prompts. Therefore, the prompt categories are scaffolded in the following order: comprehension, reflection (evaluating), connection, strategy and reflection (debugging), and transfer.

Measuring metacognition, self-regulation, and self-regulated learning

Metacognition. Quantitative assessments of metacognition such as Schraw and Dennison's (1994) Metacognitive Awareness Inventory (MAI) were only substantiated for general metacognitive knowledge and regulation (Harrison & Vallin, 2018; Pintrich et al., 2000; Schraw & Dennison, 1994). A more comprehensive instrument such as the Metacognitive Questionnaire, or MQ (Scott & Berman, 2013), offer an assessment of the collective eight components of metacognitive knowledge and regulation. The self-reporting MQ (Scott & Berman, 2013) provides a large-scale measure of metacognition in a retrospective context; retrospective assessments of metacognition were examined by Panadero, Klug, and Järvelä (2015). Unfortunately, despite numerous attempts to contact the authors of the MQ (i.e., Scott & Berman, 2013), the full metacognitive questionnaire could not be gathered in its entirety and therefore could not be repeated. Because previous researchers used the MAI to assess a post-secondary population for metacognitive improvements using the IMPROVE model (i.e., Mevarech & Fridkin, 2006), the Metacognitive Awareness Inventory was used in the quantitative assessment of all metacognition components.

Most "online" (i.e., live) instruments for measuring metacognition require extensive interviews with individual participants, providing in-depth analysis into metacognitive behaviour (Pintrich et. al., 2000). An interview based on the MAI, with the addition of transfer-related questions, creates space for continued questioning until answers are clear (Helms-Lorenz, & Jacobse, 2008). Typical for the measurement of metacognition are "think-aloud protocols" (Pintrich et al., 2000) and "systematic observations" (Akturk & Sahin, 2011). These are helpful with small groups or in laboratory conditions, however not as feasible with large groups (Pintrich et al., 2000; Akturk & Sahin, 2011). Veenman, Kerseboom and Imthorn (2000) developed a systematic method for observing think-aloud protocols. It was "proven to be reliable, less time consuming and laborious than the usage of full protocol analysis" (Helms-Lorenz & Jacobse, 2008, p. 21).

Following what was common for a think-aloud protocol, Kramarski and Friedman (2014) coded statements made by participants into cognitive (i.e., rehearsal processes, calculations, drawing simple conclusions, and formulas) and metacognitive (i.e., forethought, action, and evaluation/reflection) categories. Such categories were then quantified by frequency, providing researchers (e.g., Kramarksi & Friedman, 2014) with the opportunity to statistically derive conclusions. Akturk & Sahin (2011) identified two difficulties with online, think-aloud protocols and systematic observations: 1) the burden placed on students to express metacognition verbally while solving problems, and 2) the difficulty in observing authentic behaviour in a classroom setting. As a result, think-aloud protocols were considered similar to surveys in their assessment of metacognitive components as "traits," and therefore, required relevant contextual considerations in order to identify changes resulting from interventions (Panadero et al., 2015; Samuelstuen & Bråten, 2007).

Since a deep analysis of qualitative data was desired, a thematic analysis was considered. Thematic analysis allows for the natural emergence of a theme based on the available data (Braun & Clarke, 2006). Similar to think-aloud protocols, this method minimizes the solicitation of behaviour and is less time-consuming but also offers the opportunity to capture dialogic reflective practices between participants, with detail. The power and resolution of qualitative analyses when assessing metacognition are argued to be favourable by several researchers with respect to the use of online measures of metacognition (e.g., Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009), particularly when observing social metacognition (e.g., Mevarech & Amrany, 2008). Consequently, thematic analysis of recorded data was the preferred method for assessing metacognition qualitatively.

Self-regulation. Quantitative assessment techniques measuring self-regulation as an isolated construct only exist within the context of self-regulated learning (Pintrich et. al., 2000). Therefore, self-regulation was not measured on its own but instead was considered while assessing the results of self-regulated learning.

Self-regulated learning. Several self-reporting survey instruments were constructed for measuring self-regulated learning. The Learning and Study Skills Inventory or LASSI (Weinstein, Zimmerman, & Palmer, 1988) is a retrospective survey that uses norms for assessing metacognition and self-regulated learning, assuming a domain-general perspective (Pintrich et al., 2000). Its two prominent alternatives, the Motivated Strategies for Learning

Questionnaire, or MSLQ (Pintrich, Smith, Garcia, & McKeachie, 1993), and the Self-Regulated Learning Interview Schedule, or SRLIS (Zimmerman & Martinez-Pons, 1986; 1988), assume variations based on school, task, situation, or context; in other words, MSLQ and SRLIS assume a domain-specific perspective (Pintrich et al., 2000).

Were this study focused on the assessment of general metacognition and self-regulated learning, LASSI would have been used as a self-reporting method to assess self-regulated learning. “Online” measures of self-regulated learning focused on active behaviours, including think-aloud protocols, traces, and interviews (Panadero et al., 2015). These are more objective measures of self-regulated learning as they are designed with protocols to ensure that questions do not solicit self-regulation, resulting in valid, reliable online measures (Karoly, Boekarts, & Maes, 2005).

A most recent method of measuring self-regulated learning involves combining the assessment with the intervention in the form of learning diaries (e.g., Schmitz and Perels, 2011). The learning diary is used by the student to plan actions beforehand (prospective) as well as reflect on the learning process (retrospective), which in turn serves to improve the students’ metacognitive and self-regulatory practices (Panadero et al., 2015). Panadero et. al. (2015) illustrated the importance of embedding the self-regulatory cycle into a diary (i.e., reflective) process in order to promote self-regulated learning.

Selecting qualitative and quantitative measures. A great deal of the measurement of metacognition, self-regulation, and self-regulated learning in previous research relied on self-report measurements and Likert-scale instruments without corroborating or collaborating with participants on their actual thought processes (Dinsmore et al., 2008; Winne & Perry, 2000). Self-report methods are not always reliable due to students’ inaccuracies in their perceptions during such reporting (Panadero et al., 2015). Harrison and Vallin (2018) reported during their analysis of the literature on measuring metacognition that “self-report questionnaires are the most controversial class of instruments” (p. 16), citing issues pertaining to validity of scores. Further, these surveys assess these constructs as “traits,” and may not reflect changes in interventions unless tailored to the relevant contexts (Panadero et al., 2015; Samuelstuen, & Bråten, 2007).

Mevarech and Fridkin’s (2006) study tested the IMPROVE model with college students studying mathematics and assessed them with Schraw and Dennison’s (1994) Metacognitive Awareness Inventory (MAI). After the intervention, the students who received the intervention when compared with the control group showed statistically significant differences in all metacognitive components, including general metacognitive knowledge and regulation. Consequently, despite the aforementioned limitations of self-report measures, the MAI was used in this study to compare results with those previously conducted by Mevarech and Fridkin (2006) in order to corroborate coherence of the implementation of the IMPROVE model.

Recall, this study is focused on the transfer of general metacognition and self-regulated learning. Given that LASSI has been shown to measure improvement in general self-regulated learning for students exposed to the IMPROVE model (e.g., Mevarech & Kramarski, 2014), self-regulated learning will not be quantitatively assessed in this study. Considering the time constraints of the educational course (See *Learning context*, p. 63), the diary process recommended by Schmitz and Perels (2011) was supplemented with a dialogic reflective practice during recurrent laboratory sessions; this practice was directed equally by instructors towards prospective and retrospective metacognition (Panadero et al., 2015).

As Pintrich et al. (2000) summarize, “there is no one ‘perfect’ measure of metacognition” (p. 88). The quantitative methods (i.e., self-report methods) are not always as accurate; however qualitative, online measures of metacognition are more objective. Each form provides complementary advantages. While qualitative, online measures are labour and time-intense, they are corroborated by larger-scale quantitative measures which provide broad information about the impact of the intervention. Lastly, quantitative methods provide retrospective views of metacognition while the qualitative interview methods provide both retrospective and prospective views.

As a result, a combination of both quantitative and qualitative data was collected for assessing metacognition: the MAI (Schraw & Dennison, 1994) was used for quantitative assessment of metacognition, and thematic analysis (Braun & Clarke, 2006) was used for qualitative data to assess metacognition and self-regulated learning. Qualitative data included recordings of live discussions of the participants to observe authentic behaviour in a classroom setting (Akturk & Sahin, 2011) and a semi-structured post-intervention interview, adapted from the MAI, to facilitate clarity in understanding participants’ answers (Helms-Lorenz & Jacobse, 2008). Additional questions were incorporated into the interview to explore and assess participants’ transfer of metacognitive knowledge and regulation.

Domain-specific domain-general metacognition. Inspection of previous research revealed conflicting evidence over the past four decades concerning the general (e.g., Schraw, 2001; Veenman, et al., 2006) or domain-specific (e.g., Kelemen et al., 2000) nature of metacognition. Domain-specific components of metacognition are important as they form part of the subject-specific content, while general components of metacognition may be cross-disciplinary, and therefore could be instructed by teachers of all subjects.

Neuenhaus, Artelt, Lingel, and Schneider (2011) observed the domain-generality of metacognitive knowledge in fifth grade students. They characterized metacognitive knowledge as person, task, and strategy. Strategic knowledge was further subcategorized as per the work of Paris, Lipson and Wixson (1983): specific strategy knowledge, relational, and general metacognitive knowledge. Neuenhaus et al. (2011) confirmed the taxonomic model Borkowski, Chan and Muthukrishna (2000) described in their work: that specific strategic knowledge is necessary to develop relational and subsequently general metacognitive knowledge, and that this general performance can be achieved with practice. This aligns with other studies affirming the domain-general nature of metacognitive strategic knowledge (Anthony, 2015; Callan, Marchant, Finch, & German, 2016; Schneider, Lingel, Artelt, & Neuenhaus, 2017).

Regarding metacognitive knowledge for all three categories of person, task, and strategy, van Velzen (2016) conducted three studies in order to identify properties regarding general knowledge of the learning process (GKLP). The first study showed three levels of understanding (absent, implicit, and explicit). During the second study, students were able to be successfully taught GKLP within a classroom context demonstrating the capacity for GKLP to be taught within any subject area. The third study demonstrated students' explanations were either obvious or revealed criterion the students had in mind for intended effects.

van Velzen (2016) then argued for a process of instruction for general knowledge of the learning process (GKLP): learning situations that created learning experiences, where students are provided explicit instruction of general metacognitive knowledge (i.e., developing cognitive knowledge; learning-task demands, and of self as a learner). This explicit attention, van Velzen argued, is required to bring tacit knowledge of the learning process into the learner's retention.

Therefore, it is arguable that domain-specific components of metacognitive knowledge (i.e., person, task, and strategy) may exist alongside general processing counterparts.

This general knowledge of learning resembles the knowledge components of self-regulated learning (SRL) (i.e., metacognition within the domain of learning). SRL was also reported as general across domains, specifically the motivation and learning strategies components (Argyropoulos, Sideridis, Botsas, & Padeliadu, 2012; Rotgans & Schmidt, 2009). The task and person components of metacognitive knowledge in self-regulated learning differ with respect to task, content, and features that are individual to persons (e.g., Alexander, Dinsmore, Parkinson, & Winters, 2011). Given the similarity of self-regulated learning with GKLP, this conflicts with the findings of van Velzen (2016), revealing a gap within the literature regarding the identification of domain-general metacognitive person and task knowledge.

Schraw (2001) argued for the general nature of both metacognitive knowledge (i.e., strategic knowledge) and regulation (i.e., planning, monitoring, and evaluating). He argued that while learners acquire metacognitive knowledge in multiple domains, students may also develop general metacognitive regulatory skills, as well as general metacognitive knowledge. Schraw also argued for general metacognitive knowledge possibly compensating for low ability or lack of relevant knowledge. Recently, Scott and Berman (2013) conducted a study to assess metacognitive knowledge (i.e., strategic knowledge), regulation (i.e., planning, monitoring, debugging, and information managing) and accuracy (i.e., evaluating) across several domains, including: chemistry, biology, astronomy, history, and education. They concluded that metacognitive accuracy (i.e., evaluating) was domain-specific based on interest and perceptions of difficulty. They also concluded that metacognitive regulation was found to be domain-general.

A limitation of the research was an analysis of the same individuals across various domains – if similar performances of metacognition were shown to be equally level across domains, an argument could be made in support of domain-generality, (Scott & Berman, 2013). It should be noted that Scott and Berman (2013) referred to metacognitive knowledge as metacognitive strategic knowledge, with no assessment regarding person or task. Therefore, Scott and Berman concluded that metacognitive strategic knowledge and metacognitive regulation (i.e., planning, monitoring, debugging, and information managing) were domain-general while metacognitive evaluating was domain-specific.

Table 5

Literature Summary for Domain-General and -Specific Metacognitive Components

	Domain-General	**Domain-Specific**
Metacognitive Knowledge	Neuenhaus et al., 2011;	
Personal	van Velzen (2016)[1]	Alexander et al., 2011[2]
Task	van Velzen (2016)[1]	Alexander et al., 2011[2]
Strategic	Anthony, 2015; Borkowski et al., 2000; Callan et al., 2016; Neuenhaus et al., 2011; Schneider et al., 2017; Scott & Berman, 2013; Schraw, 2001 van Velzen (2016)[1] Argyropoulos et al., 2012[2]; Rotgans & Schmidt, 2009[2]	
Metacognitive Regulation	Van der Stel & Veenman, 2014;	
Planning	Scott & Berman, 2013; Schraw, 2001	
Monitoring	Gutierrez et al., 2016; Scott & Berman, 2013	
Information Managing	Scott & Berman, 2013	
Debugging	Scott & Berman, 2013	
Evaluating	Schraw, 2001	Erickson & Heit, 2015; Scott & Berman, 2013; Vo, Li, Kornell, Pouget & Cantlon, 2014; Winne & Muis, 2011

Note. [1] = research focused on general knowledge of the learning process (GKLP); [2] = research focused on self-regulated learning (i.e., metacognition applied to the domain of learning).

These findings are supported by other researchers, summarized in Table *5* above. Metacognitive strategic knowledge was shown to be domain-general (e.g., Callan et al., 2016; Schneider et al., 2017). Metacognitive regulation was specifically examined for its generality by Van der Stel and Veenman (2014) who concluded that part of metacognitive regulation appeared to be general, and part appeared to be domain-specific, although they were not able to distinguish which components. Metacognitive skillfulness (i.e., metacognitive regulation) developed from specific to general across domains gradually (Van der Stel & Veenman, 2008; Van der Stel & Veenman, 2014). Metacognitive monitoring was identified as domain-general by Gutierrez, Schraw, Kuch, and Richmond during their (2016) study. Calibration (i.e., metacognitive evaluation) however, was identified as domain-specific, showing distinctions in performance (e.g., overconfidence) in math over other subjects (Erickson & Heit, 2015, Winne & Muis, 2011; Vo et al., 2014).

Overall, components of metacognition are considered as domain-general or domain-specific. Given the agreement found in the literature, metacognitive regulation (i.e., planning, monitoring, debugging, and information managing) and metacognitive strategic knowledge, or any related construct (i.e., self-regulation, self-regulated learning), are considered domain-general. Inspection of the literature indicated agreement regarding the domain-specific nature of metacognitive evaluation. While metacognitive personal and task knowledge are interpreted as domain-specific (e.g., Alexander et al., 2011), any type of metacognitive knowledge related to general knowledge of the learning process (GKLP) is considered as domain-general (e.g., van Velzen, 2016). Insight into the potentially transferrable metacognitive personal and task knowledge would contribute to the literature on domain-generality of metacognition.

Transfer. An important consideration in the formation of the research questions was the interpretation of the term, “transfer”. “Learning” was identified as applying knowledge or skills into a situation equivalent to the context of instruction; “transfer” was identified as the application of knowledge or skills into a situation considered as “different” from the context of instruction (Salomon & Perkins, 1989).

Salomon and Perkins’ (1989) exploration into the mechanisms of transfer was used as the basis for the present framework regarding transfer. Salomon and Perkins considered two characteristics of transfer: item and method. Regarding the item of transfer, Salomon and Perkins noted that this can broadly be described as knowledge and/or skill. With respect to metacognition, this could be metacognitive knowledge (i.e., person, task, or strategy), metacognitive regulation (i.e., metacognitive planning, monitoring, debugging, and information managing, and evaluating), or some combination of both.

Salomon and Perkins (1989) created two broad distinctions for their framework of transfer regarding the method employed: amount and distance of transfer. The amount of transfer could be determined through an assessment of an observed difference on performance. Distinctions of a similar manner are presently being operationalized (e.g., Carpenter, 2012). Using these distinctions, transfer distance was subdivided into three categories:

- Time, divided into immediate effects and delayed effects;
- Context, divided into near (i.e., similar) and far (i.e., distant) contexts; and
- Exposure, divided into routine (i.e., familiar) and novel (i.e., new) contexts.

A graphic denoting these distinctions of transfer is included in *Figure 5* below.

As noted by Salomon and Perkins (1989), determinations of ‘similarity’ and ‘relatedness’ are subjective to the individuals making the claim. In the present research, similarity was based on comparison of the new domain to that of mathematics. Consequently, domains were considered as near-transfer if the new context was the course of study (i.e., the calculus course) or a context which was fundamentally mathematical or problem-solving in nature. Domains were considered as far-transfer if the new context was distinct from the course of study (i.e., it was not mathematical or problem-solving in nature).

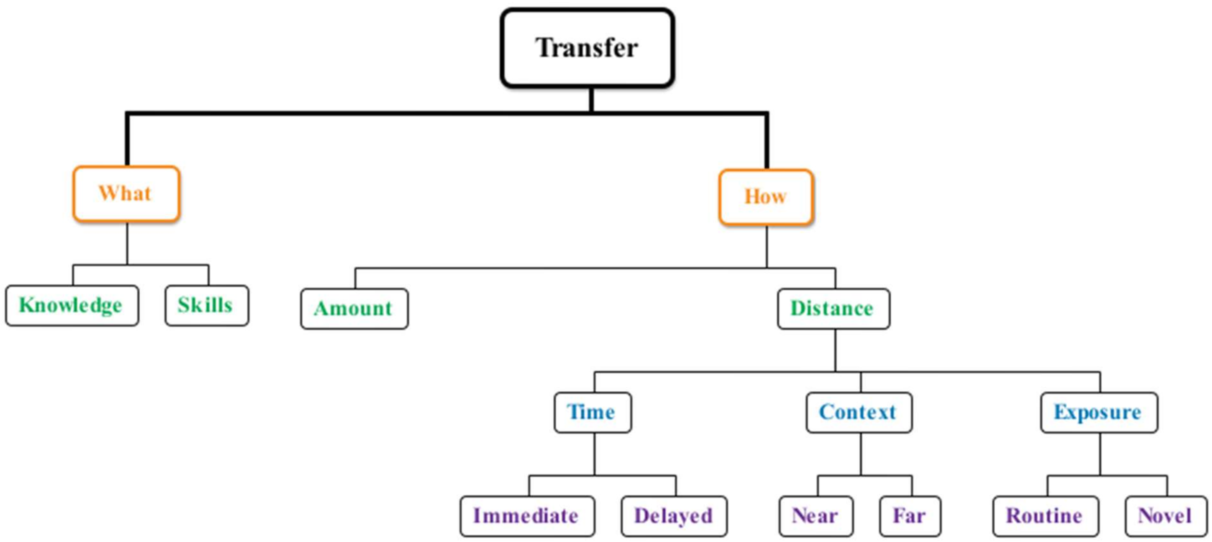


Figure 5. Framework for transfer, based on Salomon and Perkins (1989).

Salomon and Perkins (1989) identified the difference between what they termed as 'low-road' (i.e., near, and routine) and 'high-road' transfer (i.e., far, and novel). According to the researchers, low-road transfer results from extensive practice, is stimulus controlled, and is automatic in nature. High-road transfer results from mindful abstraction – either in anticipation of a future problem or in retrospection while solving a present problem. A breakdown of low-road and high-road transfer is included in Table *6* below.

Table 6
Comparing Low-Road and High-Road Transfer

	Low-Road (i.e., near, and routine)	**High-Road (i.e., far, and novel)**
Results From	• extensive practice • stimulus-controlled environments • automaticity	• *mindful*: attentive and intentional understanding • *abstraction*: a representation or method of summarizing fundamental properties
Properties	• varied practice results in general transfer • "short-circuits the link between situation…and behaviour" (p. 121) • near-transfer is a predictable outcome • may inhibit high-road transfer	• benefits from metacognitive guidance • recommended to follow active learning • focus may reduce 'learning' (i.e., no context-shift) • *requires implementation*: using the model in practice* • *requires proliferation*: successful transfer to a new/other system*
Recommended For	• socialization and acculturation • cognitive experiences, unintentional performance • implicit knowledge • knowledge based on a model driven by reinforcement	• distant transfer *(*i.e., forward- and backward-reaching) • *Forward-reaching:* projection to a future context while in original context • *Backward-reaching*: recollection from original to transfer context

Note. Based on (Salomon & Perkins, 1989); * = recommendations were based on work from Tuomi-Gröhn and Engeström (2003).

Salomon and Perkins (1989) argued that the more varied the practice, the more general a low-road transfer knowledge or skill could be applied. This type of transfer, by the nature of its automaticity, "short circuits the link between situation … and behaviour" (Salomon & Perkins, 1989, p. 121). They concluded that teaching towards the development of low-road transfer would inhibit high road transfer, making it resistant to analysis. However, they also predicted that analysis could be encouraged while practicing the automatic knowledge/skill in a context of great difficulty where completion is desired. They predicted that socialization and acculturation processes, cognitive experiences, unintentional performance, implicit knowledge, or knowledge based on a model and driven by reinforcement, would benefit most from this implicit form of instruction. They concluded that near transfer would be a predictable outcome from instruction facilitated towards low-road transfer, however the amount (i.e., the impact on performance) they predicted would increase.

Salomon and Perkins (1989) identified the central components of high-road transfer as being rooted in mindful abstraction, a "highly constructive act of (the) mind" (p. 138). Mindfulness was characterized as an attentive and intentional understanding, and abstraction as the bridge between the contexts. An abstraction could be a representation or a method of summarizing fundamental properties of a thought or idea. Overall, metacognitive guidance was cited as appearing "to play a major role" (Salomon & Perkins, 1989, p. 126) in mindful abstraction, vital to the development of high-road transfer. This supported the domain-general approach to metacognition for metacognitive regulation and strategic knowledge as argued above. The development of high-road transfer was recommended to follow active learning, where the participants discover their own abstractions, which would far exceed passive instruction in terms of distance of transfer. Current research in metacognition confirms the need for explicit instruction of such advanced skills (Wedelin et al., 2015; Van der Stel & Veenman, 2014).

Salomon and Perkins (1989) predicted high-road transfer facilitating the most distant transfer, either by projection to a future context while in learning (forward-reaching) or by recollection from an original context while situated in the transfer context (backward-reaching). They did caution, however, that a reduction in learning may result from a focus on high-road transfer. Considering this interrelationship between metacognitive guidance and transfer, studies which focus on methods of high-road transfer might achieve the furthest distance of transfer.

Salomon and Perkins (1989) acknowledge that both methods of transfer (low-road and high-road) could be instructed simultaneously through reflection and practice of a behaviour. They recommended an emphasis on constructing vocabulary and directing mindfulness towards the activity to enhance transfer.

Tuomi-Gröhn and Engeström (2003) advocated for their model of expansive learning and developmental transfer to achieve new forms in other contexts. Expansive learning begins when some individuals question existing practices of a collective activity. From this questioning emerges analysis, modeling, examination, implementation, consolidation and proliferation, and finally evaluation. An inspection of this process yielded similarity to many of the processes of metacognitive regulation itself (i.e., planning, monitoring, debugging, and evaluating), therefore one can conclude that as one develops metacognitive regulation, one would also develop transference of learning into other contexts (i.e., far-transfer). Because Tuomi-Gröhn & Engeström's learning process does not require a task as a given, it facilitates the most applicable form of learning for transfer to the furthest distance. Just like Salomon and Perkins (1989), Tuomi-Gröhn, and Engeström (2003) also viewed abstraction as a combined process of modeling from past knowledge, as well as constructing models for future use. This re-affirmed the emphasis of abstraction resulting in transfer to new contexts. Both theories therefore affirmed that metacognition, instructed through mindful abstraction, is well-positioned to facilitate the transfer of metacognitive knowledge/regulation to other domains.

Lastly, Tuomi-Gröhn, and Engeström (2003) argued for two critical actions to facilitate transfer: implementation (i.e., using the model in practice) and proliferation (i.e., successful transfer of insights and methods into other systems/organizations). Thus, they argued that learning by this method of transfer takes "what is learned in schools to be used in situations outside school" (Tuomi-Gröhn & Engeström, 2003, p. 33), emphasizing the power of individuals to develop and change where they apply learned principles. Consequently, the application of metacognition is argued to be of chief importance as an educational objective inclusive beyond metacognitive knowledge (Anderson & Krathwohl, 2001; Fogarty, 2009) to also incorporate metacognitive regulation.

Investigation of Literature on Transfer of Metacognition from Mathematics

Methodology. A literature review was conducted to investigate the effect and amount of transfer of general metacognition from mathematics into a different domain. Due to often-cited 'imperfection' in the measurement of metacognition (Pintrich et al., 2000), quantitative and qualitative data were combined to create a more complete picture of metacognition. Kastner et al. (2012) summarized various systematic literature reviews and their appropriate uses depending on the nature of the research question. A mixed studies review (Johnson-Lafleur, 2009 & Pluye, Gagnon, Griffiths) delivers greater comprehension than utilizing a single method of research due to the simultaneous examination of quantitative, qualitative and mixed methods studies. Its systematic approach facilitates thoroughly narrowing the search for studies. The "fuzzy" (Flavell, 1981) nature of metacognition, and the shifting nature of self-regulated learning (Dinsmore et al., 2008) both call for as much narrowing as possible. It was concluded that a systematic approach accomplishes this goal, while simultaneously minimizing potential loss of findings during the search.

Method. Pluye et al. (2016) identified 8 stages by which to conduct a mixed studies literature review, as indicated in Table *7* below. These stages were followed sequentially, as per the guide provided by Pluye et al. (2016).

Table 7
Stages of Mixed Studies Reviews

Stage	Description
1	Formulate a review question
2	Define eligibility criteria
3	Sources of information
4	Identify potential relevant studies
5	Select relevant studies
6	Appraise the quality of studies
7	Extract Data
8	Synthesize included studies

Note. Adapted from *Toolkit for mixed studies reviews (V3)*, by P. Pluye, Q.N. Hong, and I. Vedel, 2016, Montreal: Department of Family Medicine, McGill University and Quebec-SPOR Support Unit. Retrieved from http://toolkit4mixedstudiesreviews.pbworks.com.

Following recommendations for the quantitative (Pluye et al., 2016) and qualitative (Cooke, Smith & Booth, 2012) research questions, the following (respectively) were used for the systematic literature review:

- Do metacognitive interventions in mathematics targeting post-secondary students significantly transfer their general metacognitive ability into a different domain?; and
- How do metacognitive interventions in mathematics affect post-secondary students' learning experiences outside of the course of study?

Exclusion criteria. Exclusion criteria were created after reviewing enough articles that terms could conclusively be used without losing essential data from the report (Pluye et al., 2016). Typically, articles were excluded based on their membership to a number of commonly occurring categories. Any findings relating to the topics of: reading, literacy education, studies which focused exclusively on populations with disabilities, or studies which examined interventions delivered through technological means, were excluded. Eventually the term, "college", was supplemented with only "college student" as it removed unrelated findings without losing any articles which would later become "shortlisted". Most commonly, the definitions of “metacognition”, “self-regulation”, and “self-regulated learning” were carefully examined in each paper to determine their associated relevance with the present study of general metacognitive ability. Finally, articles were excluded if they were not peer-reviewed. This included book chapters, graduate theses, and articles submitted to conference proceedings.

Inclusion criteria. Articles were selected for analysis based on their satisfaction of two criterion: their assessment of the effect of an intervention focused on a component of general metacognitive ability, and whether transfer of any type was discovered for one of these components. A summary of the articles’ characteristics was included in *Table 8* (p. 46).

As a result of the aforementioned debate regarding metacognition’s domain-generality, components of metacognition were considered domain-general or domain-specific during the literature search. To be clear, any study which included metacognitive regulation (i.e., planning, monitoring, debugging, and information managing), metacognitive strategic knowledge, or any related construct (i.e., self-regulation, self-regulated learning) satisfied the selection criterion for ‘metacognition’ within the parameters of this literature search. Due to the nature of domain-specificity, components which are identified as specific to their domain (i.e., metacognitive person and task knowledge as well as metacognitive evaluating) were not included in the search for transference of metacognition.

During the systematic literature review, distance of transfer was acknowledged within each examined study uniquely. For example, a topic introduced in one area of mathematics (i.e., probability) and assessed in a related field (i.e., graphing) was considered as far- and novel-transfer because of the change in format delivery from a group-activity to a test. Far-transfer also included studies where the measurement of metacognition was in a domain that was distant from the domain in which the intervention was introduced (e.g., transferred to a domain not mathematical or problem-solving in nature). In summation, distance of transfer during the systematic literature review was considered uniquely to the context of each study.

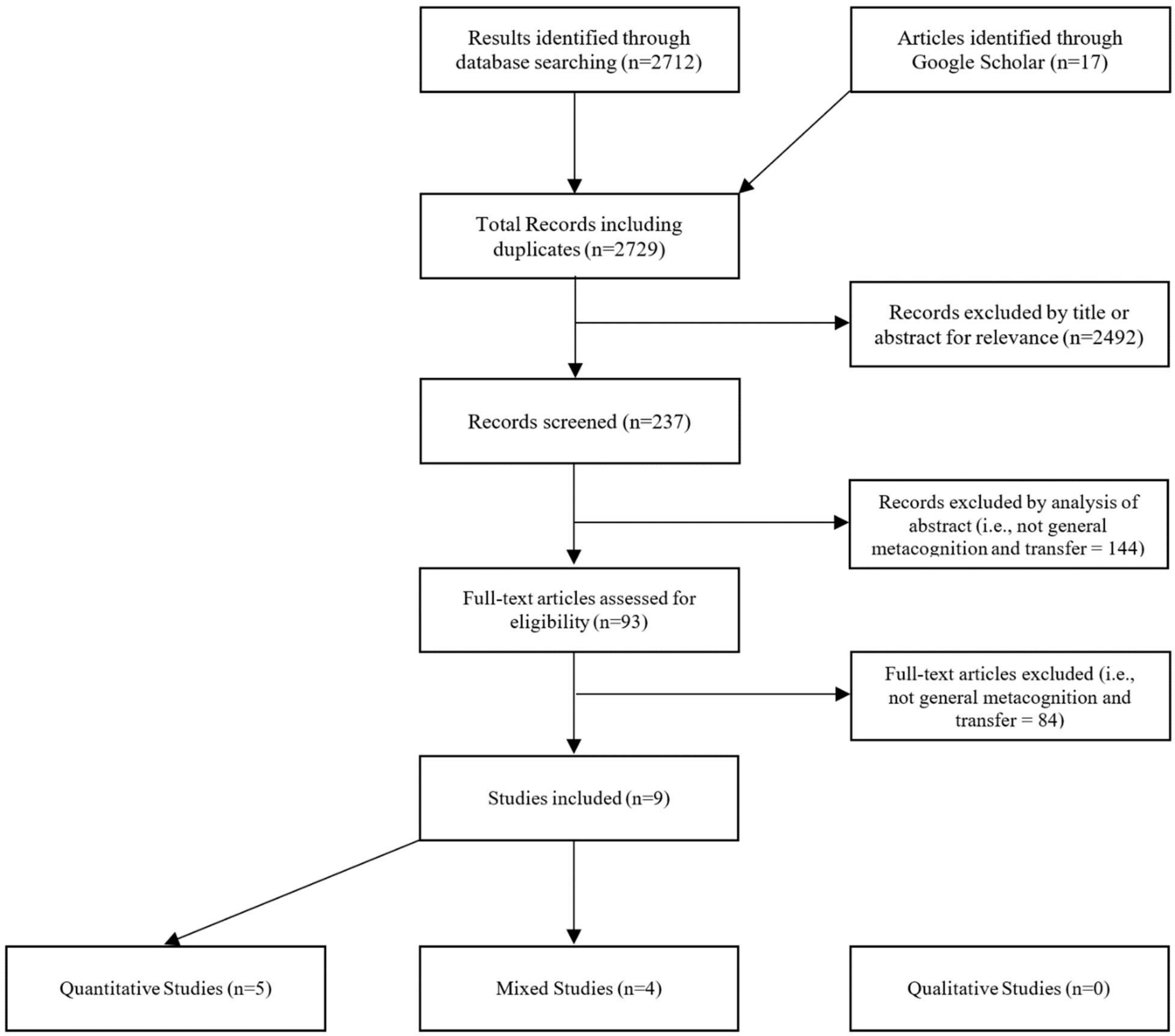


Figure 6. Flow chart for screening process of literature search.

Results. A mixed-studies systematic literature review was conducted according to the recommendations of Pluye et al. (2016). A total of 2729 articles were discovered using the search terms, of which nine matched the inclusion criterion; characteristics of these results are included in *Table 8* below. All final studies were required to fulfill the methodological assessment standards prescribed by the Mixed Methods Appraisal Tool, or MMAT (Pluye et al., 2011). A flow chart tracking the screening process is shown in *Figure 6* above.

Table 8
Characteristics of Included Studies for Systematic Literature Review

Authors of Included Studies	Metacognition			Self-Regulation		Transfer			Domain		Age		Method		
	Metacognitive Knowledge	Metacognitive Regulation	Cognitive Monitoring	Cognitive Self-Regulation	Self-Regulated Learning	Near/Far	Immediate/Delayed	Related/Novel	General	Specific	<18	>18	Qualitative	Quantitative	Mixed
Belenky and Nokes (2009)	✓	✓						✓		✓		✓		✓	
Chi and VanLehn (2010)	✓	✓	✓			✓		✓	✓			✓		✓	
Hessels-Schlatter, Hessels, Godin, and Spillmann-Rojas (2017)			✓		✓			✓	✓		✓				✓
Kapa (2007)			✓			✓				✓	✓			✓	
Kramarski and Dudai (2009)	✓	✓	✓		✓	✓		✓	✓		✓			✓	
Kramarski and Friedman (2014)		✓	✓				✓			✓	✓				✓
Kramarski, Weiss, and Sharon (2013)		✓	✓	✓		✓	✓				✓			✓	
Mevarech and Amrany (2008)			✓			✓	✓	✓		✓	✓				✓
Tajika, Nakatsu, Nozaki, Neumann, and Maruno (2007)		✓	✓			✓				✓	✓				✓

Articles were selected using the inclusion criteria if their assessment of the effect of an intervention focused on a component of general metacognitive ability and if transfer of any type was discovered for one of these components. After using these inclusion criteria, only nine articles resulted from the search. It should be noted that, due to the low number of findings on this topic, papers were included regardless of the age of the participants. A summary of the characteristics of the studies discovered is included in *Table 8* above. An examination of a significant effect of the transfer of metacognitive knowledge and regulation to a domain from mathematics in post-secondary students was not found. As a result of the findings from this literature review, it was concluded that the transfer of metacognition (i.e., metacognitive strategic knowledge, metacognitive planning, monitoring, and debugging components of metacognitive regulation) may be possible to other domains from mathematics if one adhered to the recommendations of the included studies.

Discussion. No one particular study completely answered either research question; this demonstrated gaps in the literature. Specifically, an examination of a significant effect of the transfer of metacognitive knowledge and regulation to a domain from mathematics in post-secondary students was not found. Few studies also examined students' learning experiences after participating in metacognitive interventions in mathematics with qualitative data. The majority of studies examined metacognition through codified trace data or frequency count. Despite neither literature search question being answered explicitly, several themes emerged from an analysis of the findings of this literature review. The findings were discussed first according to type of data collected (i.e., quantitative, then qualitative). Global themes were identified and discussed regarding metacognitive knowledge and regulation. Finally, gaps in the literature were identified.

A cursory examination of the findings revealed a dominance of quantitative data in the studies conducted on metacognitive interventions beginning in mathematics. This was not surprising, given the framework of mathematics education can be argued to lend itself naturally towards quantitative reasoning. The quantitative data collected involved the use of self-report questionnaires for assessing metacognition and/or self-regulated learning (i.e., Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008). These studies, which included self-report questionnaires in their analysis, aptly recognized the limitation of a self-report questionnaire possibly measuring students' perceptions of their metacognitive abilities as opposed to objectively assessing metacognitive capacities. From this data, it can be concluded that metacognitive interventions in mathematics positively affect some components of students' perceptions of their metacognitive abilities.

Four (i.e., Hessels-Schlatter et al. 2017; Kramarski & Friedman, 2014; Mevarech & Amrany, 2008; Tajika et al., 2007) of the studies in the findings completed an analysis by theme of qualitative data. The study by Kramarski and Friedman (2014), and the Mevarech and Amrany (2008) study both included thorough sample presentations of their qualitative data in addition to their analysis. It was from these samples of qualitative data that rich understanding of the impacts of metacognitive interventions was observed. Perhaps the most salient example was that provided by Mevarech and Amrany (2008). The findings of the study showed a brief conversation between students within the control group reflecting themes of limited understanding, monitoring, planning, and evaluating; the example provided by the metacognition intervention demonstrated multiple instances of social metacognition (i.e., re-evaluating, monitoring, and planning appropriate methods to take while solving the problems). Examples such as this one demonstrated the power and resolution of qualitative analyses when assessing metacognition, strengthening the argument made by several researchers included in the findings of this literature review of the importance of online measures of metacognition (e.g., Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009).

Interestingly, even the studies which examined qualitative data through mixed methods (i.e., Hessels-Schlatter et al. 2017; Kramarski & Friedman, 2014; Mevarech & Amrany, 2008; Tajika et al., 2007) employed some form of quantitative analysis of such fine-grain data. The majority of studies found assessed metacognitive performance on tasks, often through frequency counts of codified trace data or interviews (i.e., Belenky & Nokes, 2009; Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008; Tajika et al., 2007). Occasionally, the researchers themselves acknowledged the limitations of assessing metacognition through offline measures and emphasized the importance of online measures collected through the analysis of qualitative data (i.e., Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009). As noted by several researchers (e.g., Dinsmore et al., 2008; Pintrich et al., 2000; Winne & Perry, 2000), a combination of "online" (e.g., think-alouds or interviews) and "offline" (e.g., self-report) measures are recommended for a thorough assessment of metacognition and self-regulated learning. Therefore, it is recommended from this literature review that future studies in metacognition employ such a combination of online and offline measures.

Only two studies examined the population of interest – students enrolled in post-secondary education (i.e., Belenky & Nokes, 2009; Chi & VanLehn, 2010). Belenky and Nokes (2009) demonstrated that metacognitive prompting positively impacted procedural use of skills (i.e., regulation of cognition) in new contexts. Chi and VanLehn (2010) concluded that low-performing students demonstrated the most improvement in achievement and procedural use of desired steps across science domains (i.e., from probability to physics) resulting from a metacognitive intervention (i.e., regulation of cognition). They also demonstrated that high performing students were able to successfully transfer a target variable strategy while low-performing students were able to transfer a principle-emphasis strategy (i.e., strategic knowledge of cognition). The remaining findings from the literature search examined metacognition from a developmental perspective, with many of the findings focused on youth aged 7 to 16. Adults may already possess a base for metacognitive knowledge and are usually able to regulate their thoughts (Schraw, 2001), thus it could be argued that there may not be as much interest by researchers to examine metacognition of post-secondary students. However, McCabe (2011) demonstrated that this plateau of development may not always be the case for undergraduates, where one can expect measurable impacts from an intervention which targets metacognitive ability (Young & Fry, 2008). Therefore, it can be concluded that this systematic literature review revealed a gap within the literature; a need for increased depth of research was identified for the successful transfer of metacognition (i.e., knowledge and regulation of cognition) to other domains for undergraduates with metacognitive interventions beginning in mathematics.

Metacognitive strategic knowledge. Studies which examined metacognitive knowledge demonstrated that some components of metacognitive knowledge may not transfer to any context (e.g., Belenky & Nokes, 2009), in part due to the possibility that metacognitive knowledge may already be acquired by learners without necessitating the need for demonstrating the transference of this knowledge (Mevarech & Amrany, 2008). However, several studies examined the successful transfer of specific strategies (e.g., Chi & VanLehn, 2010) or strategic knowledge (e.g., Hessels-Schlatter et al., 2017). Hessels-Schlatter et al. (2017) demonstrated that some components of metacognitive knowledge (i.e., difficulty judgment and problem categorization) may be improved through the introduction of metacognitive interventions. Therefore, it is possible that while person or task-specific metacognitive knowledge may not transfer, future studies could examine the (immediate and delayed) transferability of strategic knowledge to other contexts.

Metacognitive regulation. All studies examined at least one component of the regulation of cognition (i.e., the planning, monitoring, and evaluating components), see *Table 8* (p. 46) for the complete list. Each study demonstrated improvements in self-regulated learning and/or the regulation of cognition, even when the study examined transfer to alternate domains (i.e., Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017). Although the regulation of cognition was examined in each study, no complete investigation of every component of metacognitive regulation (i.e., planning, monitoring, debugging, and evaluating) was found.

Planning. Overall, metacognitive interventions showed improvements in planning across domains (Hessels-Schlatter et al., 2017; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008) however, differences were noted in which factors affected students' use of planning. Mevarech and Amrany (2008) showed that students exposed to a metacognitive intervention planned through strategy searching more than the control group. Unsolicited metacognitive prompts resulted in greater improvements in planning than solicited metacognitive prompts (Kramarski & Friedman, 2014). This was argued by Kramarski and Friedman (2014) as resulting from the positive impact of self-regulation training on the component of planning. It was also shown that the self-explanation approach to learning enhanced planning performance more than the group-feedback approach (Kramarski & Dudai, 2009). Students who received the self-explanation metacognitive training were more apt to discuss what the researchers considered to be basic elements of discussion. Kramarksi and Dudai (2009) attributed this to the lack of a social dynamic to inspire richer discussions. Lastly, a context-specific learning strategy was shown to improve planning processes more than a generic learning strategy (Kramarski et al., 2013), which the researchers attributed to strategy acquisition induced by the context-specific nature of the metacognitive prompts. In conclusion, future metacognitive interventions should focus on providing context-specific, unsolicited (i.e., accessible-on-demand) metacognitive prompting in a social setting to facilitate the maximum increases in the transfer of planning. It is also apparent from these findings that more research needs to be conducted on the transferability of planning with clarification under which conditions planning is most optimized.

Monitoring. The results of this literature review indicated positive effects for the transfer of cognitive monitoring (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008; Tajika et al., 2007). Kapa (2007) concluded that far-transfer of product and process phases showed improvements when participants were provided metacognitive support mechanisms. Hessels-Schlatter et al. (2017) concluded that monitoring improved in both studies conducted for students who received a metacognitive intervention. Tajika et al. (2007) concluded that higher levels of explanation (i.e., inferential explanations) were shown to improve in quality for students who received metacognitive training compared with those who did not. Further, Kramarski and Dudai (2009) concluded that the social dynamics of the group feedback condition showed even more improvements in monitoring than the self-explanatory condition.

Interestingly, Kramarski and Friedman (2014) found that students who had more control over their exposure to metacognitive prompts demonstrated monitoring most substantially during metacognitive discussions. Kramarski and Friedman (2014) argued that this may be a by-product of inefficient use of their cognitive resources; the researchers, citing self-regulated learning theory, attributed the planning phase as more effective for developing self-regulation skills. The results of Chi and VanLehn (2010) affirmed a similar conclusion when their results demonstrated higher percentages of what they termed the ‘desirable steps ratio’ (DSR), indicative of a more effective monitoring (and potentially debugging) process. Lastly, Kramarski et al. (2013) concluded that the monitoring process benefited most from generic metacognitive prompts as opposed to context-specific prompts. From these findings, it was concluded that generic metacognitive prompts, delivered in a group (i.e., social) setting may provide the most enhancements to the monitoring phase of metacognition (and self-regulated learning). This aligned with other studies which affirmed that collaboration can enhance effects of transfer from near to far transfer (e.g., Cuneo, 2008). In summary, future studies should verify this conclusion through a rigorous testing in a developmental context as well as investigate this finding in post-secondary context.

Debugging. The metacognitive component of debugging was only investigated in three of the studies (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014). Kramarski and Friedman (2014) concluded that error debugging (which was categorically grouped with monitoring during their study) was discussed most by students who had more control over their exposure to metacognitive prompts, and least by students who received unsolicited prompts. Similar to the monitoring component, the researchers concluded that this may be due to inefficient use of cognitive resources. While Chi and VanLehn (2010) did not examine debugging explicitly, their constructed measure of desirable steps ratio (DSR) did indicate efficient use of steps for the group receiving metacognitive training. It was argued that this outcome, in addition to reflecting the monitoring process, demonstrated improvements in debugging; the process of error-seeking and refining was assumed to impact the number of steps employed.

The most explicit measuring of the debugging phase was found in Kramarski and Dudai's (2009) study, where substantial significant differences were found for the group feedback condition compared with the self-explanatory and control groups. The lack of studies which examined debugging can be explained by examining the constructs of metacognition and self-regulated learning. Neither Flavell (1979) nor Brown (1987) include debugging in their frameworks of metacognition. However, Schraw and Dennison (1994) included debugging and information managing into their model of metacognition for self-regulated learning, an interrelated construct for metacognition (Dinsmore et al., 2008). Therefore, those who choose more classical models of metacognition (e.g., Flavell, 1979; Brown, 1987) as their theoretical framework may not examine with as much resolution the metacognitive component of monitoring as those who use definitions of metacognition rooted within the construct of self-regulated learning (e.g., Schraw & Dennison, 1994). From the findings of this literature review, it can be concluded that the debugging (and information managing) components of metacognition warrant further investigation and inquiry to affirm that these improve in transfer contexts.

Evaluating. Regarding the evaluating component of metacognition, one studied revealed fewer improvements in evaluating (Kramarski & Friedman, 2014) while another showed stronger increases in evaluating for generic learning (Kramarski et al., 2013), evaluating was particularly improved when group feedback was provided (Kramarski & Dudai, 2009). This finding was expected as previous studies indicated that the evaluating component of metacognition may not transfer (e.g., Erickson & Heit, 2015; Vo et al., 2014; Winne & Muis, 2011) but could improve as a result of metacognitive interventions (e.g., Rotgans & Schmidt, 2009). Some elements of judgment may be general in nature, which could explain the improvements seen, but the distinctions of which elements of metacognitive evaluation are general has yet to be examined (Gutierrez et. al, 2016). Therefore, future studies could investigate the components of metacognitive evaluation to ascertain which elements transfer.

Summary of findings. In summary, this systematic literature review illustrated several themes regarding the transferability of metacognition from interventions beginning in mathematics. While some components of metacognitive knowledge may not transfer (i.e., person or task-specific knowledge), strategic knowledge and use of strategies may transfer. The planning phase of cognitive regulation appears to have substantial transfer if metacognitive prompting is unsolicited, context-specific and delivered in a group context. Cognitive monitoring was found to be enhanced most through prompts provided in a group setting that are generic in nature. While debugging (and information managing) improved in alternate domains, further study should be conducted before general conclusions can be made. Lastly, the evaluating phase of metacognitive regulation may have some elements which transfer to other domains, though it is unclear which elements these may be. In conclusion, future studies in the transfer of metacognition from mathematics to other domains should examine the metacognitive components of strategic knowledge, planning, monitoring, and debugging. Further, more detailed analysis of the transfer of the debugging, information managing, and evaluating components of metacognition is warranted; it is also recommended that evaluation be examined separately in order to tease out the transferability of the elements of evaluation.

Implications for Present Research

Consequent to this systematic literature review, the extent to which metacognition components transfer across domains (i.e., near-transfer in the case of a similar domain or far-transfer in the case of a distinct domain) was still unclear. The assertions from this literature search of the potential transferability of (strategic) metacognitive knowledge and metacognitive regulation (i.e., the planning, monitoring, and debugging phases) provided an excellent basis for the present investigation into the transferability of metacognition across domains. Although the research questions employed for this search still remain incompletely answered, the findings of this literature review provided recommendations to address the transfer of metacognition with post-secondary populations. In summation, the literature review has identified apparent gaps in the literature on metacognitive interventions in mathematics for a post-secondary population.

The studies (Belenky & Nokes, 2009; Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Friedman, 2014; and Tajika et al., 2007) each reviewed one component of transfer involving a metacognitive intervention. Generalized population statements were not made from these studies due to the diversity of the examined populations (ranging from elementary to post-secondary levels of education). A similar argument was made for studies where only two components of transfer were found (e.g., Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski et al., 2013), with a similar difficulty regarding generalizability. It was noted that only two studies (Belenky & Nokes, 2009; Chi & VanLehn, 2010) investigated the population of interest: post-secondary students. It was apparent that additional studies investigating various components of metacognition's (i.e., strategic knowledge, planning, and monitoring) transferability for the post-secondary student population need to be conducted.

Although each of the nine studies found in the literature search involved a metacognitive intervention in mathematics, not all studies assessed the transfer of all components of metacognition, particularly to other domains. This highlighted the absence of studies conducted on the transfer of the various components of metacognition with interventions beginning in mathematics. However, collectively these studies demonstrated the capacity of metacognitive interventions to transfer their effects on performance, as well as their effects on metacognitive (strategic) knowledge and regulation (i.e., planning, monitoring, debugging, and components of evaluating), within the domain of mathematics.

Therefore, this systematic literature review provided a strong basis for the possibility of metacognitive transfer to other domains from mathematics. The present study, an investigation into post-secondary students' transfer of metacognitive strategic knowledge and regulation to other domains from mathematics, was supported by this literature review. Several of the studies (Belenky & Nokes, 2009; Chi & VanLehn, 2010; Kapa, 2007; Kramarski & Dudai, 2009; Kramarski et al., 2013) were quantitative in nature, lacking the resolution capacity of qualitative analysis on the depth of metacognitive transfer. Consequently, a combination of quantitative analysis and a high-resolution, qualitative assessment of metacognition was recommended.

In addition to the benefits regarding the research on the transfer of metacognition, the present research study may validate (or call into question) the generality of metacognition. If metacognition is found to be domain-general in nature, a number of developments are possible. Metacognitive interventions in one field could show transferability into other fields. Moreover, specific metacognitive instruction could be integrated into either a subject-specific curriculum, similar to what is used in Singapore (Singapore Ministry of Education, 2013), or a dedicated course in learning metacognition could be created to assist students' overall learning. Further insight will be gained about the impacts of the well-developed IMPROVE model (Mevarech & Kramarski, 1997). Perhaps most importantly, greater insight into the metacognition construct would be gained, expanding on its definition, impact, and applicability to other fields.

Anticipated outcomes based on findings from the systematic literature review. Based on the findings of the above literature review, several components of metacognition were expected to transfer. Metacognitive strategic knowledge was expected to transfer in (immediate and delayed) near and far contexts. Using a combination of solicited and unsolicited prompts, planning was expected to transfer to near and far contexts. Generic metacognitive prompts, delivered in a social setting under explicit instruction, were expected to facilitate transfer of metacognitive monitoring to near and far contexts. Debugging and information managing components of metacognition were identified as possibly transferable. Examination into the transferability of elements of metacognitive evaluating was reserved for a future dedicated study; however it was anticipated that some elements of metacognitive evaluating may transfer.

CHAPTER THREE: METHODOLOGY AND METHOD

Research Design – Mixed Methods

The hypothesis is tested and explained from various perspectives (Creswell & Clark, 2007). Recall, this study is focused on the transfer of general metacognition and self-regulated learning from an intervention focused in the domain of mathematics. Metacognition and self-regulated learning, along with self-regulation, are considered as interrelated (Fox & Riconscente, 2008; Kaplan, 2008). Consequently, metacognition is considered from each of these perspectives.

As was described in detail above (See *Selecting qualitative and quantitative measures***.**, p. 30), metacognition was identified by previous researchers as imperfect (e.g., Pintrich et al., 2000). Consequently, a more complete picture of metacognition was sought through the combination of quantitative and qualitative data. Each form provides complementary advantages: the quantitative methods (i.e., self-report surveys) are not always accurate, yet they provide broad information about the impact of the intervention; the qualitative methods are more objective, yet they are labour and time-intense. As a result, quantitative and qualitative data were collected and analysed separately before being integrated together to assist in triangulating metacognition from the interrelated constructs of metacognition and self-regulated learning (Fox & Riconscente, 2008; Kaplan, 2008).

The assessment methods were constructed to overlap the strengths of the methods, not their weaknesses (Johnson & Christensen, 2008). See *Selecting qualitative and quantitative measures***.** (p. 30) above for details regarding the selected assessment methods. Metacognition was quantitatively assessed using Schraw and Dennison's (1994) MAI; qualitative data of metacognition and self-regulated learning were assessed using thematic analysis (Braun &

Clarke, 2006). Participants' conversations were recorded during live discussions to observe authentic behaviour in a classroom setting (Akturk & Sahin, 2011); a semi-structured post-intervention interview, adapted from the MAI, facilitated clarity in understanding participants' answers (Helms-Lorenz & Jacobse, 2008). The interview included additional questions to explore and assess participants' transfer of metacognitive knowledge and regulation.

A concurrent triangulated mixed-method approach involves both forms of data (i.e., quantitative and qualitative), to be collected and analysed at the same time (Hanson, Creswell, Clark, Petska, & Creswell, 2005). A graphic of the process for this form of mixed-methodology is included in *Figure 7* below.

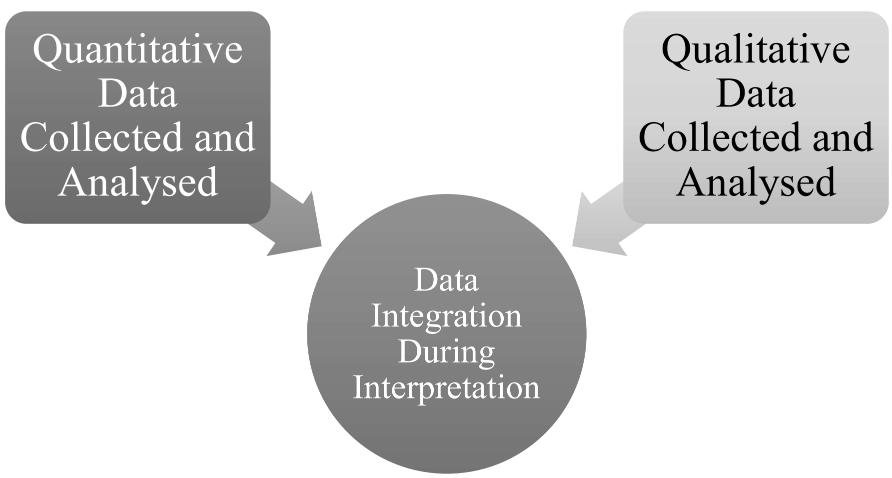


Figure 7. The concurrent triangulated mixed-method approach. Based on Hanson et al. (2005)

With usually equal priority to both forms of data (i.e., qualitative and quantitative data), analysis is conducted separately in a concurrent, triangulated, mixed-method approach and is integrated during the data interpretation stage. The extent of triangulation or convergence is usually the focus of interpretations (Hanson et al., 2005). This mixed-method approach is vital to the study of metacognition and self-regulated learning as neither quantitative nor qualitative approaches provide a complete picture of either construct (Dinsmore et al., 2008). Therefore, a concurrent triangulated mixed-method approach provides the most complete picture of metacognition and self-regulated learning rather than attempting only quantitative or qualitative procedures (Hanson et al., 2005; Klassen, Creswell, Clark, Smith, & Meissner, 2012).

Only metacognition is treated with both quantitative and qualitative data, given the emphasis of the present research on metacognition. Self-regulated learning will receive data only in qualitative form, which will be measured in parallel with metacognition, due to time constraints with the participants (See *Recruitment of participants*., p. 65). This is in part because previous research verified the improvement in general self-regulated learning for students exposed to the IMPROVE intervention using the instrument of choice, LASSI (e.g., Mevarech & Kramarski, 2014). Since quantitative and qualitative data were separately collected and analysed together, a concurrent triangulated approach is a well-suited fit, particularly as the focus of the interpretations will be on triangulation and convergence of metacognition.

A schematic summarizing the research design for the present study is included in *Figure* 8. below. This design was compiled from considering the research questions, the measurement of metacognition from a complete view, and the setting of the targeted course of instruction. A full description of the research method follows.

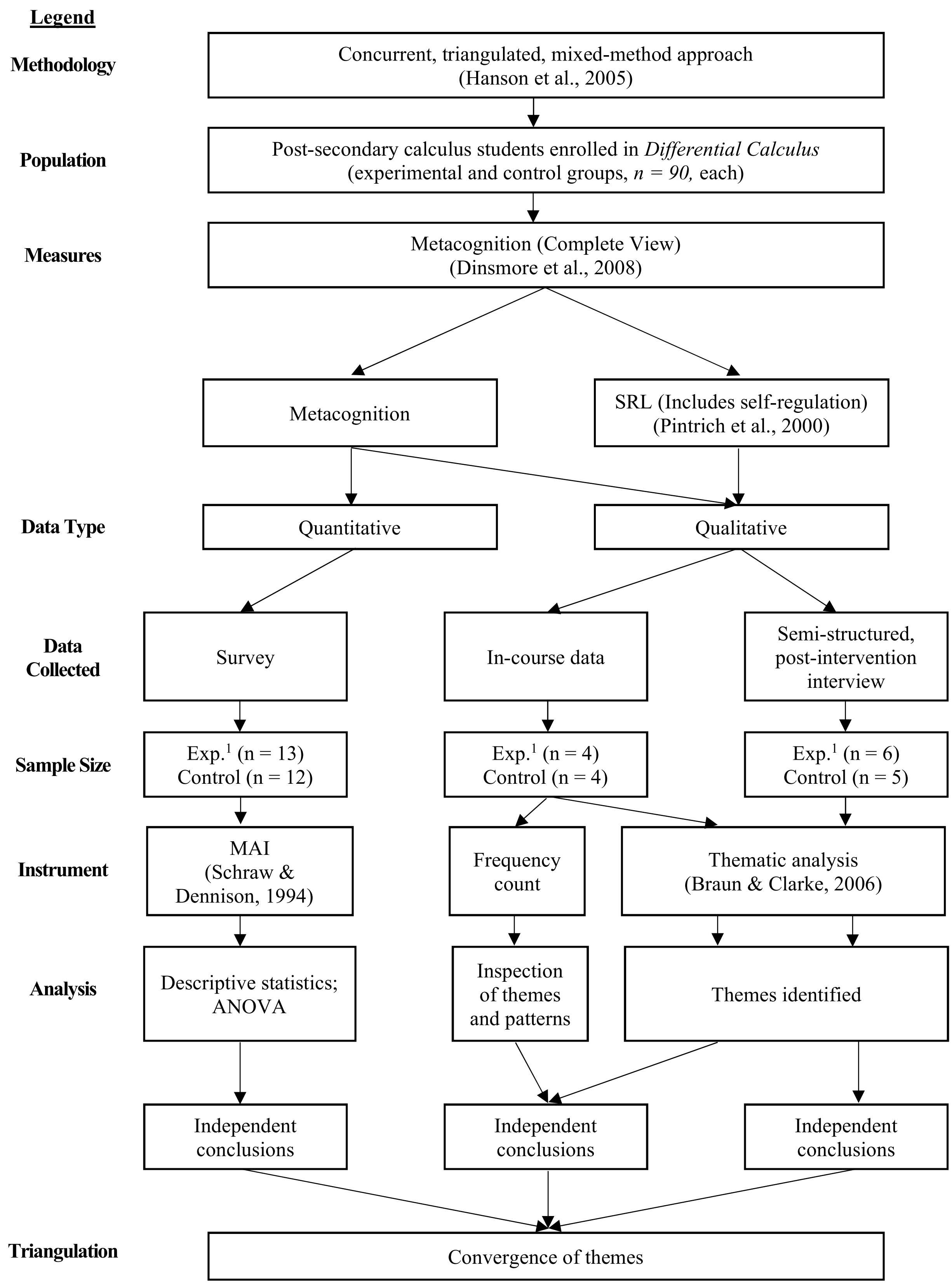


Figure 8. Schematic of the research design. [1]Exp. = Experimental; MAI = Metacognitive Awareness Inventory [2] = (Kramarski & Dudai, 2009; Mevarech & Amrany, 2008).

Participants

While adults possess a base for metacognitive knowledge, and are usually able to regulate their cognition (Schraw, 2001), McCabe (2011) showed that this is not always the case for undergraduates. Undergraduate students were chosen because of the expected measurable impact of an intervention on their metacognitive ability as opposed to more senior students (Young & Fry, 2008).

Learning context. The participants in this study were post-secondary students enrolled in in the fall of 2018 in *Differential Calculus,* a beginner-level calculus course at the University of Windsor, and (predominantly, but not exclusively) first-year students. This course was comprised of a combination of traditional lectures (four hours each week for twelve weeks) and ten two-hour weekly tutorials featuring problems for students to solve in groups. The intervention was infused into the two-hour tutorial after the completion of the fourth tutorial.

The two-hour tutorial was led by a teaching assistant and included problem sets for students to solve. In the initial three weeks of these tutorials, problems were more commonly familiar (i.e., exercises) and required students to practise particular strategies through repetition (Olson, Cooper, & Lougheed, 2011). These initial sessions were designed to assist with transitioning gaps in conceptual understanding of core concepts necessary for learning calculus; this resulted from curriculum changes and inconsistent exposure to calculus at the secondary level which required a flexible design for this first-year course (Chan & Wahl, 2013). This was intended to accommodate learners' varied prior exposure to calculus, which is integral to success in post-secondary calculus (e.g., Fayowski, Hyndman, & MacMillan, 2009; Kajander & Lovric, 2005).

Beginning with the fourth session, problems were intended to be increasingly novel and difficult for students (novel experiences were unique to students depending on their individual high school learning experiences). While several types of Problem-Based Learning were defined (Barrows, 1986), the method employed in these tutorials was most similar to Barrows' (1986) taxonomic classification of modified case-based learning which featured small tutorial groups. Problem-Based Learning is defined as being student-centered, occurs in small student groups, features problems as the stimulus of learning and developing problem-solving skills, with teachers as metacognitive guides or facilitators, and with the expectation that students will work together to discuss, compare, review, and debate learning in a self-directed manner (Barrows, 1996). In particular, Barrows (1996) acknowledged the importance of instructors guiding students through questions to better understand and manage problems with the expectation that students will take on this role themselves. Problem-Based Learning supports the development of deeper mathematical learning (e.g., Mokhtar, Tarmizi, Ayub, & Nawawi, 2013). This tutorial also satisfied the criterion of offering complex, unfamiliar, and non-routine problems suggested as appropriate for implementing Mevarech and Kramarksi's (1997) IMPROVE intervention which relied significantly on the inclusion of co-operative and explicit learning (Mevarech & Kramarski, 2014). Therefore, the infusion of the intervention into the problem-solving sessions after the fourth session ensured complexity, unfamiliarity, and novelty for the students while still providing sufficient time to deliver the intervention.

Differential Calculus was a compulsory course for both science and engineering, providing access to multiple domains including but not limited to: sciences, engineering, humanities, social sciences, and business. This diversity of domains allowed for testing the diversity and distance of domains in which metacognition may transfer. The study was completed during students' enrollment in their respective subsequent courses, during which the diversity and distance of transferred domains was potentially realized (e.g., electives in social science, business, or arts).

All relevant administrators and instructors were consulted throughout the administration of the study. Due to the demands of the course, only 20 minutes of instructional time was afforded for the lesson on metacognition for the experimental group. For the same reason, only one quantitative metric (i.e., the MAI by Schraw and Dennison, 1994) was chosen. Six laboratory sections were selected (three for the experimental group, n = 90 and three for the control group, n = 90) based on the volunteering of qualified instructors (See *Recruitment and training of instructors*., p. 70).

Recruitment of participants. Sample sizes were selected based on the anticipated needs of each instrument (See *Instrumentation*, p. 73). Summaries of the sample sizes are included in *Figure 9* (p. 66) and *Figure 10* (p. 67).

Participants were invited from the sections of *Differential Calculus* involved in the study (See *Learning context* above for details on how these sections were selected). Participants (n = 90 for the experimental group; n = 90 for the control group) were invited through email by the Mathematics Department at the University of Windsor to complete the MAI before the end of the first week of the intervention. These samples were larger than the sample size necessary for quantitative findings (n = 64 for the experimental and control group each; see *Calculating the minimum number of participants necessary for quantitative findings*, p. 77). Before the intervention, a total of n = 20 and n = 18 participants from the experimental and control groups, respectively, completed the MAI questionnaire. After the intervention, a total of n = 17 and n = 14 participants from the experimental and control groups, respectively, completed the MAI questionnaire. Because a mixed ANOVA was conducted for the present study (See *Metacognitive Awareness Inventory* (MAI), p. 73), participants' data were only included for analysis provided the individual completed the MAI questionnaire pre-test and post-test. This resulted in the inclusion of thirteen participants (n = 13, 13/90 = 14.4%) from the experimental group and twelve participants (n = 12, 12/90 = 13.3%) from the control group for the quantitative analysis.

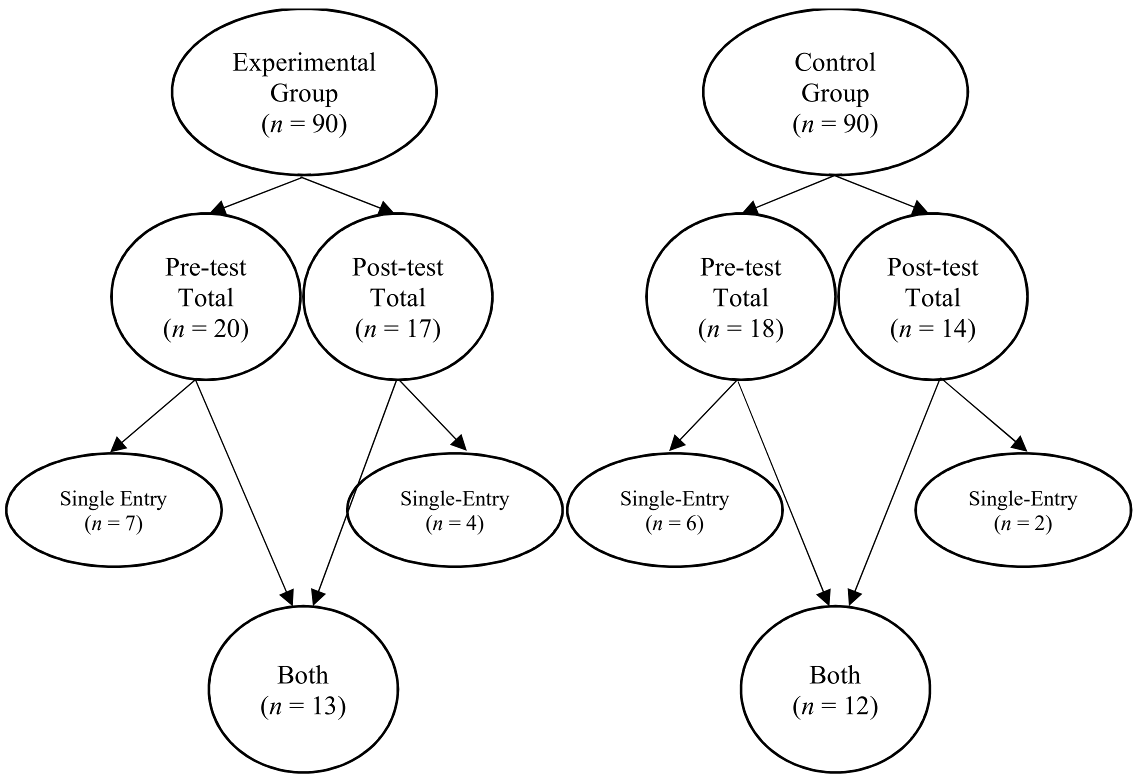


Figure 9. Sample sizes for the experimental and control group used in the quantitative analysis.

At the beginning of the first session, all individuals from each of the laboratory sections were invited in-person by the researcher to voluntarily participate in the study by permitting the recording of their conversations for the collection of the in-course data; this invitation complied with all required guidelines of the University of Windsor's Research Ethics Board. A maximum of four participants were selected for each laboratory section through lottery if more individuals volunteered. A total of twelve individuals volunteered from the experimental group (n = 12) and eleven individuals volunteered from the control group (n = 11).

At the conclusion of the fifth session, individuals from within the pool of participants who volunteered for the in-course data collection were invited to participate in the post-intervention interviews; this invitation also complied with all required guidelines of the University of Windsor's Research Ethics Board. A maximum of five individuals were randomly selected from each of the experimental and control groups. The researcher observed, during the study, one individual from within the experimental group mention explicit transfer of metacognition outside of the course of study. This individual was added to the experimental groups' pool of participants for the interview through purposeful selection. Consequently, six individuals were interviewed for the experimental group (n = 6) and five for the control group (n = 5).

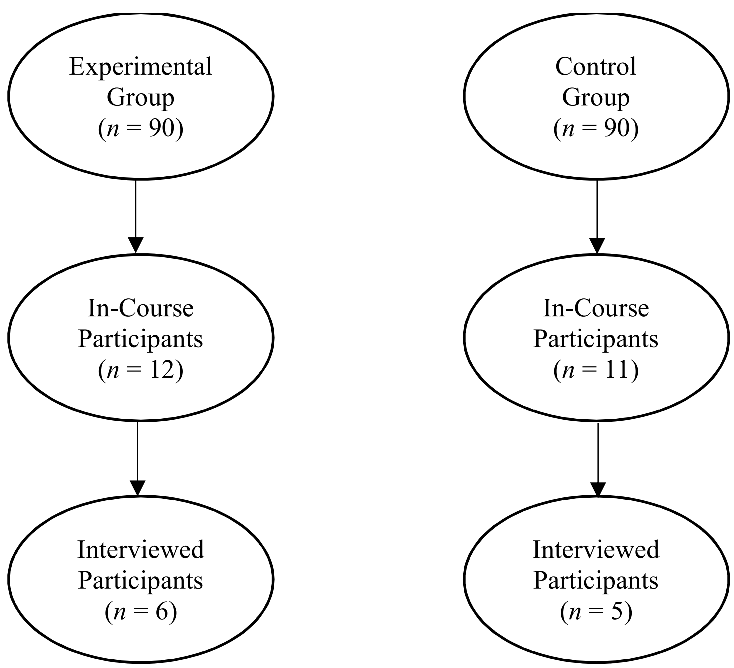


Figure 10. Sample sizes for the in-course and interview data analysis.

Data collection and ethical considerations. Secondary data sets were used for the quantitative analysis. The Mathematics Department at the University of Windsor collected the data ethically through voluntary email response incentivized by reception of a $10 gift card for completing each iteration of the survey; no consent was required at the time of data collection. Data was collected anonymously, voluntarily, and was of low risk to the participants; the data was used to assess potential benefits of metacognitive prompts integrated into the laboratory instruction component of *Differential Calculus*. A data-sharing agreement was completed and approved between the Mathematics Department at the University of Windsor and the researcher; the anonymized data was stored on a Qualtrics database and on a password-protected personal computer in an encrypted file. Because this study gathered secondary data involving human participants, the researcher obtained clearance from the University of Windsor's Research Ethics Board.

Qualitative data (i.e., in-course and interview data) was collected as primary data for the present study; consequently, the researcher obtained clearance for this process from the University of Windsor's Research Ethics Board. All qualitative data (i.e., in-course and interview data) was recorded using a unidirectional digital recorder. As mentioned above (See *Recruitment of participants*., p. 65), individuals from each of the laboratory sessions were invited in-person by the researcher to participate in the study by permitting the digital audio-recording of their conversations during their laboratory sessions for collection of the in-course data; participants understood that this meant they may be assigned randomly to a group and would not be able to choose their partners as a result. This invitation was incentivized by the offer of a $50 gift card to Amazon or the University of Windsor Bookstore upon completion of the collection of the in-course data (i.e., five-weeks of recording). Participation was voluntary and complied with all required guidelines for research by the University of Windsor's Research Ethics Board. In order to participate, individuals were required to complete consent forms, which outlined details of the study and right-to-withdraw process; individuals had the right to withdraw at any time prior to the completion of the analysis by contacting the researcher.

As mentioned above (See *Recruitment of participants*., p. 65), individuals from within the pool of participants who volunteered for the in-course data collection were invited to participate in the post-intervention interviews conducted by the researcher. Participants' interviews were digitally audio-recorded for later analysis. This invitation was incentivized by the offering of a $50 gift card to Amazon or the University of Windsor Bookstore upon completion of the interview. Participation was voluntary and complied with all required guidelines of the University of Windsor's Research Ethics Board. In order to participate, individuals were required to complete consent forms, which detailed outlines of the study and right-to-withdraw process; individuals had the right to withdraw at any time prior to the completion of the analysis by contacting the principal investigator. Participants' consent was reaffirmed at the commencement of each interview.

Participants' qualitative data (i.e., in-course and interview data), including names or other forms of identifiers, were anonymized. Data was anonymized by the generation of a random number; these numbers were organized from lowest to highest, with a rank assigned (e.g., Participant E.1 to E.12 for the Experimental Group and Participant C.1 to C.11 for the Control Group). Participants were identified by such rank; linking codes and master lists were destroyed at the completion of the dissertation defense. All data was transcribed by the researcher. All data was stored on the researcher's password-protected personal computer; at the completion of the dissertation files were stored in a password-encrypted storage system and were only accessible by the researcher and the thesis supervisor.

Intervention

Recruitment and training of instructors. Instructors for the intervention were recruited among qualified teaching assistants hired for the regular laboratory instruction. A total of three teaching assistants volunteered to operate as instructors for the intervention: one teaching assistant volunteered as the instructor for all three sections of the control condition; two teaching assistants volunteered as the instructors for the three sections of the experimental condition (i.e., one instructor for two sections; one instructor for one section).

The teaching assistant who administered the control group sections was responsible for promoting the completion of the MAI survey during Sessions 1 and 5. For the control group, the instructor was also responsible for monitoring the recording equipment; otherwise, instruction was to operate within standard guidelines for the course. The instructor was required to attend a training session on how to use and monitor the recording equipment. This instructor was compensated with a $50 Amazon gift card for each section administered (i.e., $150 total).

Teaching assistants who administered the experimental group were responsible for: participating in a 2-hour training session prior to study commencement; promoting the completion of the MAI and demographics survey during Sessions 1 and 5; delivering a 20 minute lesson on metacognition to their students; monitoring the recording equipment; and providing metacognitive prompts in addition to instructing along standard guidelines for the course. Instructors for the experimental group were compensated with a $250 Amazon gift card for each section administered.

Instructors for the experimental group were trained in using and modifying the metacognitive prompts (See *Pedagogy of Metacognition Instruction*, p. 22) appropriately to the needs of their students, with ongoing support from the primary investigator throughout the instructional period. This training was offered through a two-hour instructional session prior to the commencement of the study. During this session, instructors:

1. developed an understanding of metacognitive terminology and distinguished components of metacognition and their relationship to the prompts (See *Pedagogy of Metacognition Instruction*, p. 22);
2. experienced the process from the students' perspective by using metacognitive prompts while solving typical problems assigned in the course;
3. experienced the process as an instructor by practicing metacognitive coaching;
4. reflected on the impacts and cautions of integrating metacognitive prompts into instruction;
5. discussed research ethics, safety precautions, and troubleshooting procedures with respect to the experiment.

The training activities were nearly evenly divided between all of the goals above, with a doubled focus on the third step (i.e., teaching assistants received 40 minutes of training time dedicated to experiencing the process as an instructor, while each of the other activities received approximately 20 minutes of training time). Instructors for the experimental group also received training on how to monitor the recording equipment.

Delivery of the intervention.A full schedule of the delivery activities of the intervention for both the participants and instructors was included on *Table 9* (p. 72). Participants within the control group received instruction, assessment, and guidance identically to peers enrolled in the course, with the following additional activities: they were invited to complete the MAI questionnaire online (See *Recruitment of participants*., p. 65) during Sessions 1 and 5; and they worked in groups no larger than four during the completion of their problem-solving work.

Participants within the experimental group received instruction, assessment, and guidance identically to peers enrolled in the course, with the following additional activities: they were invited to complete the MAI questionnaire online (See *Recruitment of participants*., p. 65) during Sessions 1 and 5; and they worked in groups no larger than four during the completion of their problem-solving work. Additionally, participants in the experimental group received support through the metacognitive prompts, delivered in the format described above (See *Pedagogy of Metacognition Instruction*, p. 22).

Table 9

Schedule of Activities and Compensation for Participants and Instructors

Schedule	**Experimental Group**		**Control Group**	
	Participants	**Instructor**	**Participants**	**Instructor**
August 2018	n/a	•Attend 2-hour MC training session	n/a	•Attend training for audio recording
Session 1	•Complete MAIQ (*n* = 20) •Attend MC lesson •IMPROVE practice •In-Class Recording (*n* = 12)	•Monitor audio recording •Promote MAIQ •Provide MC prompts	•Complete MAIQ (*n* = 18) •Regular practice •In-Class Recording (*n* = 11)	•Monitor audio recording •Promote MAIQ •Regular instruction
Sessions 2-4	•IMPROVE Practice •In-Class Recording (*n* = 12)	•Provide MC prompts	•Regular Practice •In-Class Recording (*n* = 11)	•Regular instruction
Session 5	•Complete MAIQ (*n = 17*) •IMPROVE Practice •In-Class Recording (*n* = 12)	•Promote MAIQ •Provide MC prompts	•Complete MAIQ (*n = 14*) •Regular Practice •In-Class Recording (*n* = 12)	•Promote MAIQ •Regular instruction
January 2019	•Interviews (*n* = 6)	n/a	Interviews (*n* = 5)	n/a
Compensation[1]	Recording = $50 Interview = $50	$250/section	Recording = $50 Interview = $50	$50/section

Note. MAIQ = Metacognitive Awareness Inventory Questionnaire (See *APPENDIX B – STRUCTURED INTERVIEW* QUESTIONS, p. 266); MC = metacognition; 1 = All compensations were provided as Amazon Gift Cards or gift cards to the University of Windsor Bookstore at the discretion of the participant.

Instrumentation

Quantitative data. The MAI questionnaire used in the present study included in *APPENDIX A – METACOGNITIVE AWARENESS INVENTORY* QUESTIONNAIRE (p. 262). Note that this questionnaire also included demographic information including: age, gender, previous mathematics instruction, enrolment at the University of Windsor (i.e., part-time/full-time, faculty and program), and identification of laboratory section. Collectively, these were used to construct descriptive statistics for the population. The population's experience with mathematics helped describe the populations' prior metacognitive development (McCabe, 2011; Young & Fry, 2008). Enrolment in the university (i.e., part-time or full-time) described participants' workload during the intervention, which may impact overall cognitive load while learning metacognition (Wedelin et al., 2015; Van der Stel & Veenman, 2014). Participants' registered program and faculty were included to verify the diversity of accessible domains for the sample; such diversity was important in considering the distance of domains in which metacognition may transfer (See *Transfer*, p. 7). Lastly, laboratory sections were used to identify whether a participant was placed within the experimental group or control group.

Metacognitive Awareness Inventory (MAI). In order to corroborate coherence of the implementation of the IMPROVE (Mevarech & Kramarski, 1997) intervention, Schraw and Dennison's (1994) 52-item *APPENDIX A – METACOGNITIVE AWARENESS INVENTORY QUESTIONNAIRE* (p. 262) was selected for assessing metacognition for the present study with a Likert scale identical to that used by Mevarech and Fridkin (2006). Mevarech and Fridkin (2006) used the MAI to measure the impact of the IMPROVE model on all eight components of metacognition (i.e., person, task, and strategy components of metacognitive knowledge and planning, monitoring, information managing, debugging, and evaluating components of metacognitive regulation) as well as the totals of metacognitive knowledge (17 items) and regulation (35 items). The researchers demonstrated in their study that all components of metacognition showed statistically significant differences for the group who received the IMPROVE model.

Schraw and Dennison (1994) illustrated in the original analysis of their instrument that their model was reliable for metacognitive knowledge ($\alpha = 0.88$) and regulation ($\alpha = 0.91$) and inter-correlated ($r = .54$). When the researchers searched for the eight components as independent factors using exploratory factor analysis (EFA), they reported insufficient ($\alpha < .80$) values for the six-factor solutions found, “Six rather than eight factors were obtained, none of which bore a close resemblance to any of the eight predicted factors” (p. 464). The researchers concluded that the MAI was a reliable test for metacognition among post-secondary students; however convergent and divergent validity were recommended for further investigation. As reported by Pintrich et al. (2000), the lack of alignment between theory and data was recurrent in the field of measuring metacognition quantitatively, “There seem to be more…components predicted by theory than supported by the data generated from the empirical studies of the instruments” (p. 63).

Recently, Harrison and Vallin (2018) examined different factor analysis techniques of the MAI in order to ascertain reliability and validity for the instrument with a population of undergraduate biology students enrolled in a public university in Hawai’i. Confirmatory factor analysis (CFA) and multidimensional random coefficients multinomial logit (MRCML) were conducted to match the intended function of the MAI with data results, comparing four models for the MAI: a unidimensional factor; the two-dimensional model recommended by Schraw and Dennison (1994) (i.e., 25 items for metacognitive knowledge and 27 items for metacognitive regulation); the two-dimensional model corresponding with the intended question design (i.e., 17 items for metacognitive knowledge and 35 items for metacognitive regulation); and an eight-dimension model. It was noted that the researchers did not find adequate convergence for the eight-dimensional model, affirming the aforementioned difficulty in measuring metacognition by Pintrich et al. (2000).

The researchers corroborated the findings of Schraw and Dennison (1994): that the data best fit the theoretical two-factor model (i.e., knowledge and regulation) however, the use of the 52-item inventory was still a poor fit (χ^2 = 3363.28, df = 1272, CFI =.851, TLI = .845, RMSEA = .051)[1], being only slightly better than the two remaining model configurations. Based on this analysis, it was noted that this theoretical model was employed by Mevarech and Fridkin (2006) in their use of the MAI to assess general metacognitive knowledge and regulation.

Since the results were "below the conventional criteria for adequate fit" (p. 30), Harrison and Vallin (2018) searched for a better model by running simultaneous MRCML and CFA models iteratively, eliminating items to determine an optimal configuration for the model. The researchers concluded that a smaller subset of the items (i.e., 19) provided a better fit for the data (χ^2 = 352.80, df = 151, $p < .001$, CFI = .959, TLI = .954, RMSE = .046). The researchers examined this new model by comparing invariance between groups based on presentation of the questionnaire (i.e., paper-based vs. iClicker). Harrison and Vallin (2018) concluded only partial scalar invariance with five items being unconstrained; the researchers recommended further research to compare validity with groups outside the study. After comparing the configural models for the two groups, the researchers concluded that the measurement models were a good

[1] CFI = comparative fit index; TLI = Tucker-Lewis index; RMSEA = root mean square error of approximation.

fit, although Harrison and Vallin (2018) recommended further research into improving the instrument, specifically regarding content representation.

In conclusion, although Harrison and Vallin (2018) identified a modified model for scoring the MAI with greater reliability and validity for the factors of metacognitive knowledge and regulation, general metacognitive knowledge and regulation were calculated using the theoretical model designed by Schraw and Dennison (1994), and employed by Mevarech and Fridkin (2006) (i.e., 17 items for metacognitive knowledge and 35 items for metacognitive regulation). This model, supported as the best (while still poor) fit of the models used for the 52-item MAI, allowed for direct comparison with the findings of Mevarech and Fridkin (2006) in order to corroborate coherence of the implementation of the IMPROVE (Mevarech & Kramarski, 1997) intervention. Given the conclusions in the literature regarding the low validity of the eight-dimension model (Harrison & Vallin, 2018; Schraw & Dennison, 1994), caution was used when interpreting the findings of the eight components of metacognition (i.e., personal, task, and strategy for metacognitive knowledge; planning, monitoring, information managing, debugging, and evaluating for metacognitive regulation).

Consequently, ten 2x2 mixed ANOVAs were conducted for the MAI (Schraw & Dennison, 1994) comparing the performance of the experimental group with the control group. General metacognitive knowledge and regulation were calculated as total scores according to the theoretical model designed by Schraw and Dennison (1994). Metacognitive knowledge subscales included: declarative (i.e., personal), procedural (i.e., task), and conditional (i.e., strategic) knowledge. Subscales for metacognitive regulation included: planning, information managing, monitoring, debugging, and evaluating.

Calculating the minimum number of participants necessary for quantitative findings. Given previous findings by Mevarech and Fridkin (2006), a medium effect was predicted for all subscales for the experimental group when compared with the control group. G*Power (Version 3.1.9.4; Faul, Erdfelder, Lang & Buchner, 2009) was used to calculate the necessary sample sizes. Assuming an f of .25 for a medium effect (Cohen, 1988), a power of 0.8, and $\propto = 0.05$, G*Power yielded a minimum expected number of participants as 128 (i.e., n = 64 participants for each of the experimental and control groups).

Qualitative data. Qualitative data for the present study included recordings of participants' conversations (i.e., "in-course data") and recordings of post-intervention interviews with select participants (i.e., "interview data"). In-course data employed the use of both quantitative (i.e., frequency-counting and graphical presentation of the data) and qualitative (i.e., thematic) analyses. Interview data employed the use of thematic analysis. Instrumentation for analysing each of these data were explored individually.

In-course data.

Coding process. Before beginning coding, a priori categories were chosen for both student and instructor based on metacognition research. Schraw and Dennison's (1994) model was used for metacognition; therefore, groups' discussions were categorized as metacognitive knowledge (i.e., the categories of person, task, and strategy), as well as, metacognitive regulation (i.e., planning, monitoring, debugging, and evaluating). Additional categories emerged (i.e., Personal, Procedural, Prompt, Transfer, and Silence). Statements were coded to a category (For each of the categories, with samples, see Table *16* (p. 98) and Table *17* (p. 99).

Frequency counting. Conversations were categorized by topic change. Considering the interplay between cultural and personal understandings developed during mathematics as a social process (Schoenfeld, 1992, Vygotsky, 1978), categorical data pertaining to the groups' conversations was selected over individual statements. Examination of groups' conversations was expected to yield patterns in their metacognitive skills in a social context (e.g.., Kramarksi & Dudai, 2009; Mevarech & Amrany, 2008). Therefore, an analysis by topic count of groups' conversations was an appropriate manner to assess the immediate and delayed effects of the intervention on the development of metacognitive skills and participants' transfer of those skills to other contexts. Specifically, data was searched for: the metacognitive skills exposed to individuals by their environments (i.e., peers); patterns in the solicitation and emergence of these skills by the experimental and control condition; and overall patterns, over time, in participants' use of metacognition throughout the problem-solving sets.

In-course data of the experimental and control groups were analysed quantitatively. Frequency counting coded themes (See *Format for Quotations From Participants*., p. 97), based on topics of conversation. In other words, codes were identified and counted, based on changes in the topic of conversation. Consequently, it was not uncommon to identify multi-coded themes for a given topic (e.g., metacognitive knowledge of the task along with debugging). Concurrent themes were incorporated throughout the qualitative analysis. Coded themes were totalled each week and overall. The frequency with which each theme appeared was calculated as a percent of coded categories for the various conversational topics observed. Data was then analysed for dominant and minor themes.

A graphical representation of the topics was constructed to assist with the proceeding thematic analysis (See *Graphical Presentation*., p. 115). Themes were ordered based on the three components of metacognitive knowledge (i.e., person, task, and strategy), followed by the four themes of metacognitive regulation (i.e., planning, monitoring, debugging, and evaluating).

These were presented in the order based on the theoretical framework of Schraw and Dennison (1994). The final themes (i.e., Personal, Procedural, Prompt, Transfer, and Silence) were grouped together, with no hierarchy intended in their presentation. These graphical presentations, (See *Table* 22 – *Table 31*, pp. 116–125), in combination with the frequency counts, were used to complement the qualitative analysis of the in-course data.

Thematic analysis. Pintrich et al. (2000), in their analysis of different methods for measuring metacognition, indicated that "real-time" measures of metacognition require extensive interviews with individual participants. Since a deep analysis of the qualitative data was desired, a thematic analysis was also considered. Thematic analysis allowed for the natural emergence of a theme based on the available data (Braun & Clarke, 2006). The power and resolution of qualitative analyses when assessing metacognition were argued to be favourable by several researchers with respect to the use of online measures of metacognition (e.g., Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009), particularly when observing social metacognition (e.g., Mevarech & Amrany, 2008). For the purposes of this study, and for in-depth analysis on the transfer of metacognition, a longitudinal examination of one experimental group and one control group's dialogic practice was used (See *In-Course Data Selection Process*, p. 101, for details regarding group selection). In combination, these were expected to glean insight into the development of participants' metacognitive abilities and indicate qualitative differences between the conditions regarding the transfer of these skills to other domains.

Interview design. The semi-structured interview questions were included in *APPENDIX B – STRUCTURED INTERVIEW* QUESTIONS (p. 266). These questions were designed based on a qualitative approach similar to questions asked in Schraw and Dennison's (1994) MAI, with a semi-structured delivery to create space for continued questioning until answers were clear

(Helms-Lorenz & Jacobse, 2008). Questions focused on active behaviours in alignment with "online" measures of metacognition and self-regulated learning (Panadero et al., 2015). The questions were asked in the same order in which they were scaffolded during instruction (i.e., strategic knowledge, planning, monitoring, information managing, debugging, and transfer of metacognition). Questions 1 to 12 were labeled according to their corresponding targeted component of metacognition.

The transfer questions (Questions 13-17) were integrated to assess participants' transfer of metacognitive knowledge and regulation; each question was tailored to the type of transfer being investigated (Salomon & Perkins, 1989). Questions 13 to 15 were engineered to assess variance distances between the domain of learning and the transfer domain (i.e., far transfer). Question 16 was designed to assess the routine components of transfer as well as re-assessing the distance of participants' transfer of general metacognitive knowledge. The final follow-up question within Question 16 was designed in particular to assess the most distant transfer given its generalized phrasing to the participants' life. It was also intended to assess forward-reaching transfer (Salomon & Perkins, 1989) by prompting students to foresee possible uses.

Question 17 was engineered as an opportunity to observe a students' metacognitive regulation outside of the field of study. This task was chosen from biology, which though still located within the science domain, is arguably more "distant" from mathematics than other fields (i.e., chemistry or physics; see *Transfer*, p. 7). This task was designed to incorporate elements from multiple domains, including elements of cultural sensitivity, as well as the features of a complex, unfamiliar, and non-routine problem (Mevarech & Kramarski, 2014). Participants were provided with superfluous information (i.e., the common names of the species), embedded among relevant information (i.e., the conflict between the two countries) to assess their ability to manage information. Participants were given access to wikipedia.org to assist with any additional information they may need. The problem was considered complex as it was designed to assess participants' ability to manage the problem, in the timeframe given, while managing the ultimate goal of assessing the habits of at least two of the organisms. With the problem well-defined, and the solution left open, participants may engage in divergent thinking rather than the logical thinking (Wakefield, 1992) they may be used to in a mathematics class, where the problem and solution are both usually well-defined. Therefore, this problem is considered to measure the distant, delayed, and novel components of transfer.

Questions 6, 7, 8 and 18 were intended to assess the participants' metacognitive experiences; Question 18 included a follow-up question targeting the impact of the interview sequentially after examining the overall learning journey to determine separate impacts of the interview from the remaining learning experiences. Questions 6, 7, 8 and 18 were designed to solicit detailed data from the participants regarding their attitudes, and motivations with respect to the process (Argyropoulos et al., 2012; Özsoy et al., 2009; Rotgans & Schmidt, 2009).

Overall, the interview questions were designed to assess qualitatively similar questions as the MAI (Schraw & Dennison, 1994), with the addition of transfer questions intended to assess the various forms of transfer (Salomon & Perkins, 1989). They were semi-structured in their delivery to afford further questioning until answers were clear (Helms-Lorenz & Jacobse, 2008). Questions included a focus on active behaviours in alignment with "online" measures of metacognition and self-regulated learning (Panadero et al., 2015).

Interview data – thematic analysis. The interviews were semi-structured in design to create space for continued questioning until answers were made clear (Helms-Lorenz & Jacobse, 2008). Similar to the analysis of the in-course data, thematic analysis (Braun & Clarke, 2006) of the qualitative interview data was conducted. Thematic analysis allowed for the natural emergence of a theme based on the available data (Braun & Clarke, 2006). The power and resolution of qualitative analyses when assessing metacognition were argued to be favourable by several researchers with respect to the use of online measures of metacognition (e.g., Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009).

CHAPTER FOUR: SURVEY DATA– RESULTS AND ANALYSIS

A Priori Hypotheses

Young and Fry (2008) compared metacognitive knowledge and regulation of undergraduate students to graduate students using the Metacognitive Awareness Inventory. The researchers identified that, over time, metacognitive regulation increased with no significant differences in metacognitive knowledge.

Although improvements in metacognitive regulation may be expected for all participants, a previous study by Mevarech and Fridkin (2006) introduced the IMPROVE model to a similar population of undergraduates. The researchers measured each subscale of the Metacognitive Awareness Inventory pre-test and post-test for the experimental group and control group. The researchers found significant improvement for the intervention group, when compared with the control group, for all subscales of metacognitive knowledge and regulation. It was noted that prior to beginning their study, the researchers identified statistically significant differences between groups for the conditional (i.e., strategic) knowledge subscale. The findings show that despite differences in the pretest scores on conditional (i.e., strategic) knowledge, there were significant differences on post-test scores after controlling for pre-test differences. Mevarech and Fridkin (2006) concluded statistically significant improvement in each subscale for metacognition resulting from participation in the IMPROVE intervention.

Therefore, for the present research, it was hypothesized that the intervention would increase each subscale of metacognition. It was further hypothesized that general metacognitive knowledge and regulation would increase for individuals who received the intervention in comparison to the control group. To verify successful implementation of the intervention, general metacognition was measured to confirm such increases in metacognitive performance.

Data Cleaning

Participants' data (tracked using a randomly-generated ID for each individual) were included for analysis provided the individual completed the Metacognitive Awareness Inventory questionnaire pre-test and post-test, resulting in thirteen participants from the experimental group ($n = 13$), and twelve participants from the control group ($n = 12$).

All assumptions for conducting a two-way ANOVA were evaluated. The dependent variable was continuous – in the case of the metacognitive awareness inventory, all subscales were continuous. Within-subjects variables employed two categorical groups (pre-test and post-test). Between-subjects variables were two categorical, independent groups (i.e., experimental and control groups).

Boxplot inspections were used to assess the presence of outlier(s). Outliers were identified if individual cases presented beyond 1.5 boxlengths. Potential outliers were examined by ANOVAs conducted with and without the outlier(s) to assess the extent to which removing the outliers changed the ANOVA results. Potential outliers observed in the data for declarative (i.e., personal) knowledge, procedural (i.e., task) knowledge, conditional (i.e., strategic) knowledge, planning, information managing, monitoring, and evaluating subscales, as well as the overall regulation scale, minimally affected the ANOVA calculations, resulting in the preservation of the data as it was originally collected.

Outliers within the overall knowledge scale and debugging subscale required further examination. For the overall knowledge scale, one case from the experimental condition was identified as an outlier. For the interaction of time, the significance changed from $p = 0.060$ with the outlier, to $p = 0.101$ without the outlier. For the interaction of time and treatment, the significance changed from $p = 0.067$ with the outlier, to $p = 0.041$ with the outlier removed.

Although these changes were deemed moderately discrepant, though still an outlier, it was also noted that the outlier in question recurred as a low-performing outlier for two other subscales (i.e., information managing and debugging). Since the outlier case for the knowledge subscale was concluded to be a consistently underperforming case and therefore a reflection of true performance, the case was included and the data was preserved for the overall knowledge scale.

Five potential outlier cases were identified for the debugging subscale. A noticeable change in significance was observed for time for p = 0.459 with the outlier to p = 0.069 without the outlier. For the interaction between time and treatment, the significance changed from $p = 0.670$ with the outlier, to $p = 0.862$ with the outlier removed. Removing the low scores raised pre-test scores to a level in which an almost significant drop at post-test was possible. It was noted that even with this change, there was a non-significant change from pre-test to post-test. Considering the net effect, and the number of participants' data identified in this subscale potentially reflecting true diverse performance, outliers were included in the final data analysis. Overall, although potential outliers were identified, circumstantial conditions and net effects on the ANOVA calculations resulted in the preservation of the data as it was collected.

All subscales were normally distributed ($p > 0.05$) for all treatments pre-test and post-test except for: control group's pre-test measurement of planning ($p = 0.044$) and debugging ($p = 0.043$) as assessed by Shapiro-Wilk's test of normality; the experimental groups' post-test measurement of procedural (i.e., task) knowledge ($p = 0.013$) and the control groups' post-test measurement of conditional (i.e., strategic) knowledge ($p = 0.013$). Because graphical examination of the data did not show a severe deviation from normality, and because there was not an adequate non-parametric alternative, analyses proceeded with the note that results for these scales should be interpreted with caution.

Because there were also no nonparametric alternatives to a two-way repeated measures ANOVA, the ANOVA was conducted with no modifications made to the data. Analysis of all subscales' Levene statistic ($p > 0.05$) revealed that there was homogeneity of variance. Homogeneity of covariances was confirmed by Box's test of equality of covariance matrices. The results of this test are included in *Table 10*. Because only two points in time were measured, the assumption of sphericity was automatically satisfied for all measures (i.e., $p > 0.05$).

Table 10
Significance Values for Box's Test of Equality of Covariance Matrices

Subscale	Sig. ($p =$)
Metacognitive Knowledge	0.365
Declarative Knowledge[1]	0.539
Procedural Knowledge[2]	0.247
Conditional Knowledge[3]	0.364
Metacognitive Regulation	0.085
Planning	0.210
Information Managing	0.245
Monitoring	0.958
Debugging	0.472
Evaluating	0.295

Note. Sig. = significance; [1] Declarative (i.e., personal) knowledge; [2] Procedural (i.e., task) knowledge; [3] Conditional (i.e., strategic) knowledge.

Results

The population completed the survey within an average time of 510 seconds and 426 seconds for the experimental and control groups respectively. The average age of participants in the experimental condition was M = 18.85, SD = 3.08 and in the control condition the average age was M = 17.83, SD = 0.58. The noticeably large standard deviation for the experimental condition, and its larger average age, were explained by the presence of a single participant much older (i.e., 29 years of age) than the remaining participants. Further descriptive statistics were reported in Table *11* below.

Table 11
Descriptive Statistics for Group Membership

Quality	Sub-Quality	Exp.	Control
Participants		13	12
Gender			
	Male	11	6
	Female	2	6
Education			
	High School	11	12
	IB Diploma	1	0
	University	1	0
Courses			
	Grade 12 Calculus and Vectors	10	11
	Grade 12 Advanced Functions	7	7
	Grade 12 Mathematics of Data Management	4	1
	Standard Level Math	1	0
	AP Calculus AB	1	0
	University Course	1	1
Enrollment			
	Full-Time	12	12
	Part-Time	1	0
Faculty			
	Science	6	10
	Engineering	7	2

Note. Exp = experimental group participants.

Each group contained male and female participants. All participants reported a high school education except one, who specified having a previous Master Degree in Project Management. Considering this was a first-year mathematics course available to all students, this composition was anticipated. Twenty-one of the 25 participants completed the calculus and vectors course from secondary education, indicating previous experience with the course content, with two participants indicating more experience with previous university courses. All participants were full-time students except one part-time student for the experimental group. Both groups were composed of members from the Science and Engineering disciplines. The experimental and control groups were of near-equal size.

Ten ANOVAs were conducted to measure each subscale of the Metacognitive Awareness Inventory (i.e., one for each subscale). To reduce type-1 error, a Bonferonni correction (i.e., dividing by 10) was applied, thus $\alpha = 0.005$. No statistically significant differences were found for the main effects of time, nor the interaction between these variables for the adjusted alpha ($p > 0.005$) for all dependent variables. These results are included in Table *12* (p. 89) and Table *13* (p. 90).

Using an unadjusted alpha of .05, there was a statistically significant result for the main effect of time for conditional (i.e., strategic) knowledge [$F(1,23) = 7.621$, $p = 0.011$, partial $\eta^2 = 0.249$] as well as for the interaction between time and treatment [$F(1,23) = 6.178$, $p = 0.021$, partial $\eta^2 = 0.212$]; however these each fell short of the adjusted alpha of .005. *Figure 11* (p. 91) illustrated the difference in means for conditional (i.e., strategic) knowledge between the groups.

Although not a focus of the intervention, a statistically significant result for the main effect of time for Information Managing [$F(1,23) = 7.248$, $p = 0.013$, partial $\eta^2 = 0.240$] also fell short of the adjusted alpha of .005. *Figure 12* (p. 91) illustrated the difference in means for information managing between the groups. The means and standard deviations resultant from the 2x2 mixed ANOVA with repeated measures were included in (*Table 14*, p. 92).

Table 12
Analysis of Variance (ANOVA) for Metacognitive Knowledge and Subscales

Source			df	MS	F	*p*	partial η^2
Metacognitive Knowledge							
		Time	1	.206	3.9	.060	.145
		Time*Treatment	1	.196	3.708	.067	.139
		Error	23	.053			
	Declarative[1] Knowledge						
		Time	1	.040	.557	.463	.024
		Time*Treatment	1	.055	.760	.392	.032
		Error	23	.073			
	Procedural[2] Knowledge						
		Time	1	.229	1.703	.205	.069
		Time*Treatment	1	.229	1.703	.205	.069
		Error	23	.134			
	Conditional[3] Knowledge						
		Time	1	.465	7.621	.011*	.249
		Time*Treatment	1	.377	6.178	.021*	.212
		Error	23	.061			

Note. df = degrees of freedom; MS = mean square; * p < .05; [1] Declarative (i.e., personal) knowledge; [2] Procedural (i.e., task) knowledge; [3] Conditional (i.e., strategic) knowledge.

Table 13
Analysis of Variance (ANOVA) for Metacognitive Regulation and Subscales

Source			df	MS	F	p	partial η^2
Metacognitive Regulation							
		Time	1	.039	.592	.449	.025
		Time*Treatment	1	.012	.179	.676	.008
		Error	23				
	Planning						
		Time	1	.048	.261	.614	.011
		Time*Treatment	1	.205	1.106	.304	.046
		Error	23	.185			
	Information Managing						
		Time	1	.562	7.248	.013*	.240
		Time*Treatment	1	.000	.003	.955	.000
		Error	23	.078			
	Monitoring						
		Time	1	.036	.303	.587	.013
		Time*Treatment	1	.099	.842	.368	.035
		Error	23	.118			
	Debugging						
		Time	1	.076	.567	.459	.024
		Time*Treatment	1	.025	.187	.670	.008
		Error	23	.135			
	Evaluating						
		Time	1	.138	.680	.418	.029
		Time*Treatment	1	.069	.342	.565	.015
		Error	23				

Note. df = degrees of freedom; MS = mean square; * $p < .05$.

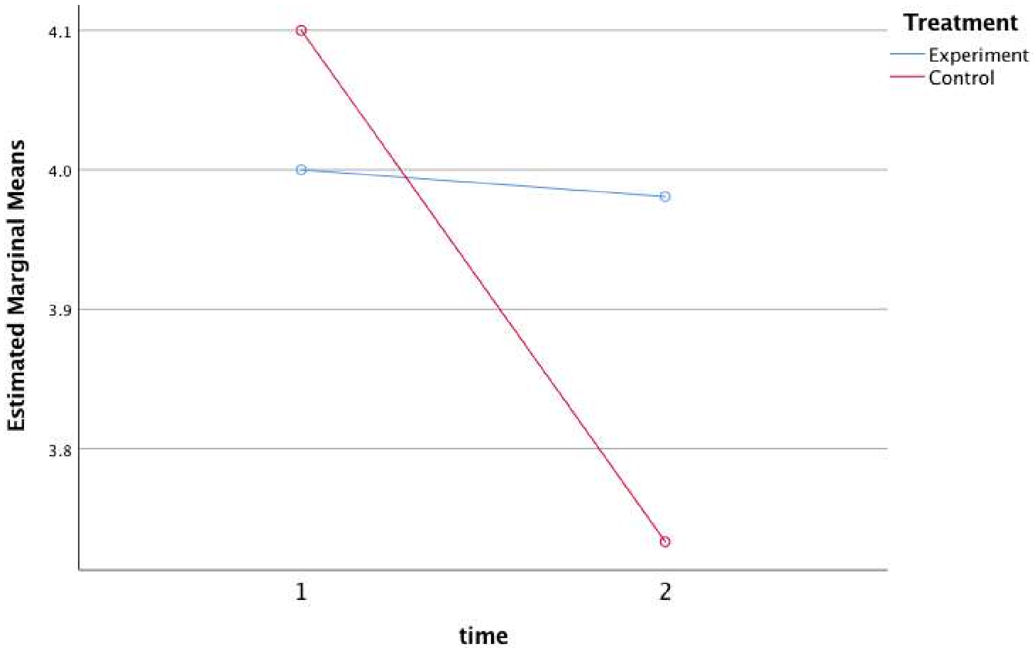


Figure 11. Comparison of means for conditional (i.e., strategic) knowledge.

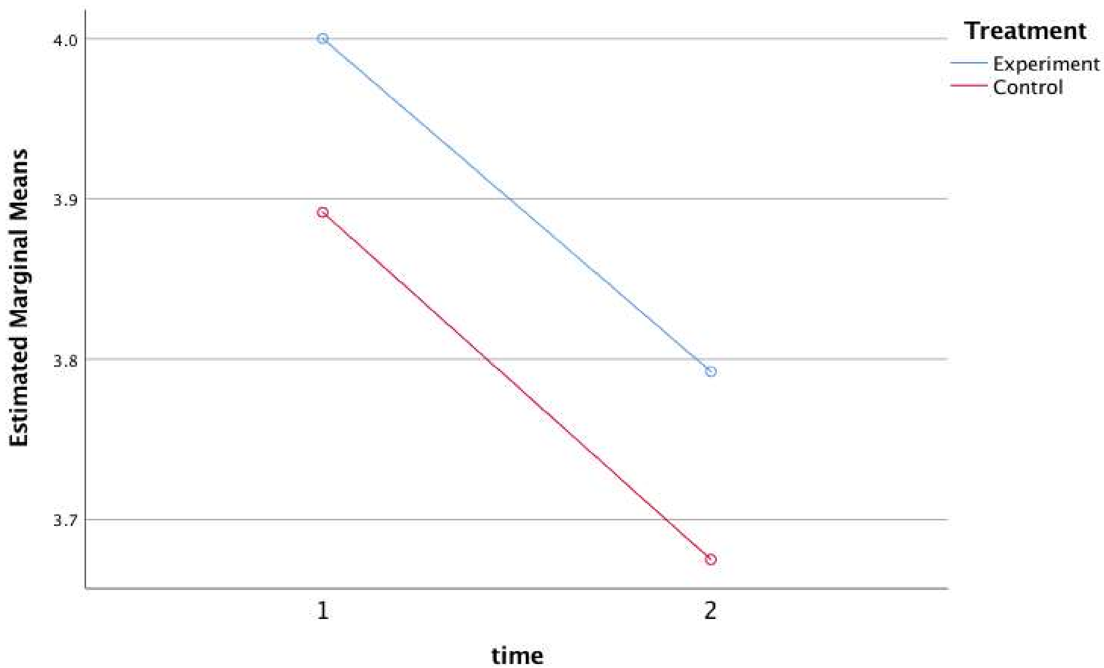


Figure 12. Comparison of means for information managing.

Table 14
Descriptive Statistics and Confidence Intervals

Measure	Experimental Group (n = 13)				Control Group (n = 12)			
	Pre-Test M (SD)	95% CI	Post-Test M (SD)	95% CI	Pre-Test M (SD)	95% CI	Post-Test M (SD)	95% CI
Metacognitive Knowledge	3.97 (0.51)	[3.71, 4.23]	3.97 (0.61)	[3.68, 4.25]	4.02 (0.39)	[3.75, 4.29]	3.77 (0.35)	[3.47, 4.06]
Declarative[1] Knowledge	4.04 (0.53)	[3.74, 4.32]	4.05 (0.61)	[3.75, 4.35]	3.94 (0.50)	[3.63, 4.25]	3.81 (0.40)	[3.51, 4.12]
Procedural[2] Knowledge	3.87 (0.62)	[3.55, 4.18]	3.87 (0.73)	[3.52, 4.21]	4.02 (0.47)	[3.69, 4.35]	3.75 (0.41)	[3.39, 4.11]
Conditional[3] Knowledge	4.00 (0.56)	[3.71, 4.23]	3.98 (0.63)	[3.69, 4.28]	4.10 (0.43)	[3.8, 4.40]	3.73 (0.36)	[3.43, 4.04]
Metacognitive Regulation	3.87 (0.52)	[3.60, 4.14]	3.78 (0.59)	[3.50, 4.06]	3.73 (0.46)	[3.45, 4.01]	3.70 (0.36)	[3.41, 4.00]
Planning	3.69 (0.69)	[3.33, 4.06]	3.63 (0.73)	[3.27, 3.98]	3.61 (0.56)	[3.23, 3.98]	3.80 (0.44)	[3.43, 4.17]
Information Managing	4.00 (0.57)	[3.73, 4.27]	3.79 (0.61)	[3.48, 4.10]	3.89 (0.35)	[3.61, 4.18]	3.68 (0.45)	[3.35, 4.00]
Monitoring	3.58 (0.48)	[3.31, 3.86]	3.73 (0.61)	[3.40, 4.05]	3.63 (0.47)	[3.35, 3.92]	3.59 (0.53)	[3.26, 3.94]
Debugging	4.25 (0.73)	[3.86, 4.63]	4.12 (0.51)	[3.85, 4.40]	4.08 (0.59)	[3.69, 4.48]	4.05 (0.44)	[3.77, 4.34]
Evaluating	3.83 (0.67)	[3.44, 4.20]	3.64, (0.76)	[3.27, 4.01]	3.42 (0.66)	[3.02, 3.81]	3.39 (0.48)	[3.00, 3.77]

Note. IMS = information managing; n = number of participants; M = mean; SD = standard deviation; CI = confidence interval for means at pre-test/post-test by group, reported as [lower bound, upper bound]; [1] Declarative (i.e., personal) knowledge; [2] Procedural (i.e., task) knowledge; [3] Conditional (i.e., strategic) knowledge.

Descriptive Statistics Characterizing Qualitative Recordings

An additional benefit of the quantitative study of the participants are the descriptive statistics which characterized the population of the participants in the study. Nine of the 11 participants interviewed completed the survey. Z-scores were calculated by taking the case score minus the mean, divided by the standard deviation of all post-test scores for each group (*n* = 17 and *n* = 14 for the experimental and control groups respectively). The average and standard of deviation for scores from the entire sample post-test for metacognitive knowledge (M = 3.88, SD = 0.56, and M =3.81, SD = 0.38 for experimental and control groups respectively) and metacognitive regulation (M = 3.70, SD = 0.53, and M = 3.75, SD = 0.39 for experimental and control groups respectively). The participants involved in the qualitative analysis with their associated z-scores were included below:

Table 15

Post-test Mean and z-Scores of Metacognition for Interviewed Participants

Treatment	Participant	Metacognitive Knowledge		Metacognitive Regulation	
		Mean	Z-Score	Mean	Z-Score
Control Group					
(n = 17)	C.5	4.49	1.82	4.47	1.83
	C.6	4.17	0.96	4.17	2.06
	C.10	3.62	-0.51	3.59	-0.39
Experimental Group					
(n = 14)	E.1	3.4	-0.84	3.30	-0.75
	E.3	3.81	-0.11	3.86	0.30
	E.5	4.24	0.65	3.82	0.22
	E.8	4.1	0.40	3.80	0.19
	E.9	4	0.22	3.48	-0.41
	E.10	3.43	-0.99	3.38	-0.94

An in spection of the interviewed-participants' post-intervention scores revealed a diversity of reported metacognitive knowledge and regulation, with some individuals' scores nearly one standard deviation below the mean, and others nearly two standard deviations above the mean. Such diversity was evaluated as an appropriate condition for sampling the population for qualitative analysis. Further, the above self-perceptions of the participants will be taken into consideration during the qualitative analysis of the participants' interviews.

Analysis

Given the low number of participants for the quantitative analysis (i.e., $n = 23$), the power of the statistical tests was limited for detecting statistically significant effects. As illustrated above using G*Power, a minimum of $n = 128$ (64 participants for each condition) would be needed to obtain findings that were statistically significant.

The conditional (i.e., strategic) knowledge subscale was found to be statistically significant, before the consideration of the adjusted alpha level, for the main effect of time and also for the interaction of time and the intervention (M = 4.000 ± 0.560 pre-test to M = 3.981 ± 0.626 post-test for the experimental group and M = 4.100 ± 0.494 pre-test to M = 3.733 ± 0.355 post-test for the control group). The present study indicated an effect just short of significance (when adjusted for $\alpha = .005$) for change over time, with a tendency for the intervention group to maintain their knowledge from pre-test to post-test. The nearly significant effect noted for the intervention was in alignment with the findings of Mevarech and Fridkin (2006) who affirmed minor increases in the conditional (i.e., strategic knowledge) subscale for participants who received the IMPROVE intervention when compared with the control group. It was noted that the control group demonstrated a decrease in the perceived conditional (i.e., strategic) knowledge in comparison with the experimental group, which was relatively stable. This was attributed (with caution, considering the lack of validity reported by Harrison and Vallin, 2018) to the metacognitive intervention, which provided increased awareness of strategic knowledge through focused attention and practice on utilizing strategic knowledge acquired.

Although not a focus for this study, Information Managing was statistically significant for the main effect of time before consideration of the adjusted alpha level (M = 4.000 ± 0.570 to M = 3.792 ± 0.605 for the experimental group and M = 3.892 ± 0.348 to M = 3.675 ± 0.454 for the control group). The means decreased over time for both experimental and control groups. The overall information managing mean was M = 3.946 ± 0.470 pre-test and M = 3.734 ± 0.530 post-test. This was attributed (with caution, considering the lack of validity reported by Harrison and Vallin, 2018) to increases in difficulty in the problem-solving sets as the semester progressed, which increased potential cognitive overload, leading to participants acknowledging lower performance in managing information.

In summation, although generalized conclusions about the effects of the intervention over time cannot be made, some results nearly aligned with those found within the literature (e.g., Mevarech & Fridkin, 2006). A full analysis with the minimum requisite participants would be needed in future studies to make conclusions about the effects of the intervention. Fortunately, previous studies showed the positive effects of the IMPROVE intervention on general metacognitive knowledge and regulation (e.g., Mevarech & Fridkin, 2006; Mevarech & Kramarski, 2014, etc.), as well as the increases in metacognitive ability over time (McCabe, 2011). Therefore, given what is known in the literature, it can be inferred that metacognition prevented a decrease in conditional (i.e., strategic) knowledge for experimental and control groups over time; a detailed analysis of the qualitative data collected in this study validated this inference (See *Triangulation of Data,* p. 224).

Lastly, the descriptive statistics indicated how the participants included in the final interview compared with those from the population assessed. It was concluded that the sample of participants which volunteered for the interview was sufficiently diverse, with participants both above and below the reported averages. This information was instrumental in contextualizing the participants' comments about their metacognitive performance, as was included in the qualitative analysis of the interviews (below).

CHAPTER FIVE: IN-COURSE DATA RESULTS AND ANALYSIS

Coding Process

A thirty-minute sample of participants' audio-recorded conversations during weeks 3 and 5 were listened to and coded according to a priori categories; selection was based on metacognition research. Schraw and Dennison's (1994) model was used for metacognition; therefore, groups' discussions were categorized as metacognitive knowledge (MK) (i.e., the categories of person, task, and strategy), as well as, metacognitive regulation (i.e., planning, monitoring, debugging, and evaluating). Additional categories emerged (i.e., Personal, Procedural, Social, Transfer, and Silence). Statements were coded to a category. Each of the categories, with samples, in Table *16* and Table *17* below, indicated the origin of the data by participant and group, with generic titles (e.g., Participant E.1 to E.12 for the Experimental Group and Participant C.1 to C.11 for the Control Group) to preserve the confidentiality of the participant.

Format for Quotations From Participants.

Several choices were made when reporting quotations from the participants to facilitate readability. First, numeric values were reported in numeric form, given the volume of numbers written. To facilitate readability, the word, "zero", substituted its numeric form. Variables were italicized (e.g., *x*), and references to questions were capitalized and italicized (e.g., *2B*). The dash, (e.g., "–") was used to signify interruption of the speaker, either by another participant or by the self. Lengthy quotations were reported in single-spaced format, contrary to standard APA guidelines. Lastly, when appropriate, descriptors of behaviour were added in square brackets (e.g., [Chuckles]) when observed.

Table 16
Metacognition Codes with Samples

Coded Theme	Description	Example	Condition	Participant
MK Person	Participant displayed knowledge of personal capabilities in a content area, task, strategy, or skill.	E.12: I never faced a question like this.	Exp.	E.12
		C.3: I didn't learn it by replacing the middle part as '*x*', I just…[Continues below] C.4: You find the derivative. C.3: …did it, use these rules, that is just how I was taught.	Control	C.3 and C.4
MK Strategy	Participant expressed knowledge regarding specific or generic strategies as students.	E.11: You know what I mean? It just kind of said show that – E.9: Yeah yayayaya, I understand, no I understand now [Both chuckle] E.11: So, here, it makes sense. E.9: Yeah. Say less. E.11: Yeah.	Exp.	E.9 and E.11
MK Task	Participant showed details and understandings of cognitive tasks.	E.5: What's the inverse of the derivative again? E.6: Just give me a sec. For cotangent inverse it's negative one over x plus x squared.	Exp.	E.5 and E.6
Planning	Participant expressed intentions towards their own personal development	E.3: I'll check those after.	Exp.	E.3
		C.1: Was just thinking I'm to use the information to do the derivative here and I just do the differentiation for the number e rule.	Control	C.1
Monitoring	Participant expressed ongoing, live monitoring of present thought on a topic.	C.1: Holy shit, this [dude?] is listening to all the songs I was just listening to all the time C.2: [Chuckles]. C.1: Enjoy the songs, mate.	Control	C.1 and C.2
Debugging	Participant demonstrated cognitively working out multiple, possible solutions.	C.4: Isn't there supposed to be something in front of the *n*? There is supposed to be something here, just like that.	Control	C.4
Evaluating	Participant stated conclusions regarding content and processes learned.	E.4: I feel like they threw in the derivatives of the inverse functions just so there's more of them.	Exp.	E.4

Note. MK = metacognitive knowledge; Exp = experimental group. Descriptions adapted from: Transmitting Metacognitive Pedagogy to Math Pre-Service Educators (p. 417) by J. Teeuwen and G. Salinitiri, 2019, in G. Mariano and F. Figliano (Eds.), *Handbook of Research on Critical Thinking Strategies in Pre-Service Learning Environments*. IGI Global. Copyright 2019 by IGI Global.

Table 17
Other Codes with Samples

Coded Theme	Description	Example	Condition	Participant
Transfer	Participant demonstrated the use of knowledge or skills in other contexts (i.e., outside of mathematics)	E.4: When [are] implicit functions used in real life? When are they used in – E.3: Probably higher level math. E.4: Yeah. E.2: That's … always the answer. E.1: Yeah, that's always the answer. When is it used? High-level math! E.4: Why do we use more difficult math? In even more difficult math! E.1: That's why. E.4: Yeah. E.3: [Concurrent, to self] Damn right. E.2: And maybe building a rocket ship, I don't know. I want to build a rocket ship that's my goal.	Exp.	E.1, E.2, E.3 and E.4
Personal	Participants discussed topics related to personal or social interests	C.2: Are you waiting to get the knowledge? C.1: I'm waiting to get the knowledge, I'm getting really inspired. I am inspired. Am I getting inspired? To get the answers? C.2: You're getting the knowledge, straight to your head. Straight to your head.	Control.	C.1 and C.2
		[Discussion about 'snapchat' for 30 seconds]	Control	C.5 and C.6
Procedural	Participants discussed procedural issues with respect to the course, laboratories, or grades of the course.	E.5: I got 5 marks for that one oh, I got full marks. E.6: You got full marks? E.5: Yeah.	Exp.	E.5 and E.6
		C.2: Me? …[In response to Instructor] C.1: You gave us quiz *4*. C.2: *5* came from over there, but, I have quiz *4* and *5*.	Control	C.1 and C.2

Note. Exp = experimental group. Description of transfer adapted from: Transmitting Metacognitive Pedagogy to Math Pre-Service Educators (p. 417) by J. Teeuwen and G. Salinitiri, 2019, in G. Mariano and F. Figliano (Eds.), *Handbook of Research on Critical Thinking Strategies in Pre-Service Learning Environments*. IGI Global. Copyright 2019 by IGI Global.

Promptings' major purpose was to emphasize corresponding metacognitive components. These components connected to the prompts of Mevarech and Kramarski's (1997) IMPROVE model via the following table (Teeuwen & Salinitri, 2019):

Table 18
Connecting Prompts with Emphasized Metacognitive Components

Theme	Prompts	Description	Emphasized Metacognitive Component
Comprehension	What is the problem/task?	Prompts addressed the participants' attention to a particular task or problem.	Metacognitive Knowledge (Person, Task, and/or Strategy)
Connection	What is the difference/similarity between the tasks/procedures? How do you justify your conclusion?	Prompts addressed comparison, analysis and justification of their conclusions.	Planning
Strategy	What is the strategy? How and when should I select/implement the strategy? Why? What other strategies are available?	Prompts addressed a particular strategy, its use, and alternatives.	Monitoring
Reflection (Debugging)	Does the solution make sense? Can the solution be presented otherwise?	Prompts addressed challenges regarding participants' thinking for the purpose of analysis.	Debugging
Reflection (Evaluating)	Am I satisfied with how I faced the task? Can the task be solved otherwise? How can I solve it in another way? Am I stuck? Why?	Prompts addressed challenges regarding judgments made during participants' reflections.	Evaluating
Transfer	Where else could these strategies/this process be used? What have you learned from solving this problem that is useful in your other courses? What have you learned about your learning process?	Prompts emphasized explicit use of learned concepts and processes outside of the course of study, particularly in their general teaching practice.	Transfer

Note. Adapted from Descriptions adapted from: Transmitting Metacognitive Pedagogy to Math Pre-Service Educators (p. 418) by J. Teeuwen and G. Salinitiri, 2019, in G. Mariano and F. Figliano (Eds.), *Handbook of Research on Critical Thinking Strategies in Pre-Service Learning Environments*. IGI Global. Copyright 2019 by IGI Global.

In-Course Data Selection Process

Pintrich et al. (2000), in their analysis of different methods for measuring metacognition, indicated that “real-time” measures of metacognition require extensive interviews with individual participants. Since a deep analysis of the qualitative data was desired, a thematic analysis was also considered. Thematic analysis allowed for the natural emergence of a theme based on the available data (Braun & Clarke, 2006). The power and resolution of qualitative analyses when assessing metacognition were argued to be favourable by several researchers with respect to the use of online measures of metacognition (e.g., Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009), particularly when observing social metacognition (e.g., Mevarech & Amrany, 2008). For the purposes of this study, and for in-depth analysis on the transfer of metacognition, a longitudinal examination of one experimental group and one control group’s dialogic practice was used. In combination, these were expected to glean insight into the development of participants’ metacognitive abilities and indicate qualitative differences between the conditions regarding the transfer of these skills to other domains.

Since three groups were recorded from both experimental and control conditions, selection criterion of a single group needed to be established. Weeks 3 and 5 were chosen to help make this selection in order to highlight potential contrasts between the conditions, understanding that few differences were expected during weeks one and two.

Regarding the samples, it was noted that a participant was absent from one group of the experimental condition during Week 3. Consequently, an additional sample was assessed from the second week in order to identify potential changes in the participants’ discussion and further assist in the selection process between the experimental groups.

Given the importance of dialogic, reflective practice, it was deemed vital that all sides of the conversation be observed. As participants were permitted to discuss with members outside of the recording, some participants' conversations were only observed on one side, preventing full access to the discussions that took place. Consequently, the first criterion was determined to be the observation of all participants within a conversation for both the experimental and control conditions. Therefore, groups who conversed between all recorded participants were selected over groups where individuals conversed with non-recorded participants.

Given the focus of the study on specific components of metacognition, a second selection criterion was the diversity of a given sample's metacognition for both experimental and control conditions. When observing the experimental condition samples, diversity of the use of prompts was an additional criterion applied, to intentionally illustrate the impact of the use of prompts on the quality of conversations.

A third criterion was the depth of the discussion which was identified in the sample by several components. Those prticipants whose conversations focused on the task took precedence over groups whose discussion fell off-task. Depth was assessed with respect to demonstrations of higher levels of cognition as per Bloom's Taxonomy (Anderson & Krathwohl, 2001). These included demonstrations of understanding, making connections to content both within and outside the course (i.e., calculus), and the groups' demonstration of critical analysis. An additional criterion for the experimental condition was the demonstration of transfer, the focus of the study. Given the predictions made for this study, demonstrations of transfer by the completion of the study were not expected to occur with a high frequency.

Lastly, groups who demonstrated diversity within the group (i.e., participants who demonstrated both novice and advanced abilities) were preferred over homogeneous groups to provide the broadest picture of the impact of the process. Previous research showed that advanced individuals demonstrated the metacognitive components of planning (e.g,. Kramarski & Friedman, 2014) and monitoring (e.g., Hessels-Schlatter et al., 2017). While participants possessed similar prior experience, not all participants demonstrated equal metacognitive ability. Consequently, participants were identified as potential advanced metacognitive practitioners if they demonstrated the use of planning and monitoring, independent of prompting, and participants who did not demonstrate these were identified as potential novice practitioners. Therefore, groups who demonstrated the most diversity in ability (i.e., both novice and advanced participants) were selected.

Summaries of the criterion for each group are included in the Table *19* below. Group 1 for the experimental condition (Participants E.1, E.2, E.3 and E.4) and Group 1 for the control condition (Participants C.1, C.2, C.3 and C.4) were selected for analysis.

Table 19
Characteristics of All Groups in the Study

Source			Criterion						
			1	2		3			4
Condition	Group	*n*	Participants Conversations	Metacognition Demonstrated	# of Prompts Used	Time on Task	Levels of Cognition	Transfer	Diversity of Ability
Experimental									
	1	4	All Participate	All Components	4	Strong	High	Yes	Advanced and Novice
	2	4	Independent Discussions	Missing MK Strategy	2	Strong	Low	No	Novice
	3	4	Two Participate Frequently	Missing MK Strategy	1	Medium	Low	No	Novice
Control									
	1	4	All Participate	All Components		Strong	Medium	No	Advanced and Novice
	2	4	Two Participate Frequently	All Components	N/A	Low	Low	No	Novice
	3	3	Two Participate Frequently	All Components		Low	Low	No	Novice

Note. n = Number of participants

Selecting a group from the experimental condition. Group 1 for the experimental condition demonstrated the only recorded instance of transfer among all samples. The majority of the group's discussion surrounded troubleshooting different problems as a group, while one member (who demonstrated advanced metacognitive capabilities) participated less often than the others. Overall, the group demonstrated a significant volume of intergroup discussion, even to the point of interrupting each other.

One such example of intergroup discussion surrounded the use of a metacognitive strategy prompt,

> E.4: I think I've started to appreciate brackets more because it's like, 'Alright, we're keeping these' –
> E.1: Just focus right there, right there, don't look at everything else. It's scary, don't look at the rest.
> E.4: Just keep these problems, over here.
> E.2: No, honestly. I have never used more brackets than I have in Calculus.
> E.4: Yeah.
> E.2: I even put brackets in when it's trig. I even use brackets with cotangent(x).
> E.4: Yeah.
> E.1: It helps me focus, 'Identify what the problem is'.
> E.2: It's a great strategy. I would definitely implement that strategy every single time I use a calculus question [Joking tone, laughter].
>
> ~Experimental Group 1, Week 3

Analysis of the above revealed that the participants discussed the merits of using brackets as a strategy in the context of applying algebra while solving problems for implicit differentiation. It was clear by the discussion that the participants recognized multiple functions for brackets, specifically on their ability to focus on an individual's attention, and on the necessity of this within the field of Calculus. Other such rich discussions were found throughout the samples by this group.

Group 2 for the experimental condition demonstrated quiet focus, with an emphasis on completing problems as a unit. Individual solutions appeared to be attempted with comparison as an implied group strategy to verify solutions. A concerted effort to collaborate and use prompts at the beginning of the sample surfaced, as demonstrated by the following quote:

> E.5: Alright, so, we have to use chain law for this, right guys?
> E.7: Wait, wait. Where is the thing?… [Continues below]
> E.6: We gotta use chain and product–
> E.7: …What is the problem/task?
> E.6: Well, the problem is to find the derivative of this question.
> E.5: And we have to use that through the chain law?
> E.6: Why not product law?
> E.7: We have to find *y* prime at–
> E.6. Yeah but chain and product, though.
> E.5: Well, chain and product. Yeah, exactly.
> E.7: Yeah, so we're going to attack this by using all of our knowledge for derivatives, and applying it.
> E.6: All of the knowledge we gained, right [Participant E.8]?
> E.8: Yes sir.
> E.6: All the knowledge.
> E.8: All the knowledge.
> E.7: I don't know; I feel so cheesy with this.
>
> ~Experimental Group 2, Week 3

It was evident from this quote that the participants attempted to use the prompts, but their discomfort with using the process was also apparent, as noted by Participant E.7. This effort waned as the group demonstrated individual practice, reciting metacognitive task knowledge and attempting to troubleshoot/debug problems as an individual or pair. One such example of this is:

> E.6: What's the inverse of the derivative again?
> E.5: Just give me a sec. For cotangent inverse it's negative one over *x* plus *x* squared.
> E.7: [Concurrent] I think, I think that's good. How are we going to tackle *B*?
> E.8 It's negative one over *x* plus one, *x* plus…
>
> ~Experimental Group 2, Week 3

Participant E.7 appeared to either be speaking individually or was unanswered by the group, while the remainder of the group focused on troubleshooting the process of finding the derivative of cotangent inverse.

Group 3 for the experimental condition demonstrated independent approaches to solving the problems during the Week 3 sample where a participant was missing, and during the Week 2 sample which featured the full group in attendance. One participant consistently engaged with participants outside of the recorded participants, making the data difficult to understand without full context. Analysis of the following example illustrated this effect,

> E.9: I'm taking the derivative of this whole thing right here so the derivative's gonna go into ln *y* and *y*.
> E.11: Okay, and it'd be 1 over *y.* Okay.
> E.9: 1 over *y* and then *y* prime. And I'm just doing product rule.
> E.11: Okay.
> E.9: And I have the derivative of *x* times the ln sin(x) plus *x* times ln sin(x) to the derivative.
> E.11: Okay.
> E.9: And then, I have *y* prime here. I just times both sides by *y.* So then I have *y* on the outside.
> E.11: What happened to the 1 over *y*?
> E.9: Oh, that's what I mean, so I'm timesing *y* by both sides [Metacognitive task knowledge follows].
> E.12: [Concurrently, as a separate discussion] I'm simplifying more than I need to, what the hell is my problem? [Off-microphone member responds]. Cos(x) over sin(x) is equal to cotangent *x.* Yeah, right? [Off-microphone member responds]. Look. Yo, did you end up getting for *C*, sin(x) to the power of *x* times ln of sin(x) plus *x* cotangent *x?* Or plus *x*. Yeah, okay. [Off-microphone member asks a question]…One second. Yeah? [Off-microphone member asks a question].That's the best way to do it. [Off-microphone member responds]. Don't put *y*, just substitute it there. Don't waste your space [Off-microphone member answers] Yeah, you have to. That's what she said, just to be safe.
>
> ~Experimental Group 3, Week 3

While Participants E.9 and E.11 continued to discuss and troubleshoot problems, Participant E.12 initiated discussions with off-microphone participants who were not recorded. A similar example was found even when the fourth participant was present during the second week,

> E.10: The question says, 'By the definition of the derivative,' we have to show that?
> E.9: Yeah.
> E.10: [Audible sigh]
> E.9: 'Cause like each one is like, six marks.
> E.10: Why is it, like, it has to be so complicated when we know the answers. Alright, by the definition of the derivative –
> E.9: What'd you get for *A*?
> E.11: Sorry?
> E.9: What'd you get for *A*?
> E.11: I'm still do – Oh – Yeah, I am still doing it for now.

> E.12: [Concurrently, as a separate discussion]: [snickers]. You're making a big mistake, *x* is zero. [Off-microphone member responds]. We know we're using this one 'cause *x* equals zero, the function equals zero. [Off-microphone member responds]…Yeah. We did it in class, like literally the exact same question [Off-microphone member asks a question] It's *h* cubed…[Off-microphone member asks a question]…It became this.
>
> ~Experimental Group 3, Week 2

Again, Participant E.12 engaged numerous others in conversations regarding the problems. It was determined that the level of engagement between the remaining participants was consistently low, with discussion revolving around troubleshooting problems. In summation, the sample analysed for Group 1 satisfied the most criterion, with all members participating at high levels of cognition and demonstrating all components of metacognition and metacognitive ability, making their group the best selection for longitudinal analysis of the experimental group.

Selecting a group from the control condition. A participant from Group 1 of the control condition frequently engaged in what was termed "self-talk"; this person discussed the completion of the problems independently from the other participants. This self-talk individual showed numerous indications of planning and monitoring, advanced metacognitive skills, as evident in the following discussion between Participants C.3 and C.4:

> C.3: So question *D*. I'm thinking that's implicit differentiation, 'cause it looks too messy to do it implicitly. So, other way around, using implicit right now, oof.
> C.4: I do not understand how to do this.
> C.3: *A*?
> C.4: Yah *A*. How do you do the inverse of this?
> C.3: Not doing the inverse, doing the derivative.
> C.4: Oh, the derivative.
> C.3: So, It's the product rule. So, derivative of the first one, so–
> C.4: Oh, I think I got it.
> C.3: *f* of *x*, and the derivative of this, *g* of *x*.
> C.4: I think I got it.
> C.3: Okay. So that is, put it down…Okay, enough for that question. So, take the derivative of both sides. Oh fun! d 6 of dx, dx *y* squared over dx, plus dx square y over dx, and it's – d, and is solve[d] by – To the power of four, over dx.
> C.3: [Presented as self-talk] Then I'm just doing the derivative, do the product rule is. Take the derivative of *y* with respect to *x*. You have to – You can't do it. You have

> to leave the function as it is, and that is just, *x*. 2*x*. 2*y,* I mean. Yeah, that's [product rule], divide by dy by dx with respect to *y*. Take the derivative of *y*, plus, to another product rule again. Do that primed, plus *x* squared, divide by dx and then derivative of this would be positive 16 by 3 multiplied by 3*y* by 3*x* equals zero. 'Cause the – and just factor out the dx, divide by the dx's and solve for it. Mmm. Hopefully it's correct.
>
> ~Control Group 1, Week 3

Here, it was evident that Participant C.3 demonstrated signs of monitoring when the individual described what tasks were being completed (i.e., "then I'm just doing the derivative…"). Further, numerous indications of planning were present in the above quote, (e.g., "I'm thinking that's implicit differentiation"). The remaining members of the group worked together, and though novice, their conversations occasionally demonstrated monitoring with awareness of them being recorded. Concurrent to the quote above, an emphasis on debugging problems and discussing metacognitive task knowledge related to the problems at hand was observed,

> C.4: This is a 1 over –
> C.2: Skip 3?
> C.1: For now.
> C.2: This one says 4, like 4*x* ? Number *1*: 2 tan(x).
> C.4: Tan(x). O-kay.
> C.2: [Self-talk featuring metacognitive task knowledge]
> C.1: Can someone shut [Participant C.3] up? [The member's] voice is annoying.
> C.2: [Chuckles]. Um [Voice trailed].
> C.1: I'm going through withdrawal, so that's really annoying, three things…withdrawal.
> C.2: Time for a break?
> C.1: He does not shut up.
> C.2: Yeah.
>
> ~Control Group 1, Week 3

This discussion showed their awareness of Participant C.3's self-talk, and other than asking for assistance with questions, the remaining participants seemed to leave the individual alone. Two of the participants of Group 2 of the control condition were distracted for more than half of the sample,

C.5: You didn't do this.
C.6: No, I just wrote it like in order instead of writing it like that I wrote it like downwards.
C.5: Is that fine if I wrote it like that?
C.6: Yeah, it's fine, I just didn't want to write the work.
C.5: How did you do number 5?
C.6: What do we do, Morty?
C.8: Morty? Yeah, she's Morty.

~Control Group 2, Week 3

While beginning on-topic, the participants spent the next two minutes discussing: the television show *Rick and Morty*; what they did for Halloween; one participant discussed completing a psychology essay and showing up late to class; finally, the conversation moved back to Halloween. One participant within this group was largely focused, while the remaining participant occasionally was on-task, and occasionally was distracted. This is evident in the following discussion where Participant C.7 attempted to instruct Participant C.8 in how to use the *ln* function to solve a problem:

C.7: Why wouldn't you do ln? Are you asking, 'Wha – How do you – '
C.8: Yah. It's in the properties. My god!
C.5: Me too.
C.8: We are not memorizing the damn properties.
C.7: Well, if you want to know, that's what you do, you asked for log right?
C.7: Yeah, log base l, that's just literally a property? I need to prove that one day.
C.8: Ahh. I know how to prove it, so you do change the bases.
C.7: So you change the log to ln.
C.8: I still don't know how to change bases.
C.7: No, you don't.
C.8: I know *they* want us to, but I want to learn how to do it.
C.7: K, I'm trying it.

~Control Group 2, Week 3

It was evident that Participant C.7 was attempting to explain the problem, while Participant C.8 demonstrated metacognitive personal knowledge about individual knowledge limitations with discomfort, "We are not memorizing the damn properties." One of the three participants of

Group 3 of the control condition regularly engaged with individuals who were not being recorded, for example:

> C.9: Yah, like, we have to, like, memorize this? We have to memorize these formulas? [Off-microphone member responds]…Cause it's longer. I mean, I wasn't there, so I'm not suppose–
> C.9: [In response to off-microphone member] That actually is really short.
> C.9: I'm just going to ask her, 'What is the answer?' 'cause it seems too easy…[Conversation continues with off-microphone member]
>
> ~Control Group 3, Week 3

Despite this, the group demonstrated collective discussions,

> C.9: But, like, look here, like, look.
> C.10: Look, there's this way, there's l-n [i.e., ln]
> C.11: Yayaya, then yaya. There's two ways.
> C.10: They would get a different answer then.
> C.11: Ya, it's a different answer than ours.
> C.11:This is the final answer here, but I just want to ask her, but wait –
> C.9: So right here.
> C.11: Oh wait, wait –
> C.9: So, you know how it's like ln *y* here?
> C.11: Oh, yayayaya I know why is that, because here, it's just simplification, because this one, where is the question? What is the question? Okay okay.
> C.10: So it's just resubstituting this for *y*.
> C.11: Yayaya.
> C.9: And they put it like that.
> C.11: So here instead of *y.* So our *y*, is this one, *e* to the [pause]. Why is our *y* like that?
> C.10: Hm?
> C.9: Where'd you get that question from?
> C.11: Our notes.
>
> ~Control Group 3, Week 3

The focus of the conversations surrounded methods to solve problems with each taking turns as the lead; however, rarely were advanced skills such as planning demonstrated. None of the participants in this group demonstrated such expertise during the samples.

In summation, Group 1 satisfied the most criterion, where all members: participated at higher levels of cognition, remained focused on-task more frequently, and demonstrated the most diversity of the components of metacognitive ability, making their group the best selection for the in-course data analysis of the control group.

Quantitative Analysis of In-Course Data

Recall, the aim of this study was to assess the impact of a metacognition intervention on participants' transfer of metacognition to domain-general (i.e., far), immediate, delayed, routine, and novel contexts. Systematic observations and "think-aloud protocols" of the groups' conversations were found to be typical methods for assessing metacognition (e.g., Pintrich et al., 2000; Akturk & Sahin, 2011).

Conversations were categorized by topic change. Considering the interplay between cultural and personal understandings developed during mathematics as a social process (Schoenfeld, 1992; Vygotsky, 1978), categorical data pertaining to the groups' conversations was selected over individual statements. Examination of groups' conversations was expected to yield patterns in their metacognitive skills in a social context (e.g.., Kramarksi & Dudai, 2009; Mevarech & Amrany, 2008). Therefore, an analysis by topic count of groups' conversations was an appropriate manner to assess the immediate and delayed effects of the intervention on the development of metacognitive skills and participants' transfer of those skills to other contexts. Specifically, data was searched for: the metacognitive skills exposed to individuals by their environments (i.e., peers); patterns in the solicitation and emergence of these skills by the experimental and control condition; and overall patterns, with time, in participants' use of metacognition throughout the problem-solving sets.

Frequency counting. In-course data of the experimental and control groups (i.e., Group 1 of both conditions) were analysed quantitatively. Frequency counting of themes employed the coded themes listed in Table *16* (p. 98) and Table *17* (p. 99), based on topics of conversation. In other words, codes were identified and counted, based on changes in the topic of conversation. Consequently, it was not uncommon to identify multi-coded themes for a given topic (e.g., metacognitive knowledge of the task along with debugging). Concurrent themes were incorporated throughout the qualitative analysis below.

Coded themes were totalled each week and overall. The frequency with which each theme appeared was calculated as a percent of coded categories for the various conversational topics observed. These results were included in *Table 20* and *Table 21* below.

Table 20
Frequency Counts of In-Course Data for the Experimental Condition

Theme	**Week 1**		**Week 2**		**Week 3**		**Week 4**		**Week 5**		**Totals**	
	#	%	#	%	#	%	#	%	#	%	#	%
MK Person	5	3.4	9	6.2	10	4.6	3	2.3	5	2.7	32	3.9
MK Task	43	29.5	33	22.8	62	28.4	37	28	51	27.7	226	27.4
MK Strategy	7	4.8	12	8.3	20	9.2	9	6.8	11	6.0	59	7.2
Planning	9	6.2	5	3.4	8	3.7	10	7.56	9	4.9	41	5.0
Monitoring	10	6.8	15	10.3	9	4.1	6	4.56	9	4.9	49	5.9
Debugging	32	21.9	34	23.4	57	26.1	35	26.5	52	28.3	210	25.5
Evaluating	15	10.3	19	13.1	24	11	12	9.1	25	13.6	95	11.5
Transfer	3	2.1	3	2.1	3	1.4	1	0.8	0	0	10	1.2
Personal	5	3.4	8	5.5	8	3.7	7	5.3	14	7.6	42	5.1
Procedural	7	4.8	3	2.1	5	2.3	4	3.0	5	2.7	24	2.9
Prompt	7	4.8	2	1.4	9	4.1	3	2.3	2	1.1	23	2.8
Silence/Quiet	3	2.1	2	1.4	3	1.4	5	3.8	1	0.5	14	1.7

Note: MK = metacognitive knowledge

Table 21
Frequency Counts of In-Course Data for the Control Condition

Theme	Week 1		Week 2		Week 3		Week 4		Week 5		Totals	
	#	%	#	%	#	%	#	%	#	%	#	%
MK Person	8	7.3	9	9.4	5	3.6	7	5.6	5	3.5	34	5.5
MK Task	39	35.8	27	28.1	45	32.1	34	27.0	38	26.8	183	29.9
MK Strategy	7	6.4	8	8.3	1	0.7	9	7.1	5	3.5	30	4.9
Planning	4	3.7	2	2.1	9	6.4	7	5.5	2	1.4	24	3.9
Monitoring	0	0	2	2.1	8	5.7	3	2.4	3	2.1	16	2.6
Debugging	29	26.6	22	22.9	37	26.4	24	19.0	34	23.9	146	23.8
Evaluating	7	6.4	14	14.6	21	15.0	14	11.1	20	14.1	76	12.4
Transfer	0	0	1	1.0	0	0	0	0	1	0.7	2	0.3
Personal	7	6.4	4	4.2	4	2.9	13	10.3	21	14.8	49	8.0
Procedural	5	4.6	5	5.2	6	4.3	14	11.1	10	7.0	40	6.5
Prompt	0	0	0	0	0	0	0	0	0	0	0	0
Silence/Quiet	3	2.8	2	2.1	4	2.9	1	0.8	3	2.1	13	2.1

Note: MK = metacognitive knowledge.

Dominant themes. An inspection of *Table 20* and *Table 21* revealed the top three categories observed throughout the in-course data of both conditions. Ordered from most frequent to least, these are: metacognitive task knowledge, debugging, and evaluating. This was consistent throughout the data, with only two notable exceptions. Although evaluating was ranked third overall for the control condition, results from Week 4 indicated equal recurrence for procedural and evaluating topics (11.1% each); results from Week 5 indicated a greater focus on personal topics (14.8%) when compared with evaluating (14.1%); and results overall indicated that the sum of personal and procedural topics (14.5% collectively) exceeded evaluating (12.4%) (See the theme *Explicit instruction*., p. 135). Week 5 in the experimental condition indicated a higher frequency for debugging over metacognitive task knowledge. An inspection across all weeks for the experimental condition showed that, although these two categories were similar for Weeks 2 through 5 (i.e., within 2.5%), metacognitive task knowledge exceeded debugging, overall. Although further data was required before population generalizations were made, it was concluded that metacognitive task knowledge and debugging were the two most frequently observed themes in participants' discussions, followed by evaluating.

These results were expected, as researchers indicated metacognitive task knowledge and evaluating as frequently demonstrated novice skills (e.g., Kramarski & Dudai, 2009; Mevarech & Amrany, 2008). The high incidence of debugging aligned with the findings of Kramarski and Friedman (2014) who showed that debugging occurred more frequently with participants who had no exposure to prompts or had control over their exposure to metacognitive prompts, when compared with individuals who received unsolicited prompts. In summation, the most observed themes of metacognitive skills, in alignment with what was expected from the literature, were metacognitive task knowledge, debugging, and evaluating for the experimental group (27.4%, 25.5%, and 11.5% respectively), with similar findings for the control group (29.9%, 23.8%, and 12.4% respectively).

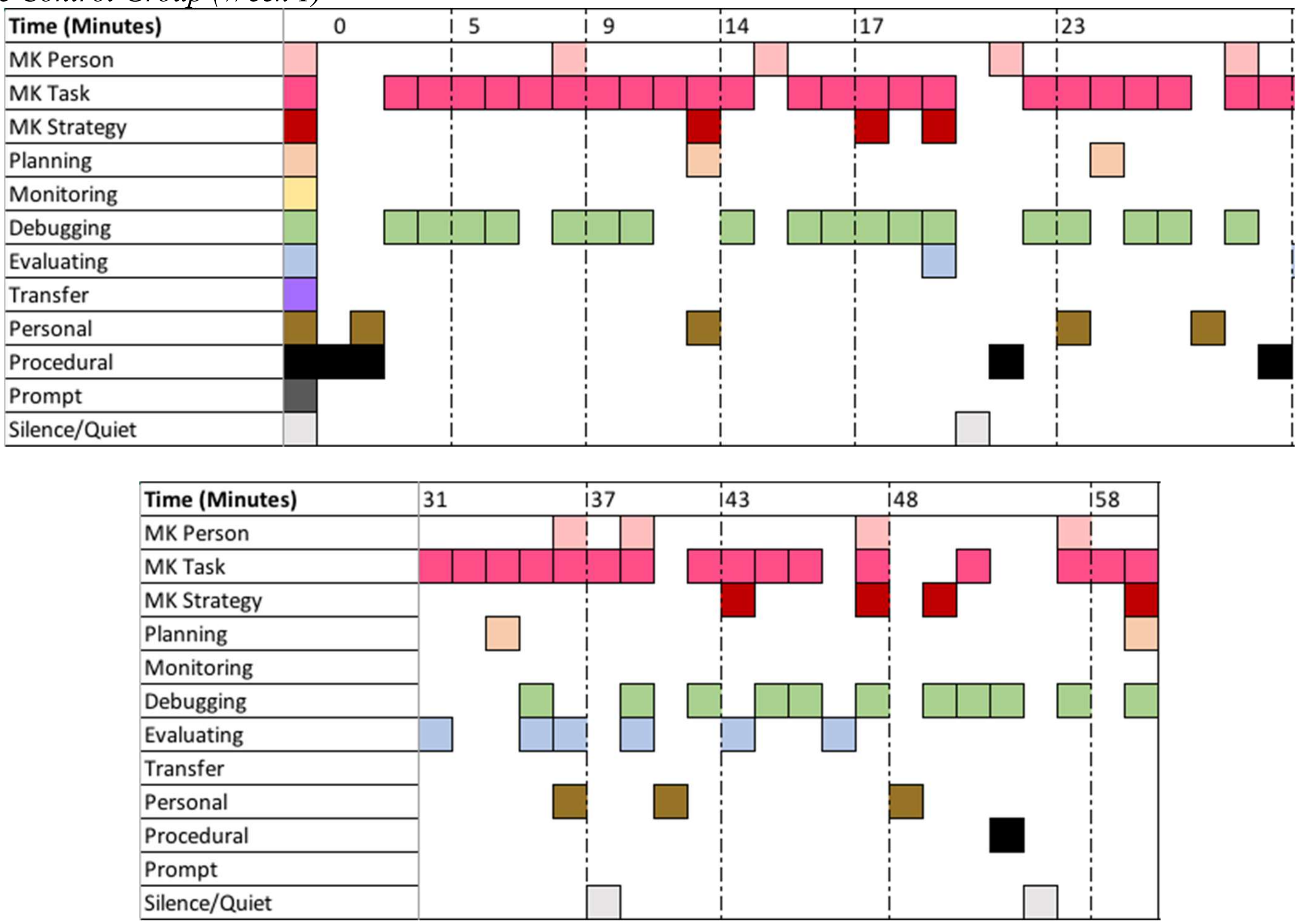
Minor Themes. While the major themes listed above were easily identifiable, the remaining categories were less distinguishable by rank. Differences between the remaining categories were small enough that, though it was not possible to generalize to the population, a number of observations were made regarding the experimental and control conditions. Firstly, it was noted that the prompt theme was only observed during the experimental condition. This was expected as participants were not instructed in the use of prompts for the control condition by experimental design. Second, it was apparent that transfer was also observed predominantly for the experimental condition (1.2%), compared with the control condition (0.3%). While this suggested that the experimental condition solicited transfer more often than the control condition, a qualitative analysis of the themes was required to examine the veracity of such a claim (See *Impacts of use of prompts,* p. 154). Lastly, it was apparent that personal and procedural topics were more prevalent for the control condition (8.0% and 6.5% respectively) when compared with the experimental condition (5.1% and 2.9% respectively). Since membership composition of each group could influence the selection of conversational topics, a qualitative analysis of the personal and procedural topics was placed under the theme, *Explicit Instruction*, to assess such differences. In summation, while the highest-ranked themes were easily identified, a qualitative inspection of the data based on themes was required for the remaining categories.

Graphical Presentation. A graphical representation of the topics was constructed to assist with the proceeding qualitative analysis; these were included in *Table 22 – Table 31* (pp. 116–125). Note that “MK” represents metacognitive knowledge for each. The second column in each table indicated the colour scheme for each theme. Themes were ordered based on the three components of metacognitive knowledge (i.e., person, task, and strategy), followed by the four themes of metacognitive regulation (i.e., planning, monitoring, debugging, and evaluating). These were presented in the order based on the theoretical framework of Schraw and Dennison (1994). The final themes (i.e., Transfer, Personal, Procedural, Prompt, and Quiet) were grouped together, with no hierarchy intended in their presentation.

Note that each column identified a topic of conversation. It was frequently observed that multiple themes were identified for a given topic. Subsequent columns identified changes in the topic of conversation. Time (listed in minutes) was not displayed with equal intervals; spacing was based on the unique conversations that occurred within each group. Therefore, the graphical presentation of the codes was used to indicate codes for a given topic. In summation, *Table 22 – Table 31* demonstrated a volume of themes used by topic. These tables, in combination with the frequency counts listed above, complement the qualitative analysis of the in-course data.

Table 22

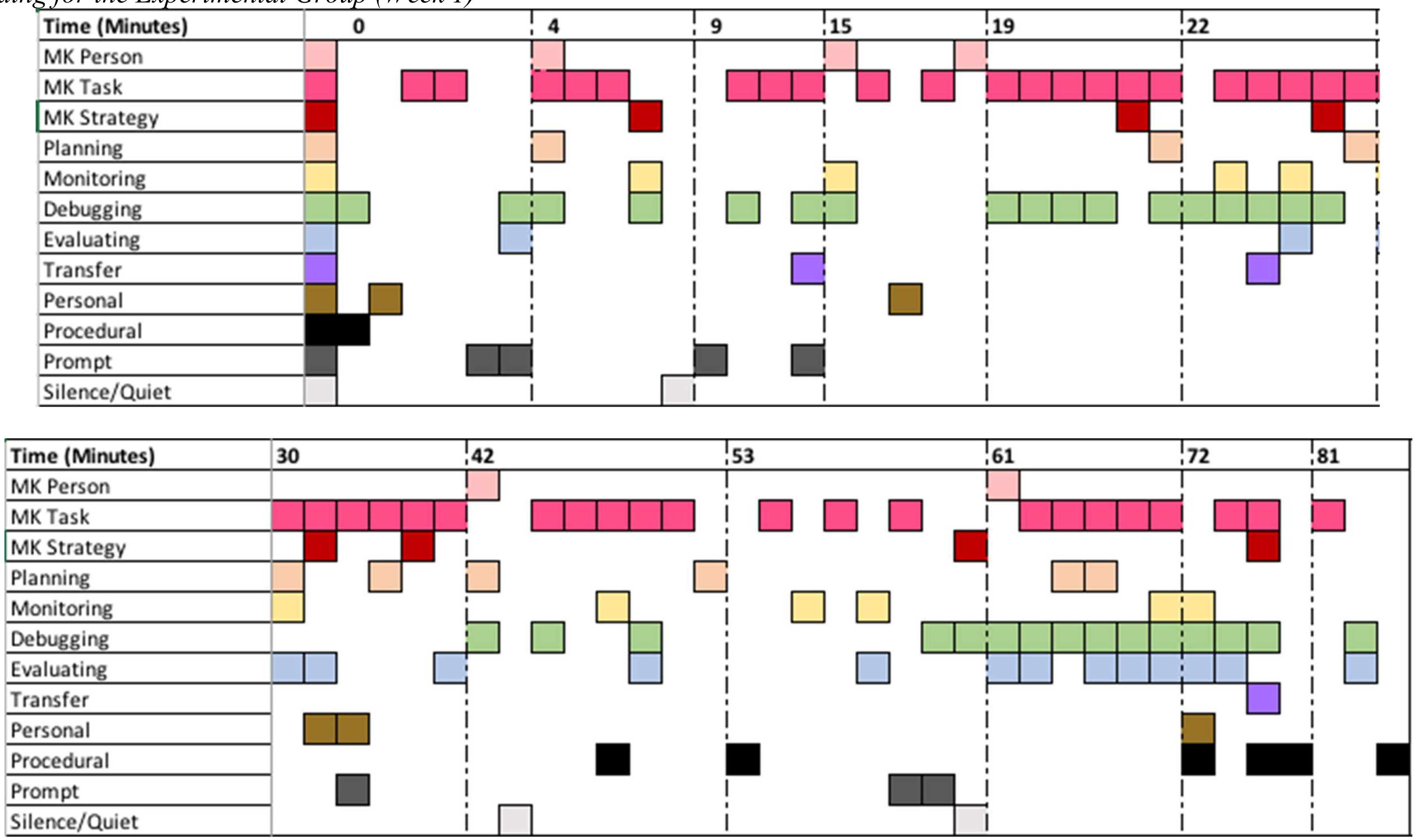
Coding for the Control Group (Week 1)



Note. MK = metacognitive knowledge.

Table 23

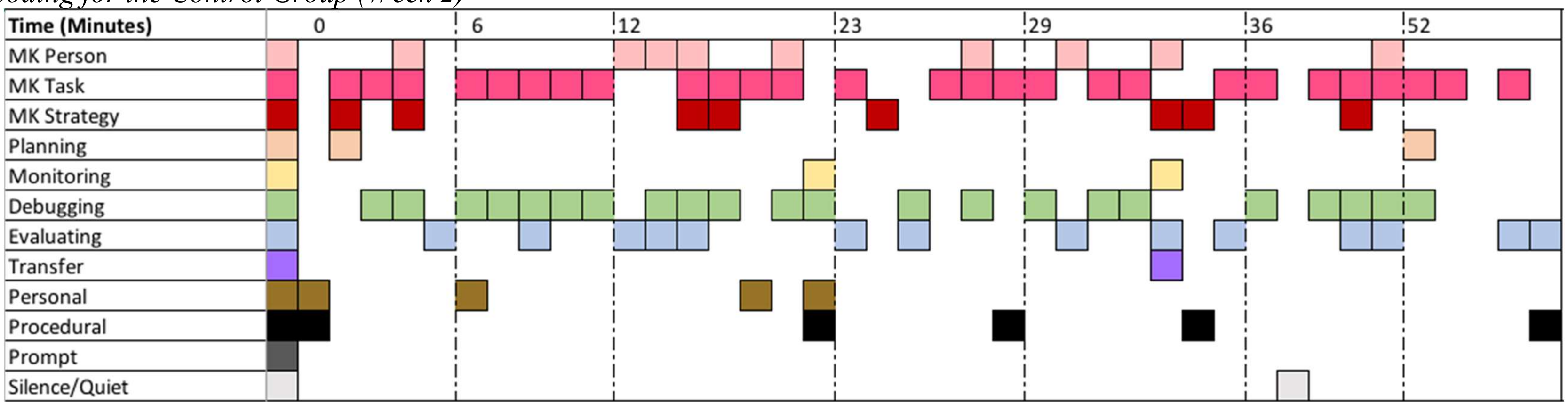
Coding for the Experimental Group (Week 1)



Note. MK = metacognitive knowledge.

Table 24

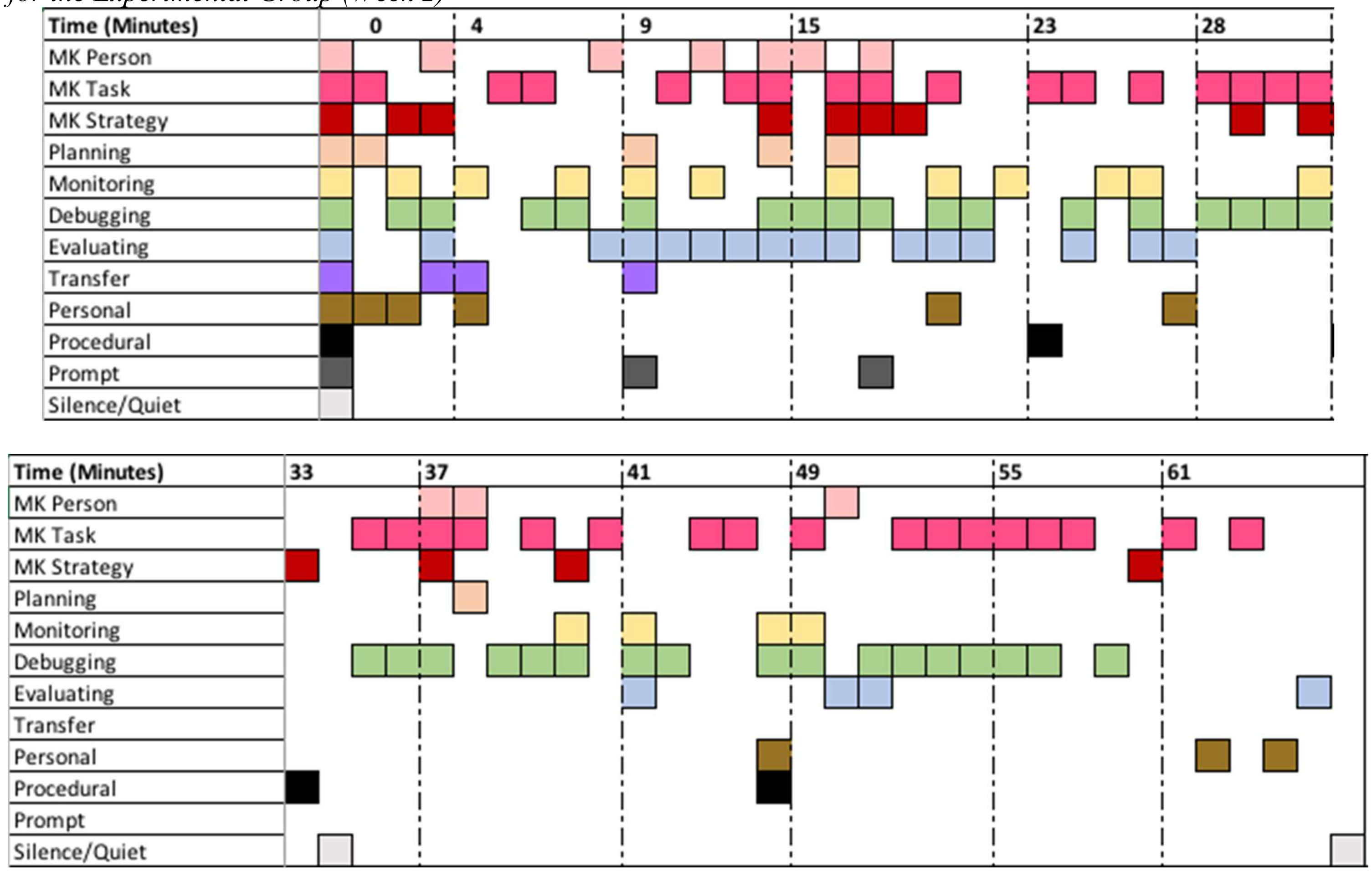
Coding for the Control Group (Week 2)



Note. MK = metacognitive knowledge.

Table 25

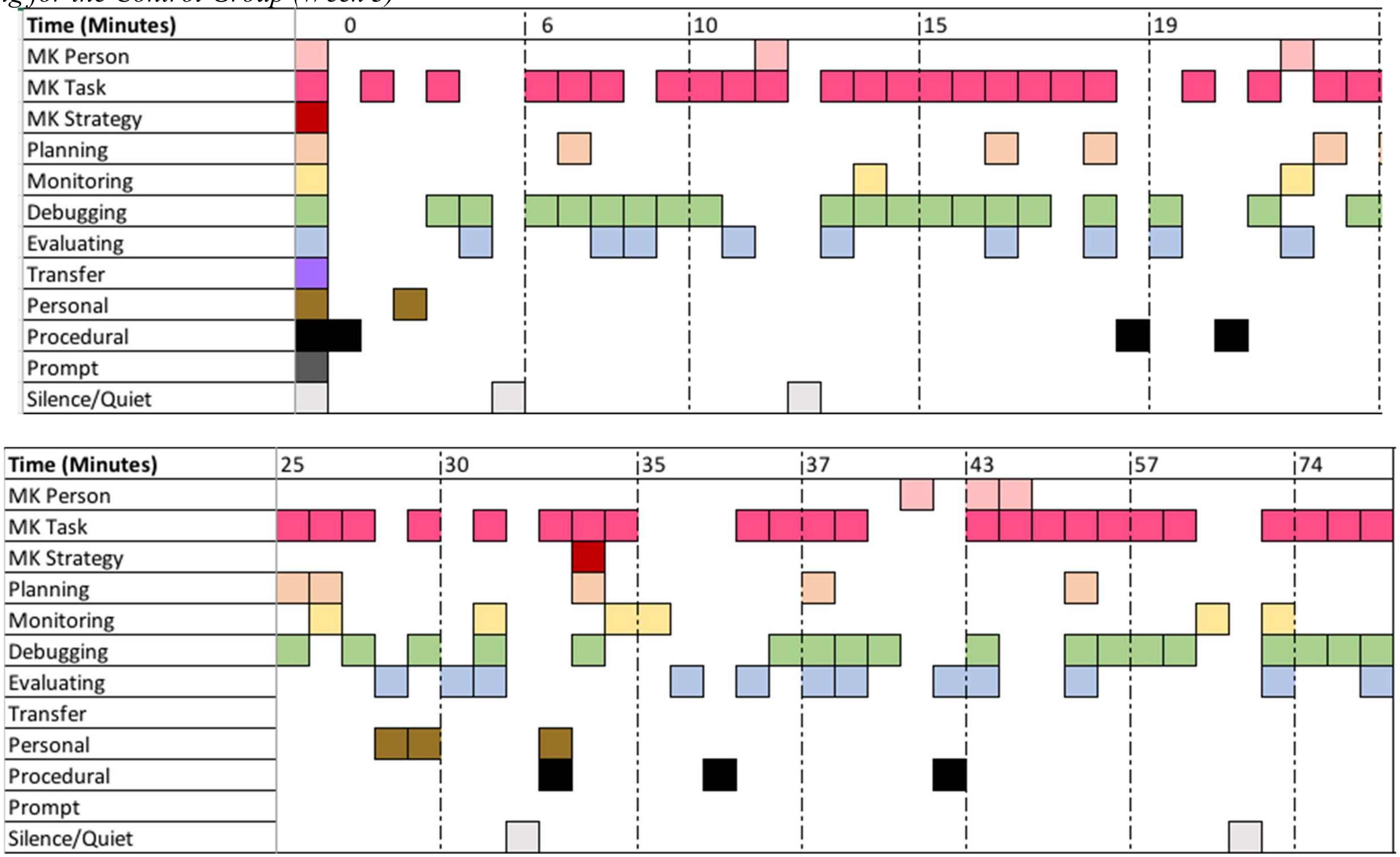
Coding for the Experimental Group (Week 2)



Note. MK = metacognitive knowledge.

Table 26

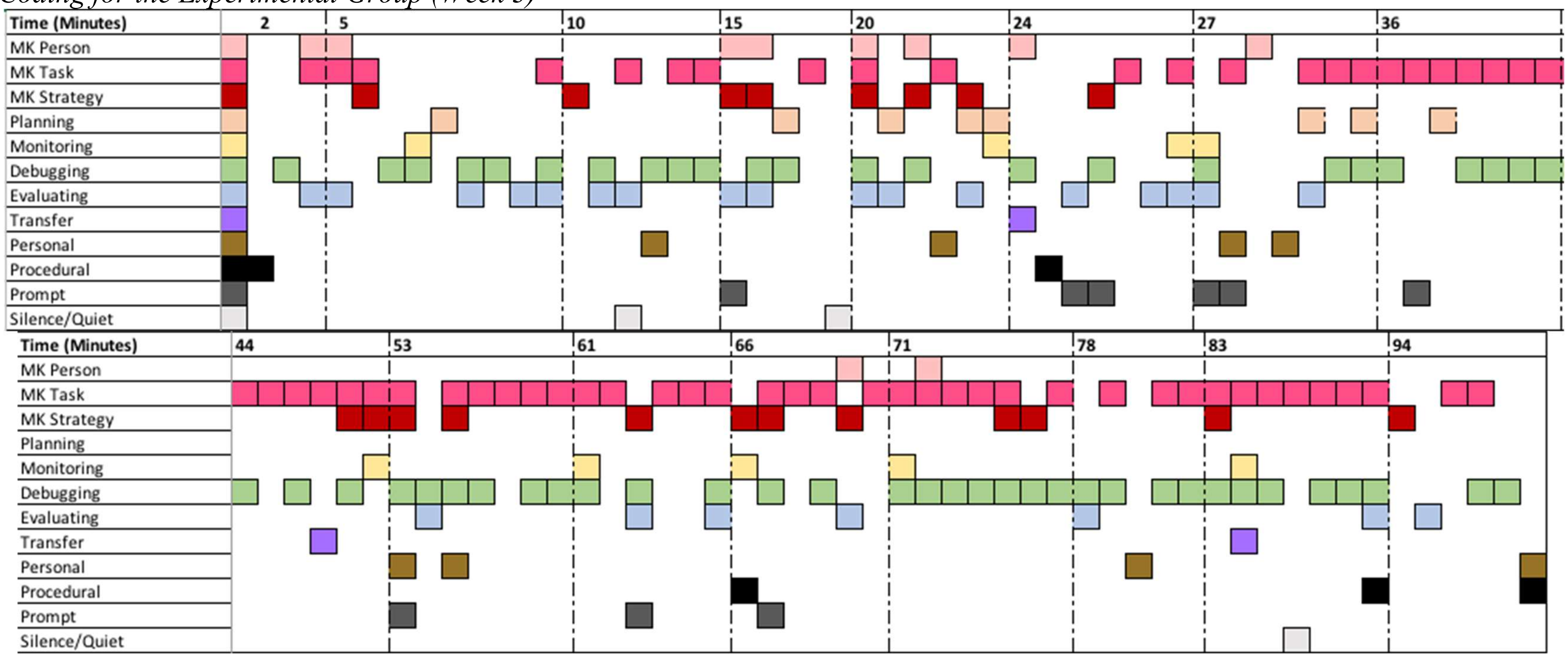
Coding for the Control Group (Week 3)



Note. MK = metacognitive knowledge.

Table 27

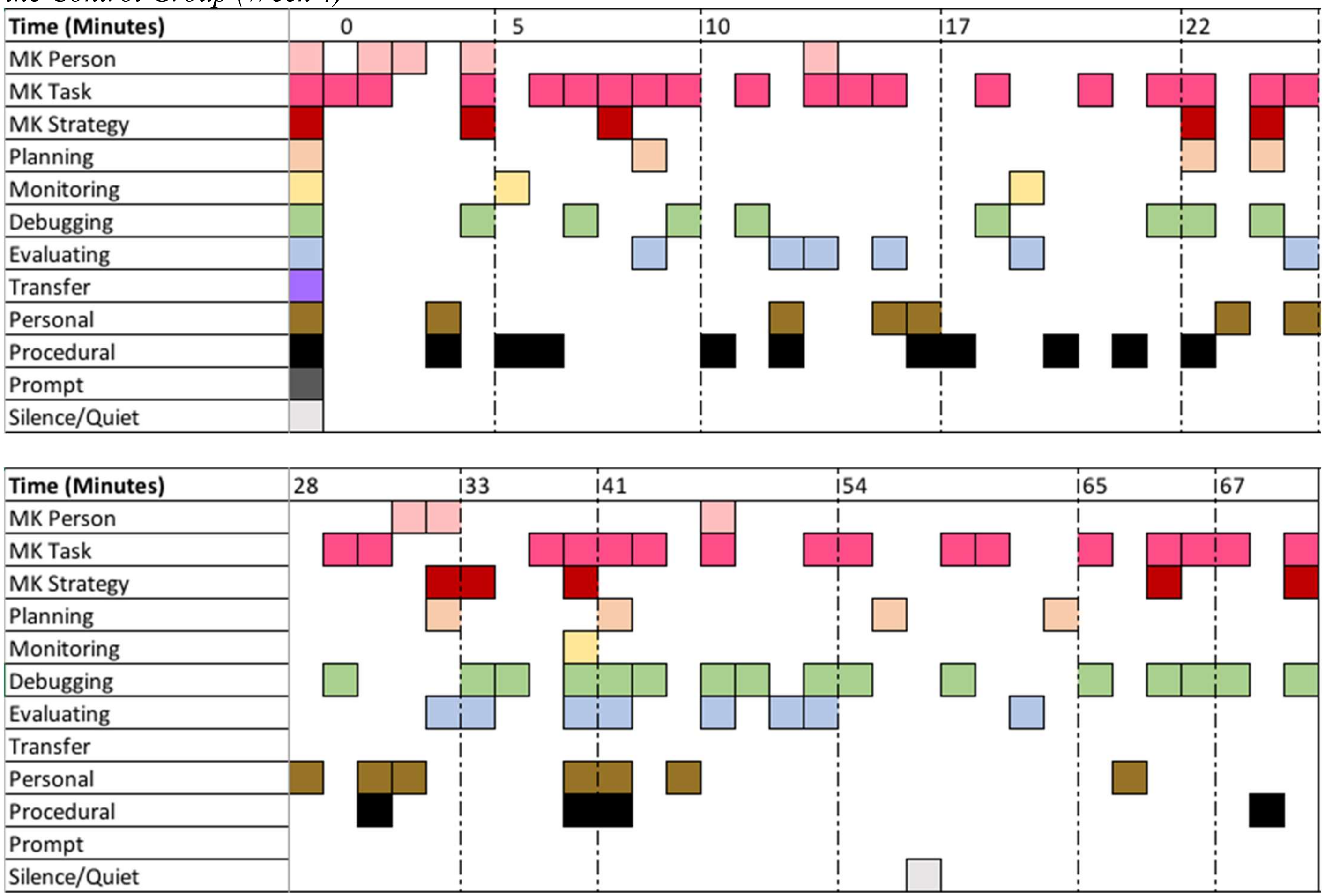
Coding for the Experimental Group (Week 3)



Note. MK = metacognitive knowledge.

Table 28

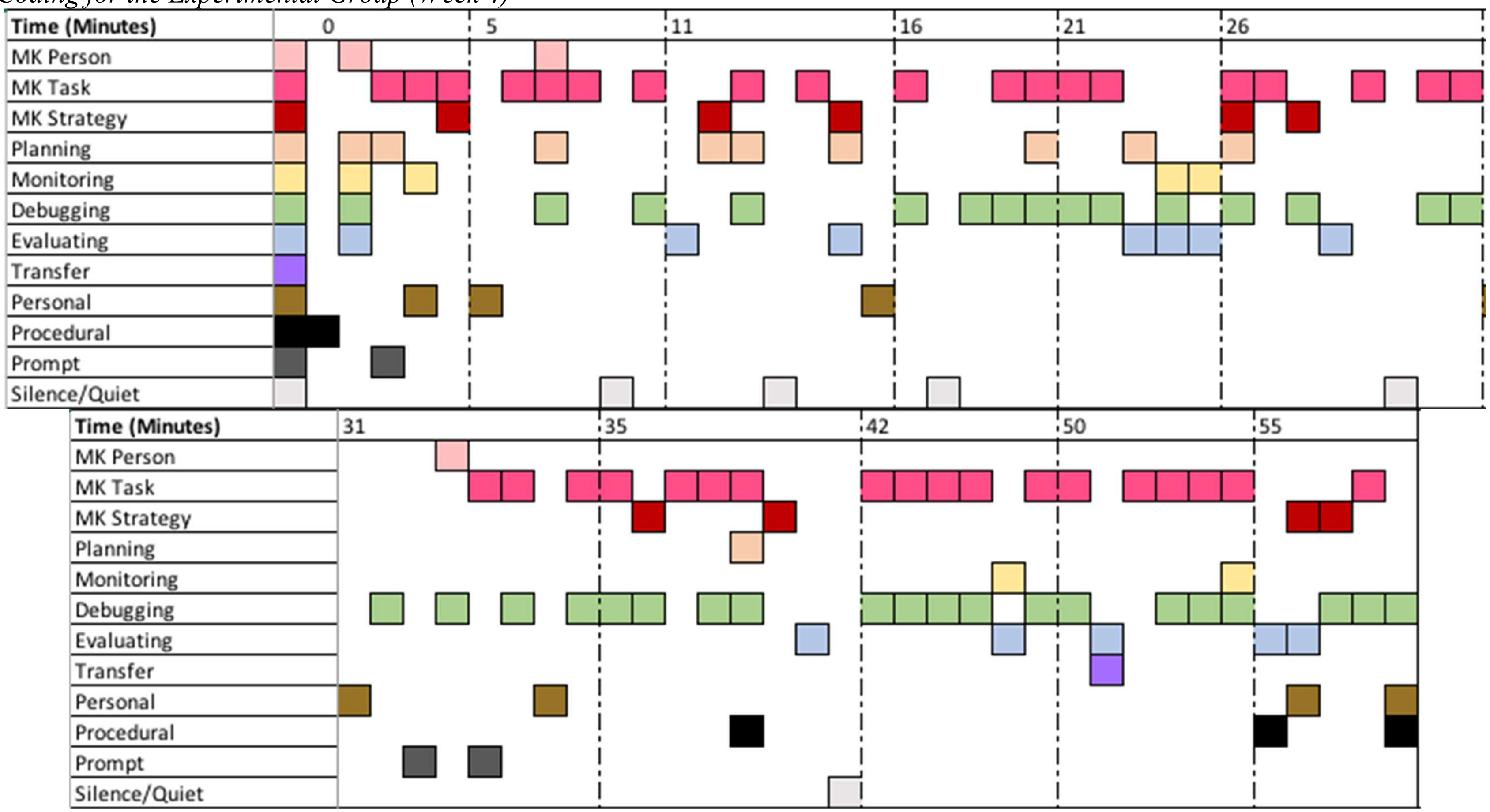
Coding for the Control Group (Week 4)



Note. MK = metacognitive knowledge.

Table 29

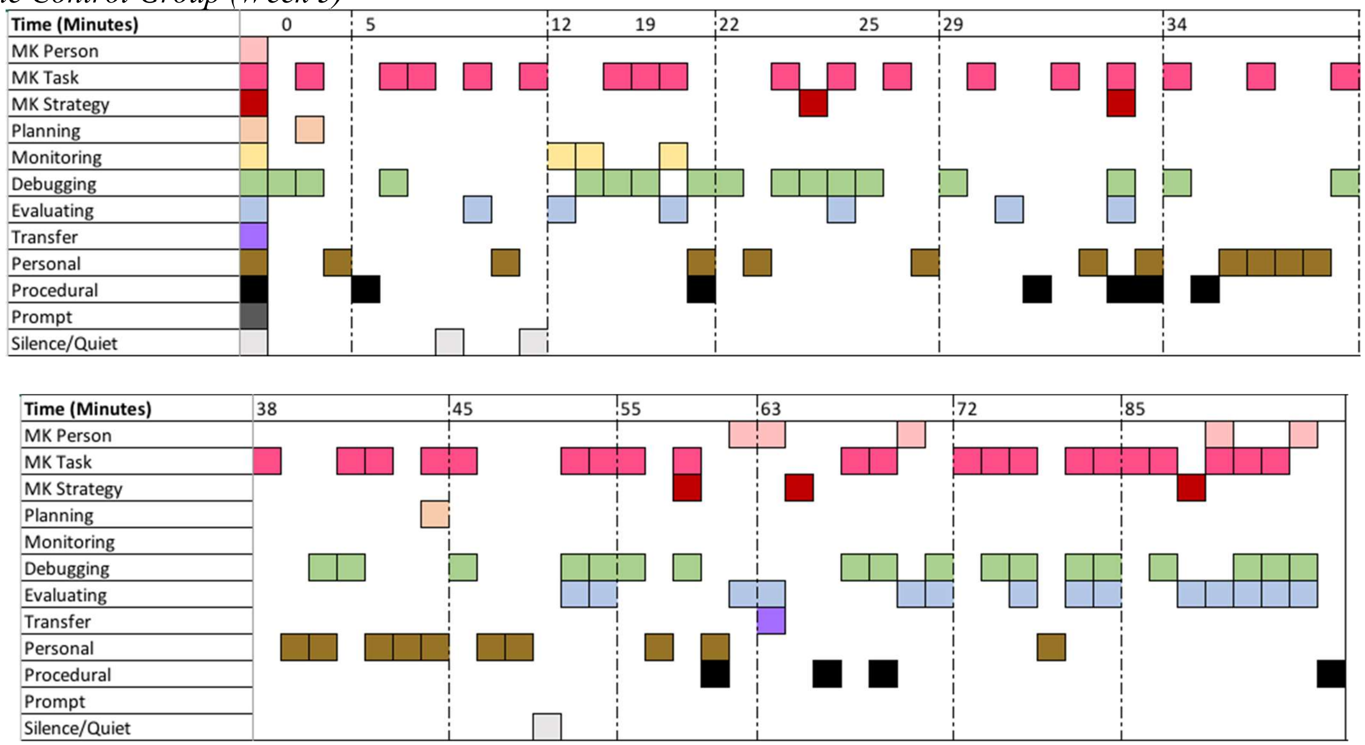
Coding for the Experimental Group (Week 4)



Note. MK = metacognitive knowledge.

Table 30

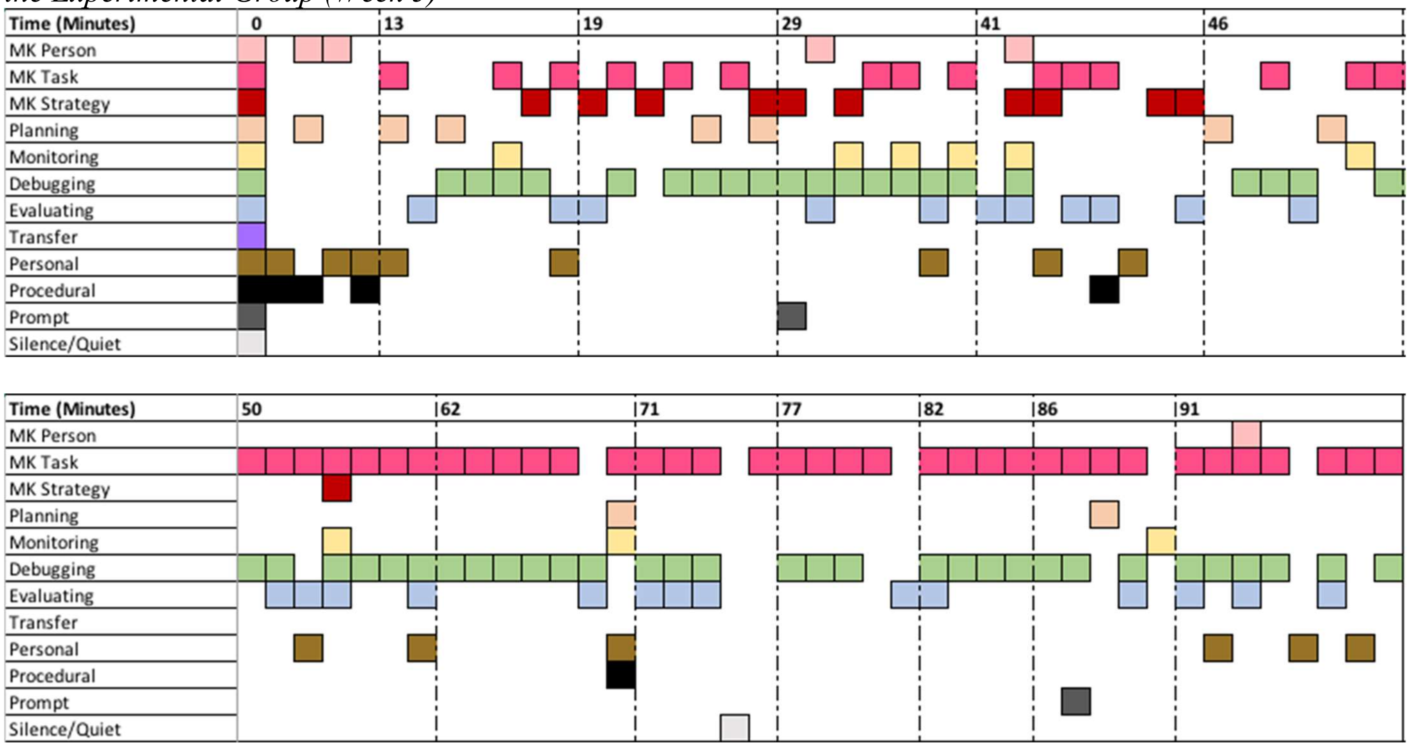
Coding for the Control Group (Week 5)



Note. MK = metacognitive knowledge.

Table 31

Coding for the Experimental Group (Week 5)



Note. MK = metacognitive knowledge.

Qualitative Analysis of In-Course Data

An analysis of the in-course data revealed: 1) limited immediate effects on the participants in the experimental condition; 2) the need for enhanced explicit instruction for both conditions; 3) optimal conditions to facilitate advanced metacognitive expression; and 4) enhanced depth of conversation quality for the experimental condition when prompts were used. Each of these conclusions was formed on the basis of a theme, listed in Table *32* below.

Table 32
Themes and Corresponding Conclusions

Theme	Corresponding Conclusions
Attribute Similarity	• Few distinctions were observed between experimental and control conditions, therefore the intervention had limited immediate effects on the participants. • Due to the small (n = 4 each) size of the samples necessary for the requisite depth of qualitative analysis, conclusions were not generalized for any population.
Explicit Instruction	• Conversation quality would be enhanced by restricting participants to discussions involving recorded members only. • Think-aloud data would be improved by enhanced explicit instruction for both conditions.
Optimal Conditions for Advanced Metacognitive Expression	• Two conditions, independent of time and ability, and supported by research within the literature, were confirmed: o Goal orientation affected the use of self-regulated learning skills; and o Metacognitive quality increased with complex, unfamiliar and novel problems.
Impacts of Use of Prompts	• Prompts facilitated metacognitively-rich conversations, which in turn facilitated transfer. • Prompts should be encouraged semi-frequently by the instructor, with gradual release of responsibility.

For ease of presentation, each theme was presented individually with its corresponding evidence and conclusions.

Attribute similarities. Both the experimental and control groups that were examined demonstrated a number of common attributes in their composition and conduct throughout the collection of the in-course data. These similarities suggested that there were limited, immediate effects on the participants.

Group composition. As described above during the *In-Course Data Selection Process* (p. 101), the groups that were selected for analysis were similar in composition for their membership: both groups were focused on-task; all members participated in higher levels of cognition; all components of metacognition were observed; and finally, advanced and novice members were identified in both groups revealing the diversity of metacognitive capabilities.

Numerous instances of strong teamwork among group members were identified. Both the experimental group and control group illustrated cohesive and synergistic teamwork. For example, the experimental group showed the ability to solve complicated problems as a team,

E.3: ’Cause you’re shadow’s always behind you, right?
E.2: Yes.
E.1: Yeah, no. It didn’t make sense to me.
E.3: So the variables would change, wouldn’t it? Would it be *L* [a variable] and *x?*
E.2: I mean, you can still use the same variables, it’s just this situation, the shadow would be growing.
E.4: Yeah, I know it is, [we] still have the placement of the pole and the shadow.
E.2: Both will be growing as you walk away.
E.4: Yeah, the shadow’s still – She’s walking away, the shadow’s still going to be in front of her.
E.2: When you walk away from light, the shadow stays in front of you.
E.4: ’Cause how does it make sense that the light source is behind her.
E.3: That’s what I was thinking.
E.4: So, the shadow’s gonna be in front of her.
E.3: Okay.
E.2: It never says the shadow’s behind her.
E.4: Well I mean it’s just, logically [Chuckles]. I get what you mean. I do my diagram like this, with the shadow in front
E.2: Would it be like: person, shadow, here and then why’d you write *L* be the length of shadow.
E.4: I wrote shadow here, so I’m just tripping.

E.2: This would still be L, and this would still be *x*, it's just that both would be increasing at a different rate from each other.

~Experimental Group, Week 2

Here, Participant E.4 indicated the central problem addressed by the group – the location of the shadow in relation to a person walking away from a light source. Participant E.1 echoed confusion, while Participants E.2 and E.4 dialogued to sort between different possible outcomes. Participant E.4 followed along the conversation. While Participant E.4 was focused on the variable labels, Participants E.2 and E.4 discussed the location of the shadow of the person walking in relation to the light source. Participant E.2 concluded by identifying the essential issue of the group's conversation – the rate of change of the variables based on the circumstances of the question. In conclusion, the group's teamwork, as evidenced by their diverse discussion of issues (i.e., variable labels and locations), led the group towards identifying the central issue being addressed.

The control group demonstrated similar strengths as a team during their conversations. Through the group's attempt to debug their search for vertical asymptotes, teamwork was shown,

C.3: In our notes, it says for vertical asymptote we have to take the limit–
C.2: For which one?
C.3: So you just factored out the denominator.
C.2: Yeah.
C.3: That gave us the possible asymptotes, but you never tested them in our notes.
C.2: Yeah.
C.3: We took the limit of the factored denominator.
C.2: Oh I see.
C.3: So, there's only one asymptote.
C.2: There's only one? It's probably *x* equals 5 'cause 12 cancels out with the numerator, right? Did I do it on this page? I think I did.
C.3: So you just have to…[Continues below]
C.2: So just *x* equals 12?
C.3: …test it.
C.1: Yeah it's 2 over zero.
C.2: Yo, for *2a*, did you get 2 vertical asymptotes or 1?
C.1: *2a*? *2a* I got two.
C.3: Two verticals?

C.1: Two verticals.
C.3: The graph is only one asymptote ’cause the 12 just reduces.
C.2: It’s just negative 5 right? It’s just negative 5.
C.1: 12 is not, and only 5 is one.
C.3: You also have to prove it, I think.
C.1: Yeah, you also have to prove it.
C.3: So you have to take the limit when *x* approaches 5; that’s what it says here.
~Control Group, Week 1

Participants C.2 and C.3 began the discussion by comparing metacognitive task knowledge for finding vertical asymptotes. Through this process, the pair narrowed their discussion to specific solutions to the problem. Participant C.1 joined the discussion by offering a solution. It was through this process that Participant C.3 identified the importance of proving the asymptote, which was affirmed by Participant C.1. Evidently, the participation of all members led the group towards a swift conclusion, affirming the unfamiliar process of finding vertical asymptotes.

An inspection of *Table 22– Table 31*(pp. 116–125) revealed similar patterns in the metacognitive discourse for both the experimental and control groups. Beginning with the control group, *Table 22* (Week 1) showed that the majority of topics featured metacognitive task and debugging discussions occurring together, with intermittent topics emerging. A similar pattern appeared in *Table 24* (Week 2), with the exception that additional diversity in discussions appeared up to 30 minutes. An increase in the diversity in topic was observed in *Table 26* (Week 3), although again, after 35 minutes, topics appeared to coalesce around the concurrent appearance of metacognitive task knowledge, debugging, and evaluating. *Table 28*(Week 4) showed an increase in the diversity when compared with the previous weeks, for the first 40 minutes; however, the concurrence of metacognitive task knowledge, debugging, and evaluating after this point was observed. A similar pattern was observed in *Table 30* (Week 5), with diversity in discussion lasting until 45 minutes, following which the same three themes emerged. In summation, *Table 22*; *Table 24*; *Table 26* ; *Table 28* ; and *Table 30*, indicated that most discussions for the control group were diverse for the first 45 minutes, followed by the concurrent appearance of metacognitive task knowledge, debugging, and evaluating for discussions after this initial period.

For the experimental group, *Table 23* (Week 1) indicated a diversity of topic discussions for 60 minutes, followed by the concurrent appearance of metacognitive task knowledge, debugging, and evaluating. It was noted that discussions were dominated by metacognitive task knowledge, with debugging from 19 to 30 minutes. *Table 25* (Week 2) showed increased diversity in discussions for the first 33 minutes, with discussions after this period being dominated by the concurrent appearance of metacognitive task knowledge and debugging. *Table 27* (Week 3) revealed a fairly diverse array of topics for the first 36 minutes, followed again by the concurrence of metacognitive task knowledge and debugging. *Table 29* (Week 4) displayed diversity in the discussion for 16 minutes, followed again by metacognitive task knowledge and debugging. An inspection of *Table 31* (Week 5) showed a diversity of topic discussion for the first 46 minutes, followed by the concurrence of metacognitive task knowledge, debugging, and evaluation in discussions. Considering the overall analysis for patterns in *Table 22– Table 31*, it was evident that both the experimental and control groups shared in their diversity of topic discussion for approximately 15 to 45 minutes, followed by a dominance of the concurrent themes of metacognitive task knowledge, debugging, and evaluating.

The pattern of conversations with diverse metacognitive topics, followed by a focus on metacognitive task knowledge, debugging, and evaluating, was a finding that was supported by the literature. Given the nature of the problem-solving sessions, it was expected that participants would have conversations diverse in nature while solving non-routine, unfamiliar, and difficult problems (e.g., Mevarech, et al., 2010). Although at first it was not expected for conversations to lose such diversity, once solution pathways were determined for all problems in the session, it was reasonable to observe only the expression of novice skills. This aligned with the literature, which indicated the dominance of novice skills such as metacognitive task knowledge, evaluating (e.g., Kramarski & Dudai, 2009; Mevarech & Amrany, 2008), and debugging (e.g., Kramarski & Friedman, 2014), particularly once problems were identified as familiar or solutions were obtained for difficult problems. In summation, once participants formulated their plans for the problems they were solving, utilizing necessary debugging, monitoring, and metacognitive strategic knowledge, novice skills became the dominant metacognitive skills.

Impacts on behaviour due to the presence of a microphone. Throughout the discussions of both groups, the presence of the microphone affected the participants' behaviour, soliciting the monitoring component of metacognition. Occasionally, the microphone appeared to solicit mindfulness of the participants, "I think I'm good. I hope this mic was recording, it was recording, right? (Participant E.3, Week 3). This quote directly followed a debugging and metacognitive process engaged in by Participant E.3. Apparently, the participant's feelings about the solution articulated were evaluated as meaningful by the participant, which the individual linked to concern for ensuring the conversation was recorded, perhaps out of concern for the quality of the study. The control group also showed awareness of being recorded and its potential impact on the study,

> C.2: Yo, we're not talking at all during this, I feel bad for this. [Chuckles]
> C.3: I'm talking.
> C.1: Hey, I told the person, I'm here for a free 50 bucks.
>
> ~Control Group, Week 2

The above quote illustrated the initial awareness of Participant C.2's concern for the group's overall contributions to the study. Participant C.3 self-evaluated individual contribution as being overall positive. Interestingly, concern for the quality was not shared by all as evidenced by

Participant C.1's motivation for participating in the study for money. Despite this motivation, Participant C.1 demonstrated mindfulness to being recorded, speaking directly to the researcher,

> C.1: Holy shit, this dude is listening to all the songs I was just listening to all the time.
> C.2: [Chuckles].
> C.1: Enjoy the songs, mate.
>
> ~Control Group, Week 3

This quote illustrated Participant C.1's awareness of personal contributions, followed by direct communication with the researcher.

Both groups displayed awareness of being recorded. This was evidenced by monitoring statements about their current behaviour, which though infrequent, occurred at least once per session. Overall, the presence of the microphones solicited infrequent monitoring statements and behaviours.

Individual Traits. Characteristics of the experimental group and control group were shared in Table *19*, p. 103 (See *In-Course Data Selection Process*, p. 101). While all individuals participated, it was apparent after detailed analysis of the data that distinctions in overall contributions emerged between the participants.

Some participants appeared more naturally talkative, either participating in private discussion through self-talk or engaging peers in group discussions (e.g., Participants E.3 and C.3 in the experimental and control groups, respectively). However, others were more introspective and participated more frequently through questions to peers than in discussing thoughts out loud (e.g., Participants E.4 and C.4 in the experimental and control groups, respectively). These differences in overall contribution volume by the participants affected the characterization of the statements shared. Participants who were not as open about their thought processes left a void which was not inferred beyond the data.

Additionally, some individuals demonstrated more advanced metacognitive abilities (i.e., monitoring and planning) than others. From the experimental group, Participant E.3 regularly displayed monitoring,

> E.3: No I get what – You're saying, go back to the *e* example. I think I know what You're saying…[Off-microphone member speaks]…Yeah but that's tan of a function, though. That's not tan being multiplied by the function 'cause this is just – All this is, is just 5 cotangent squared…[Off-microphone member speaks]…I'm just trying to think it through, why it's chain rule. I'll show you what I was going to do.
>
> ~Experimental Group, Week 2

Through a discussion with an off-microphone member, Participant E.3 emphasized purposeful monitoring with, "I'm just trying to think it through, why it's chain rule." The advanced skills of metacognitive planning and monitoring were recurrent throughout the sessions for Participant E.3. Participant C.3 of the control group also displayed regular instances of monitoring and planning,

> C.3: Yeah, so [I] was just thinking in *2*: the information to do the derivative is here, and I just do the differentiation for the number *e* rule. So, that's the root of *f* of *x* times e. So, *x* ln sin(x), over that. We need the derivative of [sentence not finished], and then since *e* to the *x* is the derivative of *e* to the *x*, so it's just the same. I'll just copy that down.
>
> ~Control Group, Week 3

Again, Participant C.3 had a private monologue focused on evaluating available metacognitive task knowledge for differentiation. At the end of this discussion, Participant C.3 displayed the next steps planned. To conclude, it was evident from both the experimental and control groups examined, that certain individuals (e.g., Participants E.3 and C.3, respectively) displayed advanced metacognitive skills such as monitoring and planning in a private manner, often distinct from their partners.

Similarly, some participants in both the experimental and control groups demonstrated more novice metacognitive abilities (i.e., metacognitive task knowledge, debugging, and evaluating) than others. For example, Participant E.2 from the experimental group recurrently displayed novice skills as evidenced by the following,

> E.2: Okay, this is the correct calculation for *1b*. You stick the *x* up and it turns into *x* squared. Yeah. I'm going off of these two steps. In the example he gave us, he stuck the *x* up and it turned into *x* squared. I mean, that's what the example he gave us showed, and once it's in there you can split it up to each one.
> E.1: I guess, yeah.
> E.2: It ends up being the same value either way. It's all just incredible manipulation so, like, I don't know. It ends up being 1 over…[Self-talk specific to metacognitive task knowledge continues].
>
> ~Experimental Group, Week 1

While debugging the calculation for a specific question, Participant E.2 discussed understanding of a particular strategy (i.e., "sticking the *x* up" and it "turned into *x* squared"), based on personal metacognitive knowledge of information witnessed from an instructor. Participant E.2 evaluated that, regardless of the method, the outcome was the same. Low confidence in understanding the approach was indicated, followed by a lengthy discussion of metacognitive task knowledge specific to the question. These novice skills were recurrent for Participant E.2 throughout the collection of the in-course data. Similarly, the use of novice skills such as debugging, metacognitive task knowledge, and evaluating was recurrent for Participants C.2 and C.4.

Overall, it was evident that each participant illustrated unique characteristics, either through high/low volumes of discussion or by displaying predominantly novice/advanced skills throughout the study. The above exemplars revealed the unique contributions by the participants, which required consideration before conclusions were made.

Conclusions for attribute similarities. Both the experimental and control groups had similar characteristics in the composition of their membership: focus, presentation of metacognition and higher levels of cognition, diversity in members' metacognitive capabilities, possession of strong teamwork capacities, and demonstration of similar patterns in overall metacognitive discourse. Both groups also displayed awareness of being recorded, which in turn, solicited infrequent monitoring behaviour. In conclusion, because few distinctions were observed between experimental and control conditions, it was determined that the intervention had limited, immediate impacts on the participants. Further, because of the size (n = 4 each) of sample necessary for the requisite depth of qualitative analysis, and the subsequent, unique characteristics of the participants' volume and quality of contributions, no generalizing conclusions were made for any population.

Explicit instruction. It was evident throughout the analysis of the in-course data, that participants' own think-aloud practices were limited to previously acquired skills on an individual basis. This limitation revealed the need for explicit instruction of a think-aloud process to facilitate metacognitively-diverse, meaningful conversations.

Discussion with unrecorded individuals. During the study, participants were permitted to discuss and work with members who did not volunteer for being recorded in the study (referred to as "off-microphone" members). This was granted to minimize the impact on participants in the study, as members in the laboratory sessions were allowed to work with other participants in their sections. As a consequence, conversations emerged between recorded participants who volunteered for the study and off-microphone members.

Predominantly, participants' side conversations were centred comparison of solutions as a debugging strategy, with off-microphone members. From the experimental group, for example, Participant E.3 engaged with off-microphone members to compare and debug problems,

> E.3: So why does that stay? [Off-microphone responds]…This is what I have, 'cause I'm just wondering, 'How is that chain rule, this whole time?',…'Cause chain rule is, like, of a function [Off-microphone responds]…If you do product rule, [Chuckles]. If you're gonna tell me, 'Oh, this is wrong,' you're gonna need to prove it. You need to prove it to me. [Off-microphone responds]. Yeah, that's why I'm working on *B*, man, 'cause *B* is pretty straight forward even if it sucks.

~Experimental Group, Week 2

This quote illustrated a discussion between Participant E.3 and an off-microphone member. It was evident that Participant E.3 sought clarification, (e.g., "Why does that stay?"). The answer led Participant E.3 to consider the metacognitive task knowledge of the 'chain rule'. It was evident by the change in Participant E.3's discourse that there was disagreement between the suggested answer and what Participant E.3 deemed an adequate solution. Similar examples of participants' debugging problems, through comparison with off-microphone members, were found in the control group. In summation, the above example illustrated participants' engagement in conversations with off-microphone members to debug solutions to difficult problems for comparison purposes.

Occasionally, participants from both groups engaged in conversations with off-microphone members that were off-topic for personal purposes. The experimental group showed evidence of off-topic discussions with off-microphone members,

> E.3: What are you talking about?
> E.2: The infinity gauntlet.
> E.3: Oh. [Chuckles]
> E.2: I'm trying to remember which one made it, DC or marvel, and I remember which one made it because Spiderman died.
> E.4: Spoiler.
> E.3: Tobey Maguire will be sorely missed. [Off-microphone member responds]. Bro, bro I love Tobey. Don't hate. [Off-microphone member responds].
> E.2: Honestly, yeah.
> E.3: Facts, *Spiderman* 3 is a masterpiece.

~Experimental Group, Week 5

It was evident by Participant E.3's response, "Bro, bro I love Tobey. Don't hate," that the off-microphone member disagreed. To sum up, participants in both groups engaged in off-topic conversations with off-microphone members.

In conclusion, participants engaged in conversations with off-microphone members as a strategy to debug answers through comparison or to engage in off-topic conversations. As evidenced by the examples above, the loss of information from those individuals not recorded significantly detracted from the quality of the conversations. Further, some participants, (e.g., Participant C.1 of the control group) regularly engaged in conversations in this manner, revoking potential use of the data. Therefore, conversation quality would be enhanced by restricting participants to discussions involving recorded members only.

Personal conversations. In addition to off-topic conversations, the 'personal' theme, as coded throughout the in-course data, revealed benefits for the groups through social interaction. Given the social nature of problem-solving (Schoenfeld, 1992), it was expected to find demonstrations of pro-social behaviour by the groups. The experimental group shared experiences for mutual support. The control group also indicated group encouragement. These are demonstrated through the example from the control group of a request to assist with self-regulation,

> C.1: I'm actually surprised I haven't lost my anger yet.
> C.2: Really?
> C.1: Yeah, I'm actually happy about it, that I haven't lost it. I would have lost it by now.
> C.2: Think so?
> C.1: Yeah. [An off-microphone member] would have been shut up by now if I'd lost it. I'm *really* [emphatic] proud of myself at this time in my life. I'm like you.
> C.3: Now? Good for you.
> C.1: Thank you.
>
> ~Control Group, Week 5

It was noted that although Participant C.1 expressed sarcasm, reassurance was being sought as evidenced by the statement, "I'm actually happy about it, that I haven't lost it." Participant C.3 responded with little enthusiasm, "Now? Good for you," perhaps to relay empathy to Participant

C.1. In summation, participants engaged in both positive social interactions, as well as off-topic conversations.

Procedure conversations. The "procedure" theme coded throughout the data revealed: conversations about mechanics of the lab session, and conversations about the study. The experimental group showed coordination in solving the problems,

> E.4: Let me have that sheet of known laws.
> E.2: Yeah, this one?
> E.4: No, the one for limits.
> E.3: Oh, like the physical sheet? This one?
> E.4: Yeah.
>
> ~Experimental Group, Week 2

Participant E.4 requested access to a copy of known laws from peers. Participants worked together to complete secondary tasks to the problem-solving assignment. While discussing the mechanics of the class, the control group considered grades received. The control group also demonstrated discussions about tools (i.e., books) used in the lab,

> C.2: Did you guys get this from the school, like, they gave it to you?
> C.1: Inside the bookstore.
> C.2: Oh, you have to buy it?
> C.1: Yeah, it's like 5 or 6 bucks.
> C.2: Like you have to though.
> C.1: Yeah, you have – I bought it. It's really useful. I use it for all my labs and all my notes.
>
> ~Control Group, Week 4

Participants C.1 and C.2 discussed the origins and usefulness of a notebook. In summation, both groups demonstrated procedural discussions about the course to fulfil secondary needs.

Additionally, procedural conversations focused on both the mechanics of the study, as well as motivation for the study. The experimental group demonstrated mindfulness of 'good' recordings,

> E.2: I think this is good. Is this good?
> E.3: Am I on? Oh wait, I gotta turn it on, oh it's on.

E.2: I should be 4 [i.e., microphone number] then? 2?

~Experimental Group, Week 4

The experimental group clearly monitored their recording quality from the setup provided. Likewise, the control group sought support for permitted behaviours. The awareness and regulation of behaviour of the group towards the study were evident. Further, the control group participants acknowledged the importance of the financial incentive for participating in the study,

C.2: I think we all are.
C.1: That's my beer money, You're not taking away from my beer money.
C.3: I'm actually interested in it. I'm kind of interested.
C.2: It's kinda, but, it's like, whatever. We just talk to him like, 'Hey man, how are you?' [Chuckles].
C.1: Hey buddy, when you're listening to this, I'm telling you: I'm a bit high, I'm a bit drunk. Do not consider anything else.

~Control Group, Week 2

Above, various motivations were simultaneously revealed. Participants C.1 and C.2 admitted to responding to the financial incentive, while Participant C.3 acknowledged interest in the study. Finally, Participants C.1 and C.2 both joke, in words and tone, with their concluding remarks. To sum, participants discussed mechanics of the lab and study during procedural topics.

Overall quality in think-aloud process by participants. A surprising fraction of time was used by both the experimental group and control group, discussing personal or procedural topics, excluding time spent in silence. 5.1% and 2.9% of topics discussed by the experimental group were personal or procedural, respectively, compared with 8.0% and 6.5%, respectively, for the control group. 1.7% of topic changes were complete silence or indiscernibly quiet self-talk for the experimental group, compared with 2.1% of the control group. It was noted that periods of silence at times ranged as long as 5 minutes in duration before a participant spoke. In summation, 9.7% of topic changes were isolated to personal topics, procedural topics, or silence for the experimental group, compared with 16.6% of topic changes for the control group. Further, it was evident from discussions by the participants from both conditions that, on average, the instructor interjected with personalized comments to the group no more than one time each session. Overall, the quality of the think-aloud processes displayed by the participants was substantially focused on silence, personal or procedural topics.

Conclusion for explicit instruction. Considering the aforementioned volumes of off-topic conversations, it was argued that conversation quality would be enhanced by explicit instruction for both the experimental and control conditions. By limiting conversations with participants being recorded, and enforced by the instructors, a complete set of data may permit further analysis of the participants' discussions. While social benefits were interpreted as positive for group dynamics when solving problems, off-topic conversations revealed participants' distraction, which again could have been mitigated by engaged instructors. Lastly, thorough description of the mechanics of the study, combined with detailed instruction on effective think-aloud protocols, might minimize data spent on procedural matters and silence, thus increasing more opportunity to observe metacognitive behaviours. In conclusion, think-aloud data would be improved by enhanced, explicit instruction for both the experimental and control conditions.

Optimal conditions for metacognitive expression. Analysis of the in-course data illustrated optimal conditions for soliciting advanced metacognitive concepts. It was evident that achievement goal-orientation affected the use of self-regulated learning skills. Further, the higher the level of complexity of a problem, as well as the degree of novelty and unfamiliarity, solicited advanced metacognitive skills in comparison to familiar and easy problems.

Self-regulated learning observations and impact on metacognition. According to Elliot and Church (1997), individuals who seek to display competence compared with others possess performance-approach goals, ultimately motivated by achievement, high competency expectations, and a fear of failure; those who seek to avoid demonstrating incompetence possess performance-avoidance goals, ultimately driven by a fear of failure and low competency expectations. Mastery learners possessed achievement motivation and high competency expectations. Pintrich and Garcia (1991) found that students' self-regulated learning was influenced by their goal orientations. During the present study, the participants revealed a performance-approach achievement orientation which led to the use of two primary strategies: skipping questions which were deemed too difficult for their grade worth, and utilizing direct comparison as a strategy for completing problems.

It was evident throughout the in-course data that many participants were identified as possessing the performance-approach achievement orientation. While debugging a problem, a participant revealed a performance-approach,

> E.1: Like literally one step turned into six.
> E.2: So this is what you got for *2a*.
> E.3: Ya.
> E.1: But you can't do it that way, you gotta do it this way.
> E.3: It says in the question, 'Use the definition of the derivative'.
> E.2: Oof.
> E.1: Yup, you gotta do *f(x)* plus *h* minus *f(x)* over *h.*
> E.3: Luckily most of the answers are pretty straightforward so you can just fly through most of these. I'm already on the last one.
> E.1: Look at this guy, just flying through them. It's literally been, like, 10 minutes.
> E.3: What –
> E.4: I notice that the more I try to fly through, the more I make more mistakes.
> E.2: I'm just trying to get as many correct because I want to raise my mark as high as possible, 'cause I'm not doing too fly [i.e., doing too well] right now, hm.
>
> ~Experimental Group, Week 2

The discussion began with debugging the task. When Participant E.4 revealed progress, Participants E.1 and E.4 commented on the speed. Participant E.2 provided an exemplary indicator of performance-approach, “I want to raise my mark as high as possible,” indicating achievement motivation, while also revealing a fear of failure, “’Cause I’m not doing too fly right now.” A similar emphasis on achievement was found from the control group,

> C.3: Do you have to show the squeeze theorem?
> C.2: Yah, I think so. How many marks is this? It’s six marks. So yeah, I think you do. Just keep going until you reach the limit part, then try zero greater than or equal to zero. You just fill in everything with zero…[Voice trails to quiet self-talk].
>
> ~Control Group, Week 2

Participant C.2 used the weight of the question (i.e., six marks) to dictate task behaviour, indicating achievement orientation, with no apparent interest in approaching the problem to search for meaning. It was the emphasis of achievement over an interest in the search for meaning which led to the assumption that this participant was avoiding failure. In summation, participants revealed an achievement motivation and fear of failure, indicating a performance-approach for the participants’ achievement orientation.

Participants of both groups engaged in utilizing the “skip” strategy when questions were deemed too difficult for their grade worth. At times, the experimental group demonstrated disinterest in the lab, skipping questions in order to complete the task,

> E.4: I’m going to move on to the next question, ’cause I just want to finish this lab.
>
> ~Experimental Group, Week 1

It was evident that Participant E.4 was more motivated by completion than fulfilment of the problem. The experimental group also showed a lack of interest in solving problems, which were evaluated as low value,

> E.2: Okay, I don't mind it's only one mark, but like negative 1 over negative 1 equals 1 not negative…[Instructor interjects]. Okay, I probably messed up somewhere, to be honest.
> E.3: That's yours, right?
> E.2: Okay 1 mistake, cost me three marks. Whatever, it's only 1%.
>
> ~Experimental Group, Week 2

Rather than focusing on learning from failure, Participant E.2 determined that its low value was not worth examination and therefore, did not address the problem (i.e., skipping it). This pattern recurred throughout the laboratories,

> E.2: Oh my god, I really don't want to do *2.*
> E.4: I thought *2* was easy, *2* wasn't easy.
> E.3: We're 'til like [Time of day], right? Well, this is the lab I'm dropping then.
>
> ~Experimental Group, Week 5

Participant E.4 first confirmed the amount of time remaining before the individual evaluated that the lab would be 'dropped' (i.e., it would not be evaluated in a final mark); therefore, Participant E.4 chose to skip learning about the problems. Similar behaviours were evident with the control group, who also engaged in the skip strategy,

> C.2: Is this a negative or is this just a part of the line?
> C.1: This is a negative.
> C.2: Skip *3*?
> C.1: For now.
>
> ~Control Group, Week 3

Participant C.2 deliberately invoked the skip strategy, agreed upon by Participant C.1. This strategy was repeated when questions appeared difficult,

> C.3: Are you still working, on number *2*?
> C.4: Yeah, I was trying to figure it out, but I can't.
> C.3: Well, we'll figure it out for the exam.
>
> ~Control Group, Week 4

Evidently, Participant C.3 elected to skip understanding the question, deferring until examination due to the groups' inability to solve it in the moment. The control group skipped questions that were perceived difficult and low in value,

C.2: They should be the same?
C.3: They should be. Because, it's a cube. I don't know
C.2: I'm too lazy to change it now. I don't really mind, It's literally gonna be worth like nothing, at the end of the day.
C.3: [Concurrent] Three marks, I know.
C.2: It's gonna be worth like, point 2, of our final mark–

~Control Group, Week 5

Participant C.2 admitted to being "too lazy" due to its low worth, as evaluated by the estimate of, "Point 2, of our final mark". In summation, both the experimental and control group exercised a skip strategy when questions were evaluated as low value, in comparison to the effort required to understand the answers.

Direct comparison was also used as a strategy for completing problems. The experimental group engaged in direct comparison of answers when they were collectively stumped,

E.1: What did you get for the derivative, for *5*?
E.2: This is what I got, but I don't know if that's right or not.
E.1: That's not what I got, but I don't know if I got it right either.
E.2: Guys, what did you get for the derivative for *5*?
E.4: Derivative for *5*. Yeah, no there's a minus, 'cause cos to sin.

~Experimental Group, Week 3

Participant E.1 reached out to Participant E.2 to determine if the answer obtained was correct. When neither were confident, the pair reached out to other members for direct comparison. Similarly, the control group engaged in direct sharing through the use of photographs taken by personal phones,

C.2: Okay, here. I'm done if you wanna take a look at it.
C.4: For *e*?
C.2: Yeah, that's just, *3a* and *3b*. If you wanna just take a picture of it so you can see it.
C.4: I have a lot of pictures in my phone.
C.2: Yeah? Really? It's okay. Thanks. So now we're gonna close this. Can you pass my first paper? I think it's that one right?
C.4: Where's number *1*?
C.2: Do you need this one still or no?
C.4: I think I need number *1*.

C.2: Right here, number *1* is right here, *2A, 2B, 2C, 2D, 2E,* and *1A*. Do you need another one or no?
C.4: I think that's all.

~Control Group, Week 2

Participant C.2 offered the solution to problems without explanation to Participant C.4. Participant C.4 clarified which question was sought, to which Participant C.2 offered apparent solutions to numerous problems for direct comparison. In summation, both the experimental and control groups engaged in direct comparison as a strategy for solving difficult problems.

Conclusion for impact of self-regulated learning on metacognition. A performance-approach led to the use of two primary strategies: skipping questions which were deemed too difficult for their grade worth, and utilizing direct comparison as a strategy for completing the problems. While comparison was an effective strategy for finding an agreed-upon answer, it did not necessarily guarantee understanding nor accuracy. Therefore, the desire to achieve correct results, derived by a performance-approach, led participants to selecting a strategy (i.e., direct comparison) which was not necessarily effective for understanding, nor achieving correct answers. Similarly, when difficulty arose, decisions were made by the participants of both groups to skip questions which were perceived to have comparatively low value. Therefore, goal orientation (i.e., a performance-approach) affected the use of self-regulated learning strategies, ultimately determining how participants of both conditions used their time.

Impact of complex, unfamiliar, and non-routine problems. Complex, unfamiliar, and non-routine problems affected the quality of metacognitive discourse, soliciting advanced skills from the participants. By comparison, problems that were familiar and easy solicited novice skills from participants.

E.4: Oh my god I just want to finish *1*, these other ones are nine eight-mark questions.
E.1: [Concurrent] Yeah, but they're like, 'find the horizontal'.
E.2: [Concurrent] Wait what? Oh, yeah, they're a little bit easier.

E.3: [Concurrent] They're not that bad.
E.4: Yeah.
E.1: That's literally, just checking, so yeah, it just takes a while.
E.4: [Concurrent] Yeah. No – oh, that's the one that's like, a ship and a work.
E.1: Oh snap, it takes awhile. (All chuckle)

~Experimental Group, Week 1

Participant E.4 initiated the discussion by noting the grading weight of questions not yet completed. Participants E.1, E.2 and E.3 responded concurrently, with all speaking at the same time, that the problems were not difficult in nature. Participant E.1 pointed out the primary task of "just checking", while Participant E.4 evaluated that the problem was "a ship and a work", which by context was interpreted to mean it was time-consuming but not challenging. The control group demonstrated similar novice skills when a problem was evaluated as familiar,

C.2: There's still one more other thing, *c* equals negative 8 and *c* also equals zero, because of this *c*, if you multiply by zero then it will give you zero. That is something I learned in high school.
C.4: I don't understand.
C.2: What part don't you understand?
C.4: Did you like divide both sides by *c* plus 8, or –
C.2: No, I just factored everything by *c* [Explains dividing by *c*].
C.4: What I don't understand is how you got this minus 8 from this equation.
C.2: Okay so, like, usually when we factor we have like two brackets, right? You know, like in the last question we had *x* plus 12 and *x* plus 5, right? So this is like the same thing but only one bracket. So this would be negative, so once you take the 8 out it would be negative 8, and this *c*, because it's being multiplied is a zero; I can't really explain that one that's just how it is. If it's like this, it's just a zero. If you want to take a picture of it for now, just so you can look over it, 'cause I have to go.

Control Group, Week 1

Participant C.2 identified that the skill required for the question (i.e., factoring) was learned in high school. Participant C.4 engaged in debugging, exchanging metacognitive task knowledge with Participant C.2. Overall, both groups engaged in the novice skills of metacognitive task knowledge, debugging, and evaluating when a problem was evaluated as familiar and/or easy.

Impact of unfamiliar and non-routine problems. Participants in both the experimental and control group displayed the advanced skill of monitoring when faced with unfamiliar and non-routine problems. While debugging a problem, participants from the experimental group engaged in monitoring,

> E.1: I literally did a step that was useless: I put *h* into the bottom, and I took it out in the next step. Why? [Chuckles]
> E.2 Yeah, no, I did. I was going off this example, and I didn't realize a square root situation is different from the situation I was doing.
> E.1: Yeah.
> E.2: So I ended up writing a lot more, and erased more, and almost confused myself.
>
> ~Experimental Group, Week 2

Participant E.1 began the discussion by attempting to debug while monitoring progress on a solution. Participant E.2 empathized, "I didn't realize a square root situation is different from the situation I was doing," which was simultaneously monitoring and evaluating efforts made on the problem. The control group also engaged in monitoring,

> C.3: *1H*. I don't know how to solve this [Chuckles], is it *3*-long?
> C.2: I know, knowledge is flowing through my head right now [Off-microphone member responds]. Yeah like, that's how I learn. To be honest, I learn by looking at answers. [Off-microphone member responds]. That makes sense. That's how I study too. When I study, I don't do practice; I literally just look at the questions and answers: [I look for] what works the best.
>
> ~Control Group, Week 2

Participant C.3 initiated the discussion by acknowledging unfamiliarity while monitoring a solution to a current problem. After empathizing, Participant C.2 provided strategies for answer-seeking and study. This, in turn, led to an immediate moment of near-transfer when Participant C.2 admitted, "When I study, I don't do practice; I literally just look at the questions and answers: [I look for] what works best." In summation, non-routine and unfamiliar problems solicited monitoring behaviour from both groups, which, in turn, precipitated other advanced skills into near contexts.

Planning was also evident as a result of discussions involving non-routine and unfamiliar problems. During the solution of a linear approximation problem, the experimental group debated the correct path to approach a solution,

> E.3: Did he say how many uni[ts] – how many digits we go to, for an approximation?
> E.2: I don't know.
> E.3: I don't think he gave a specific number, I guess just go to as many as you feel is necessary.
> E.2: Wait, we don't have to do this.
> E.3: Use the linear approximation to estimate it.
> E.2: Ya, we don't have to reach here.
> E.3: You sure? It says estimate.
> E.2: Yeah, 'cause that's the plan, this is the linear approximation of the function *f* and this is what he gave us.
> E.3: Yeah, but you have to estimate the value itself; you have to plug it in. If you do sine 29 over pi.
> E.2: Okay.
>
> ~Experimental Group, Week 4

Participant E.4 began the discussion by debugging with a partner the metacognitive task knowledge surrounding linear approximation. Participant E.2 recognized a different approach during the analysis, "…that's the plan, this is the linear approximation of the function *f* and this is what he gave us." The process of debugging unfamiliar problems by developing a plan was also evident from the control group,

> C.4: So, what does the IVT stand for?
> C.3: [Flips papers]. Intermediate Value Theorem, I don't know, I learned it a few days ago. So, it just has to satisfy these conditions, so *f* of a has to be larger than *L* [a variable] and *f(b)* has to be.
> C.4: What is *L*, what does *L* stand for?
> C.3: I don't know, to be honest, limit? I don't know. Oh, I think *L* is just the answer, before something? I don't know. *L* is what you test it with, so I guess it's just the zeros right here.
> C.4: So, basically if the first one is greater than zero, then the second one has to be less than zero.
> C.3: Or flip-flop, if the first one is less than zero, the–
> C.3 and C.4 (together): …Second one has to be greater.
> C.4: Ok.
> C.3: And if that satisfies either one of these conditions and get these numbers to be less than or greater than zero, then there's a root between a and b. So for what I did here,

> my numbers were zero and 2, I got the root, so I said there's a root between zero and 2. You understand that?
> C.4: Yeah, I think.
>
> ~Control Group, Week 1

Participants C.3 and C.4 indicated a lack of familiarity with the Intermediate Value Theorem. Debugging the problem, Participant C.4 began to develop a plan, while confirming metacognitive task knowledge, "…if the first one is greater than 0, then the second one has to be zero". Later, Participant C.3 specified the criterion and approach for the problem, using a "guess-and-check" strategy, based on the conditions. In summation, both conditions revealed metacognitive planning as a debugging strategy when faced with unfamiliar and non-routine problems.

Lastly, metacognitive strategic knowledge was displayed as a result of unfamiliar and non-routine problems. The experimental group revealed metacognitive strategies when faced with unfamiliar material,

> E.2: Cos of pi over 6 is 1 over 2.
> E.3: Pardon me? Pi over 6? Wouldn't it be root 3 over 2?
> E.2: Yes, root 3 over 2.
> E.3: Honestly, I'm just going off the note that he had right now.
> E.1: I don't have the note so I have to go into the book and find it.
> E.2: I have the note, and it's –
> E.1: It's in my old notebook which ran out of pages.
>
> ~Experimental Group, Week 4

Participant E.2 began by evaluating the ratio of a trigonometric function; Participant E.3 responded with an alternate answer, but the individual also admitted, "I'm just going off the note that he had right now." Participant E.1, also lacking familiarity, declared the use of a searching strategy, "…I have to go into the book and find it." When faced with the unfamiliar, the experimental group made use of metacognitive strategies. The control group also discussed metacognitive strategies when solving an unfamiliar problem,

> C.3: Oof. Let’s draw a picture, driving south. Travelling east, what route is the distance between the cars increasing? Car A is that, Car B is this. Okay, so, Car A is driving south, A. B…[Continued with self-talk].
> C.2: Whose paper is that? Yeah. Can I see? Okay.
> C.3: Isn’t the distance between car to car, or car to intersection?
> C.2: Car to car.
> C.3: So it’ll be like the diagonal.
> C.2: It’s right here if you wanna look at it. I drew a picture, too.
> C.3: Yeah, that’d be good, thanks.
> C.2: And this, it should be the right answer too, ’cause she wrote the answer on the board, I got the same thing.
>
> ~Control Group, Week 4

Participant C.3 began the problem with a plan to use the strategy of drawing pictures. This strategy led to debugging the distance being assessed; Participant E.2 confirmed the placement of the distance, “It’s right here if you wanna look at it. I drew a picture, too.” Evidently, the use of the picture-drawing strategy was effective in the control group’s ability to solve the problem. Overall, unfamiliar and non-routine problems solicited the use of metacognitive strategic knowledge during debugging processes for the groups.

Impact of complex problems. When faced with complex problems, participants in both conditions demonstrated the advanced skill of monitoring. While evaluating the difficulty level of a problem, a member of the experimental group illustrated monitoring,

> E.1: Like, you think it would be easy. No, you gotta go the long way. What am I doing now? Oh, right, continuing. I always forget to write the limit in front of the definition.
> E.4: I never forget because my teacher used to take off big marks for that.
>
> ~Experimental Group, Week 2

Participant E.1 admitted to the difficulty of the problem, before expressing openly a moment of monitoring, “What am I doing right now? Oh, right, continuing,” followed by an evaluation of metacognitive personal knowledge. Participant E.4 echoed metacognitive personal knowledge of how the individual learned the same lesson. The control group also demonstrated monitoring when faced with challenging problems,

C.2: Yo, this question is so long.
C.1: We're usually done by this time. If it's taking [an unknown participant] time, then it's really hard.
C.2: I know. Bro, [the participant]'s smart.
C.1: [The participant]'s smart.
C.2: I wish I was that smart.
C.1: I'm dumb, I accept it.
C.2: [Chuckles].

~Control Group, Week 3

Evidently, the difficulty of the problem precipitated Participant C.2's monitoring statement regarding the length of the solution. Participant C.1 responded with an evaluative and monitoring statement, "We're usually done by this time." This was followed by evaluations of other participants' intelligence, followed by what was interpreted as sharing for social purposes. In summation, the experimental and control groups demonstrated monitoring when faced with challenging problems.

Participants also displayed planning when challenged by the problems. The experimental group appeared to use planning to resolve difficult questions,

E.2: Wow, these are a lot longer than it seems.
E.1: Everything is a lot longer than it seems.
E.2: I'm going to start writing smaller, that's the idea.

~Experimental Group, Week 3

Participant E.2's observation of length indicated an evaluation of the difficulty of the material. Participant E.1 echoed this at a larger scale. Participant E.2 responded with a plan to adjust the size of writing in order to fit solutions onto a perceived limited space. The control group displayed planning at the conclusion of a robust debugging session for a problem,

C.4: When you find the lim[it] – that's the question, right now.
C.3: Okay.
C.4: The way you solved it. When you find the limit of this, isn't this going to be zero?
C.3: Yeah.
C.4: And then multiplied by this, isn't this not going to be zero.
C.3: You take this out and then the limit –
C.4: It's just confusing.

C.3: I don't really know.
C.4: And this part 2, I don't understand part 2.
C.3: No, the last question I couldn't get. This question was really hard.
C.4: It's because of this cosine stuff, if it was just a normal number –
C.3: See, so you just do the trick with it.

~Control Group, Week 2

Participants C.3 and C.4 discussed metacognitive task knowledge, attempting to debug a solution to the problem. Participant C.4 admitted a personal struggle, "And this part 2, I don't understand part 2." This was shared by Participant C.3, "No, the last question I couldn't get. This question was really hard." Participant C.4 evaluated the precise nature of the problem by isolating "this cosine stuff" as the difficulty. Participant C.3 concluded with a plan, "See, so you just do the trick with it." Overall, both the experimental and control groups used plans to address difficult problems.

Lastly, participants from both conditions made use of metacognitive strategic knowledge to manage challenging problems. Participants in the experimental group utilized metacognitive strategic knowledge during a challenging problem set,

E.4: Which one's the hard one, *2*?
E.2: Wait, *2*'s a hard one?
E.4: Oh I mean, which one are you guys struggling on?
E.1: Right now I'm on *1*.
E.2: How much more time do we have?
E.3: Probably not a lot.
E.2: Not a lot?
E.3: We probably wasted a lot, I feel like we did.
E.2: Yeah, but there's only like three questions and the third one looks really easy.
E.4: The same time it took you guys to do *1* and *2* it took me to do *3*. I'd say it's okay.

~Experimental Group, Week 5

Participant E.4 initiated the discussion while apparently attempting to offer support to fellow teammates. Each participant provided numerous monitoring and evaluating statements while the group attempted to determine which problems were challenging. At the end, Participant E.2 evaluated, "Yeah, but there's only, like, three questions and the third one looks really easy." This evaluation was interpreted as also making use of metacognitive strategic knowledge: the participant selected problems on which to focus time and energy. Participant E.4 concluded with an evaluation that the problem was more difficult than the first two questions. After this discussion, the group concluded with an assessment of the time left in the laboratory session and determined there was sufficient time to complete the assignment. Participants within the control group utilized metacognitive strategies in an effort to debug difficult problems,

> C.3: So, you didn't write down for anything, for *2b*?
> C.2: I kinda just scribbled. Here, look. I just kinda, like, avoided the question and I just put down the answer. I know the answer, I pulled it up on a calculator but how the answers are right – I just don't know. The horizontal asymptotes make sense, but the vertical I don't understand.
>
> ~Control Group, Week 1

Participant C.3 consulted with Participant C.2, while comparing solutions. Participant C.2 engaged in two metacognitive strategies: avoiding the question while writing down the answer; and looking up a solution on a calculator. These strategies were used to answer the question; however, Participant C.2 acknowledged not understanding part of the solution (i.e., the vertical asymptotes). Overall, both the experimental and control groups used metacognitive strategic knowledge when solving complex problems.

Conclusion for impact of complex, unfamiliar, and non-routine problems. In conclusion, complex, non-routine, and unfamiliar problems solicited metacognitive monitoring, planning, and metacognitive strategic knowledge. This was in alignment with what was found in the literature, confirming the variety of metacognitive skills shown when participants were presented with complex, unfamiliar, and non-routine problems (Mevarech et al., 2010). Recall from *Table 20* and *Table 21* (p. 113) that metacognitive strategic knowledge, planning, and monitoring emerged with low frequency for the experimental group (7.2%, 5.0%, and 5.9%, respectively) and the control group (4.9%, 3.9%, and 2.6%, respectively). Considering the impact of non-routine and unfamiliar problems in their solicitation of these advanced metacognitive skills, these already low frequencies would be further reduced by the absence of complex, non-routine, and unfamiliar problems. It was noted that all above examples were taken from each week, demonstrating that these impacts were observed independently of time. Further, all participants were included, illustrating that this impact was independent of ability. Therefore, it was concluded that, independent of time and ability, metacognitive quality increased with complex, unfamiliar, and non-routine problems.

Impacts of use of prompts. The experimental group received instruction on the content and use of metacognitive prompts (See Table *18*, p. 100). These prompts were used with decreasing frequency as the study progressed and were not always effective. Despite this, evidence was found that the prompts seemed to have the potential to solicit rich discussions and occasionally facilitated near-transfer in an immediate context.

Prompts were not always effective at soliciting diverse behaviour. Analysis of the in-course data revealed that prompts were not always effective at soliciting diverse metacognitive behaviour. It was evident on rare occasions that the prompts were ineffective. When used properly, prompts were able to solicit the component of metacognition that was emphasized by the prompt. Lastly, at the beginning of learning to use the prompts, participants used the prompts in a joking manner that indicated a lack of understanding of, or discomfort with, metacognition.

Participants' use of the questions solicited the behaviour targeted by the metacognitive prompts,

> E.4: Nice. Number *3*. What are they asking us? What is the problem slash task? I know the points on the curve, *x* squared, *y* squared, equals to 2. The slope of the tangent line is negative over 1, slope of the tangent is negative 1, so that means the derivative is…[Fades to quiet].
>
> ~Experimental Group, Week 4

Participant E.4 used the comprehension prompt, “What is the problem/task?” This prompt solicited the component targeted by the question, metacognitive task knowledge. Participant E.1 initiated a discussion with peers through the use of a debugging prompt,

> E.1: Right? That’s what that means, when it’s *y* equals to *x*, when you end up with that? That makes sense, right?
> E.2: Hopefully, we don’t have to do the ln *y*. Well, we don’t know what *y* equals.
> E.3: Where would you state that? ’Cause that goes to infinity. (Followed by quiet self-talk).
> E.2: Do we have to do another – That’s not a triangle. What in the hell? ’Cause if you try to sub *y* by itself, you kind of need [*y*] for this situation.
>
> ~Experimental Group, Week 3

Participant E.2 responded to the prompt with debugging efforts, attempting to troubleshoot an approach to the problem. Participant E.3 continued the discussion by pointing out properties of the function. Evidently, the prompt, “That makes sense, right?” solicited debugging efforts from fellow group members. Finally, a participant began by asking peers about a plan for a question,

> E.1: So how are we going to approach this question?
> E.4: You know, we gotta use some linear approximations. We need to know *f* at *x*, *f* prime at *x*, we need to know *a*, *f* at *a*, *f* prime at *a*. We need all of those, find those things and then we can do linear approximation on that bad boy.
> E.2: We make up the *a*?
>
> ~Experimental Group, Week 4

Participant E.1 used the question, “So how are we going to approach this question?” in an effort to initiate planning with the group. Participant E.4 responded with metacognitive task knowledge but also formulated a plan of approach, “We need all of those, find those things and then we can do linear approximation”. Overall, prompts generally solicited the emphasized components of metacognition intended by the question.

Occasionally, prompts were ineffective at soliciting metacognitive behaviour, either by misunderstanding or misuse,

> E.4: You’re asking for the inverse of cotangent inverse?
> E.1: [Laughing]. Yes.

> E.4: It'd be cotangent.
> E.3: [Concurrent] What cognitive thinking process is this?
> E.4: What does this mean? [Indiscernible speech follows]
> E.1: I'm confused myself [Chuckles].
>
> Experimental Group, Week 3

Prior to the above example, Participants E.1 and E.4 debated the nature of Participant E.4's question, "[What is] the inverse of cotangent inverse?" Participant E.3 offered the prompt, "What cognitive thinking process is this?" in an effort to resolve the debate. It was evident that Participants E.1 and E.4 either did not listen or did not respond to this prompt. At times, the term, "metacognitive", was used incorrectly,

> E.3: Are you guys still doing *B*? Conjugate, then you do a fraction. You do a conjugate, but you make sure you leave it as a fraction, take the biggest term out of the bottom.
> E.1: Yeah, that's what I was thinking.
> E.3: And if you do that, the square root of x squared, it's going to be dividing it by x. So, divide everything by x.
> E.1: Yeah, that's what I was thinking.
> E.3: Proper metacognitive thinking, trust. [Laughs].
> E.1: What was your strategy and how did you implement it?
> E.3: You get friendly with [Indicates an ethnic group] people.
> E.1: That's the way to do it.
> E.3: In all fairness though – Oh, you can cancel that.
>
> ~Experimental Group, Week 1

Participant E.3 provided a process for approaching a question; this approach was supported by Participant E.1. It was evident that Participant E.3 misunderstood 'metacognitive' when it was concluded, "Proper metacognitive thinking, trust." This was referring to the recitation of only metacognitive task knowledge for a given question, which on its own was not understood as thinking about one's own thinking. Participant E.1 seemed interested in how this solution was determined when using the prompt, "What was your strategy and how did you implement it?" Participant E.3 turned the answer into a joke by inferring that the solution came from an ethnic group. This joking disposition continued in other instances within the first week, E.3: We divide it by *x*, bro. You can't do that, it's going to infinity. You're still going to have this on the bottom. Okay, this is how I did it. Let me show you my metacognitive thinking process and how I accomplish this. Yah, there you go. Take this term on the bottom, divide everything by *x*, so this becomes 2.

~Experimental Group, Week 1

Participant E.3 used the expression, "metacognitive thinking process", to refer to metacognitive task knowledge, articulated when a solution process was shared. Again, there was no evidence revealed from this quote to indicate that this was a "thinking-about-thinking" process. Lastly, the participants attempted to use the prompts in moments that appeared inauthentic,

E.1: Where's the sheet. We gotta ask questions. So, let's see.
E.3: Oh, now you're asking? [Chuckles] Just tell me, for *C*.
E.1: Are you satisfied with how you solved that problem?
E.3: For *1C*.
E.4: I'm very satisfied.

~Experimental Group, Week 1

Participant E.1 declared effortful use of the questions. Participant E.3 did not perceive this as authentic, "Oh, now you're asking?" Participant E.1 chose the evaluating prompt, "Are you satisfied with how you solved that problem?" which was answered with a simple affirmative, "I'm very satisfied." In summation, prompts were not always effective in soliciting meaningful behaviour, particularly when the participants were initially learning how to use the prompts to enhance their problem-solving solutions. It was concluded that prompts initiated behaviours intended by the questions; however, it was evident that the prompts required practice, and an accurate understanding of metacognition, for effective results.

Improvement in rich discussions when prompts were used effectively. While diverse, rich conversations were demonstrated without the use of prompts (e.g., See *Group composition*., p. 127), numerous examples emerged of rich discussion initiated by a participant using a prompt. When participants were just beginning to use the prompts, a diverse discussion emerged,

E.1: Okay. I'll be sure to ask these, like right now? [Instructor responds].

> E.3: Stating word for word, ‘How do I do *B*?’ is different than, ‘What is the problem/task?’ Speaking of which, how do I do *B*?
> E.4: I think it’s the same thing but I –
> E.1: Actually, I was already going to ask this, does the answer make sense if it’s zero over 1 when you’re approaching infinity or zero over 3?
> E.2: So the horizontal asymptote would be zero, so, yes. It would make sense. Yes.
> ~Experimental Group, Week 1

Participant E.3 began the discussion with the use of a comprehension prompt. Participant E.1 added by modifying to a debugging prompt. This in turn was answered by an evaluation, “So the horizontal asymptote would be zero, so, yes.” The use of a debugging prompt was also effective in guiding a participant to a solution, even when engaged with a member off-microphone,

> E.3: Wait, I’m debating if this would work. I want you to think this through where *m* and *n* [sentence unfinished]. So, what I did – this might seem like a simple fix – all I did was give them each their own variable…[Off-microphone member responds]. They can be equal, but they don’t have to be. I’m just thinking, ‘Does that make sense?’ [Off-microphone member responds]…Why wouldn’t it be? [Off-microphone member responds]. In terms of radians, so sine, 2. 2 pi over 6. Yeah, that works out.
> ~Experimental Group, Week 3

Participant E.3 explored an approach to solving a problem. After discussion with an off-microphone individual, monitoring was demonstrated through use of the prompt as a metacognitive strategy, “I’m just thinking, ‘Does that make sense?’ ” (Participant E.3). This was interpreted as an effort to debug the solution. Once Participant E.3 explored the task knowledge, Participant E.3 affirmed the chosen path. Diverse behaviours were revealed as a consequence of a debugging prompt,

> E.4: I have a good one for you, am I stuck? Am I stuck? Why?
> E.1: I am stuck.
> E.4: Why?
> E.1: ’Cause I’m looking at this cotan inverse and I’m like, ‘What’s the derivative of the inverse of cotan’?
> E.4: Well, there is a strategy that you could use which is: look at the known derivative notes.
> ~Experimental Group, Week 3

Participant E.4 initiated the discussion with the use of a debugging prompt. Participant E.1 explained the nature of the difficulty, "What's the derivative of inverse of cotan?" As a result, Participant E.4 correctly identified a strategy for answering this question (i.e., searching through notes). In summation, prompts solicited diverse metacognitive behaviour and facilitated rich discussions for the participants.

An inspection of Table *18* (p. 100) revealed that the frequency of prompt use decreased over time: 4.8%, 1.4%, 4.1%, 2.3%, and 1.1% for Weeks 1 through 5, respectively. Prompt use increased during Week 3, perhaps precipitated by the difficulty of the problems or by renewed efforts to use the prompts. Overall, prompt use decreased over time, even though the questions in the final weeks were difficult problem sets for the participants.

Prompts, with persistence in a topic, occasionally yielded transfer. Inspection of the transfer moments displayed by the experimental group revealed that prompts facilitated transfer, even when used in a joking manner. It was noted that transfer was also demonstrated without the use of prompts. The experimental group correctly identified when transfer occurred,

> E.1: For this one, you can't use anything other than the first principle, whatever you call it.
> E.2: The only difference between this one and the one he gave us is this one is x to the power 19, and this one is x to the power 3.
> E.4: That just means we are using really good transfer skills right here.
> E.2: Mmhmm.
> E.1: Look at these transferring abilities.
>
> ~Experimental Group, Week 2

Participant E.2 displayed near-transfer by recognizing a question as being similar to an example provided. Participants E.1 and E.4 acknowledged this transfer in response. Members of the experimental group discovered common errors made, exemplified by Participant E.2, "1 point 1 times negative 50. Yeah, those are the wor– [Laughs]. 'Cause, like, see? okay. It's the small errors that always get me. Errors. Errors. Errors." Participant E.4 recognized that small errors were a common occurrence for the individual. This application of a present circumstance to other situations was a recurring illustration of transfer. Overall, transfer was displayed in situations independent of the use of prompts.

Participants' use of prompts facilitated transfer. This was evident even when participants were joking about their use of the prompts,

> E.1: What's the next question, with the definition? Find *y*. So, we do these three using these six, five, then the next two.
> E.4: *A* is a power rule, then power rule, power rule again, then a little ln, then a chain.
> E.1: Are you supposed to do that or does he want us to do the *f(h)* minus *f* of *x* plus *h* minus?
> E.4: Ohhh. Shoot. That is the definition.
> E.3: Ohhh, Yayaya.
> E.4: I almost got like, zero marks on this question.
> E.1: No, you're good, you're good. You're asking these questions, and learning.
> ~Experimental Group, Week 3

Participant E.1 began with an adapted comprehension prompt, "What's the next question, with the definition?" which was followed by a plan for approaching the problem by both Participants E.1 and E.4. While clarifying this process, Participant E.1 debugged a solution. When Participant E.4 realized that an incorrect answer was delivered, Participant E.1 responded in a joking tone, "No, you're good. You're asking these questions, and learning," after which joking ensued by the participants. Participant E.1 evaluated Participant E.4's behaviour, transferring the context of the situation to a universal evaluation. When debugging a problem, one participant asked a question of depth on the use of implicit functions,

> E.2: I hate Implici–
> E.1: [Chuckles] Implicit, yeah.
> E.2: Is it implicit differentiation? He's like, 'It's so much harder,' but yeah, why is it so much longer?
> E.4: When is implicit functions used in real life? When are they used in –
> E.3: Probably higher level math.
> E.4: Yeah.
> E.2: That's always the, always the answer.
> E.1: Yeah, that's always the answer. When is it used? High-level math!

E.4: Why do we use more difficult math? In even more difficult math!
E.1: That's why.
E.4: Yeah.
E.3: [Concurrent, to self] Damn right.
E.2: And maybe building a rocket ship, I don't know. I want to build a rocket ship that's my goal.

~Experimental Group, Week 3

Participant E.4 provided the prompt, "When (are) implicit functions used in real life?" to which Participant E.4 made the near-transfer connection of "higher level math". Participants E.1, E.2, and E.4 connected this to "all" situations in their own joking manners, (e.g., "Why do we use difficult math? In even more difficult math!"). Despite their joking tones, the acknowledgement indicated understanding. Participant E.4 showed the most understanding with the quiet, "Damn right," comment that was muttered. Recall also, in *Selecting a group from the experimental condition*. (pg. 104), an analysis of the strategy surrounding use of brackets by the participants yielded a moment of transfer. In summation, the experimental group displayed transfer initiated by prompts when they persisted to work through problems.

Conclusions for the impacts of use of prompts. The inclusion of prompts impacted the experimental groups' behaviour in several ways. Although prompts were not always effective at soliciting diverse behaviour, the questions were able to facilitate behaviours intended by the questions. Additionally, when used properly, prompts were able to facilitate diverse metacognitive behaviours, including transfer. Of all coded categories, transfer was least displayed by the experimental group (i.e., 1.2% overall). Further, the moments of transfer decreased over time (i.e., 2.1%, 2.1%, 1.4%, 0.8%, and 0% for weeks 1 to 5, respectively). Since the prompts solicited transfer, it was concluded that the intervention impacted the solicitation of transfer. This could have resulted from: participants becoming aware of the purpose of transfer from the study, the effect of increased metacognitive diversity precipitated by the use of prompts, or both. Therefore, prompts facilitated metacognitively-rich conversations, which in turn, precipitated near-transfer in an immediate context. Since transfer increased with practice, and decreased as a displayed behaviour over time, it was concluded that prompts should be encouraged semi-frequently by the instructor, with gradual release of responsibility.

Overall conclusions from the in-course data . Analysis of the in-course data led to the following conclusions:

1. The experimental and control conditions possessed similar characteristics in their composition and patterns of discourse. Therefore, the intervention had limited immediate impacts on the participants;
2. For both experimental and control conditions: conversation quality would be enhanced by restricting conversations between participants to recorded members only; think-aloud data would be enhanced by explicit instruction;
3. Goal orientation affected the use of self-regulated learning skills, particularly in the use of skipping and comparing strategies. Further, metacognitive quality, assessed by diversity and depth, increased with complex, unfamiliar, and non-routine problems;
4. Prompts facilitated deeper and more diverse metacognitive behaviours, which in turn facilitated transfer. Prompts should be encouraged semi-frequently by instructors, with gradual release of responsibility.

The above conclusions were derived from a qualitative thematic analysis of the in-course data. In summation, although the intervention was less effective than was intended by design, some insight was gained regarding the transferability of metacognition and the impact of prompts on metacognitive development in post-secondary Calculus students. Optimal conditions were confirmed for soliciting advanced metacognitive skills (i.e., through complex, unfamiliar, and non-routine problems) as stated in the literature (e.g., Mevarech et al., 2010). Lastly, it was concluded that some components of metacognition may transfer, such as metacognitive strategic knowledge, monitoring, and planning. Future study of the impact of prompts on both metacognitive ability and transfer would benefit by following the recommendations enumerated above, specifically: limiting participants to discussions with recorded members only; explicit instruction of think-aloud processes for experimental and control conditions; and semi-frequent reinforcement of the use of prompts for the experimental condition, with gradual release of responsibility.

CHAPTER SIX: QUALITATIVE INTERVIEW DATA ANALYSIS

The interviews created space for continued questioning until answers were made clear (Helms-Lorenz & Jacobse, 2008). Thematic analysis (Braun & Clarke, 2006) of the qualitative interview data revealed six themes: reinforcement of intervention design; characteristics of participants' learning; metacognitive strategic knowledge; impacts of the intervention; transfer; and impact of the interview.

In order to assess potential transfer differences, intervention design and consequent metacognitive enhancement were verified. The design of the intervention was reinforced by the participants' collective testimonial. Characteristics of the participants' learning process, and approaches to learning, were observed during the analysis of the interview data. Participants shared developments of metacognitive strategic knowledge. Analysis of the interview data revealed that the experimental group, in comparison with the control group, demonstrated some enhancements in metacognitive personal knowledge, strategic knowledge, managing information, monitoring, planning, debugging, and evaluating. Transfer of metacognition presented in immediate, near, and far contexts in both conditions but with greater diversity of skills in the experimental group. The experimental group displayed some elements of delayed-transfer during the hypothetical task within the interview. They also reported transfer into contexts considered to be further than those reported by the control group members and. The interview indicated the potential of operating simultaneously as both instrument and intervention of metacognition. Each theme was explored individually.

Reinforcement of Intervention Design

Throughout the interviews, participants within both groups reinforced several characteristics of the design of the intervention. First, participants disclosed distractions to their thoughts. Participant E.3 acknowledged the challenge of examining the self, “It’s hard to take a look back at yourself. It’s really easy with other people, because it’s staring you in the face…When I’m writing down stuff…I don’t know why I wrote x equals this, I just know it.” Participant C.9 shared, “I tend to be all over the place. So, sometimes I’d zone out and I’d become…aware, basically, in like a minute or two…‘Hold on. What am I doing? I need to focus’”. Participant E.9 also identified distraction while learning, “Information…was very scattered. My mind would be everywhere whenever I received information…It became hard to use the information that I learned.” Participant C.10 recognized the need for increased relevancy, “When we did the labs, not only me, some people in the class [wondered], ‘Why do we do Calculus if we’re not going to use it in our life, in the future?’ ” Participant C.4 acknowledged pressure from family stress, with thoughts focused on, “Thinking about my family. If I fail, I will be failing everyone, and no one will be happy with me. I don’t want that.” Collectively, these examples illustrated similar distraction of thought from individuals from both conditions.

Participants in the experimental group reported using the metacognitive prompts to assist with focus during the laboratory sessions. When asked to clarify how the prompts were used, Participant E.8 described the prompts as a, “resource to feedback our work…Before starting, I would read the questions [prompts], make sure I have a clear answer for them, and then start doing it. That ultimately would give me confidence I’m on the right track.” Participant E.1 credited the metacognitive prompts with facilitating access to strategies,

> It started with being in the study, how we were just encouraged to employ these tactics to think about how we’re thinking about a question. We haven’t really done that before. As the semester progressed, it would become me just thinking about the questions [metacognitive prompts], without being told to do it, or reminding myself, ‘Oh, don’t

> forget to think about the question.'…The prompt cards led to the implementation of the...time management and learning strategies.

Stressors and distractions, which affected the process of thinking, were reduced through metacognitive training such as that provided by the intervention.

Participants also reported positive impacts from the recording process, while being in a social context, on their learning.

> [After] the voice recordings started, I was able to think about exactly what I was doing and verbally stating that made me more aware of my thought process. Doing the recordings as a whole made me realize how much thought I have to put into a question, and what I do during a question…What I'm thinking about how I have to approach the question, …verbally saying that, …helps me do a question in the future because I have that verbal recollection. Verbally stating the thought process I have allows me to recollect it and do it again later on. (Participant E.5)

The social setting enhanced the sharing of ideas and debugging during problem-solving as summarized by Participant C.10, "There is a question that was written where it's not…a normal math equation…I wasn't that good in the thing [finding variables] until the labs. My team helped me to understand how to find the variables…They explained the question." Participant E.5 identified group learning as a style of learning within a STEM program (Science, Technology, Engineering, and Mathematics), "My faculty is targeted at: group learning (communicating in a group…working together, and developing a sense of teambuilding), repetition, and learning through applications." Evidently, vocalizing thoughts in a social context had a positive impact on participants' thought processes, particularly in facilitating metacognitive expression.

The difficulty of problems amplified monitoring for the experimental group. For example, Participant E.3 admitted,

> My awareness has definitely improved, of my thoughts of whatever I'm thinking…It doesn't really exist until a difficult problem. It tends to ignore what doesn't work…If it does work…this might be able to be used in different questions.

Evidently, difficulty and utility were important considerations with respect to awareness for this individual. This same member characterized a positive, yet anxious, increased use of thought and focus when faced with challenging problems.

> There was an instance where I didn't get one of the questions…it [my brain] tends to focus on that a lot more, way more than it should…It's like it [my brain] can't not know…It's like I *had* to know…Even if I get 98% on the test, my brain will focus on the…2% if I got it wrong or I didn't understand it. (Participant E.3)

Participant C.5 admitted, "I usually think about what I'm thinking when I'm stuck…I take a step back and try to think about the problem, instead of the bare basics about the problem, … [and] why I'm doing the problem." Participant E.1 reported monitoring thoughts to move through difficult problems by letting go of past strategies,

> This usually happens at the moments where I am able to get past my preset thinking strategies. [For] example, where I thought about trig identities as variables, instead of just random words, I was aware of my thinking then…and also when I finally was able to properly derive larger equations. I thought of about it in a more intense way.

This individual provided insight into why difficult problems were necessary for precipitating metacognitive monitoring. Participant E.1 identified the importance of getting "past…preset thinking strategies" in order to reach awareness. Although automatic processes are generally resistant to mindful analysis and high-road transfer, learning contexts great difficulty were predicted within the literature to facilitate analysis and potential high-road transfer (Mevarech & Kramarski, 2014; Mevarech et al., 2010; Salomon & Perkins, 1989). It was evident that problem difficulty amplified monitoring, necessary for analysis.

Further, novel (i.e., non-routine) problems solicited metacognitive growth when conducted in a social context, “I encountered a lot of problems I wasn’t aware of or how to approach this sort of thing. Bouncing ideas…with other peers who were thinking…slightly different[ly] in one way or another…One of them [ideas] would work out.” Participant E.9 admitted to growth after facing adverse, novel problems, “The first day, I’m not doing so well. I’m wondering why I’m not doing so well…It made me realize I need to change, if I want to succeed, because how I was before wouldn’t make it that far.” Note, that Participant C.6 acknowledged a desire to learn and think of meta-level processes, particularly when faced with difficult problems,

> I feel like I need to understand the process…[rather] than just seeking for only the answer, because then I would only understand the question properly…and develop the skills to answer that problem. The early labs…were more easy, and I already knew how to do that material, so the answers came to me quick. When it was later on in the labs, with…harder problems, like word problems,…that was when I realized about this. (Participant C.6)

Novel, challenging problems were necessary for participants to grow. Participant C.4 summarized the impact of novel problems on cognitive load,

> Normally, as a student, I don't want to think of anything [that] stress[es] my mind…I just want to see the questions and be able to solve them. As a student, you have to stress your brain, to start thinking…It's not really comfortable, but…you have to do it.

Participants' use of monitoring was proportionally solicited by the difficulty of the problem as summarized, "My awareness was similar to the questions I get" (Participant C.4). It was evident that the participants, as a collective, self-identified the positive effects of difficult and novel questions on their learning, particularly in their use of metacognitive monitoring, which supported previous findings regarding difficult and novel problems (Mevarech & Kramarski, 2014; Mevarech et al., 2010; Salomon & Perkins, 1989).

Solutions to challenging problems were facilitated by repeated practice of new strategies in order to develop metacognitive skills. Participant E.1 admitted, "It [metacognitive monitoring] would just happen from the repetitive application of the process…" Participant E.5 shared, "Repetition, …gives you instinct on how to approach a question. Repeating a similar question to a topic in Calculus really helped me [with] how to do that question, and how to approach it…[It] allows me to finish it quicker." Further, comfort was reported from time spent with the intervention program, "When you're in a study geared towards metacognitive research…the interaction became a lot more apparent. We got more comfortable with the situation and we started asking each other those types of [metacognitive] questions without realizing it" (Participant E.3). Participant E.10 reported a reduction in performance due to cognitive load,

> When I'm doing questions or I'm playing basketball or games, sometimes I can remember to use metacognition. But sometimes, I forget, and sometimes, when I'm really stressed, it's not very easy to use it…I'm not used to it…When you get stressed, your mind goes blank, and everything is gone.

This same individual emphasized the importance of practicing using the prompts for automaticity, “Sometimes you forget to use them, because [of] not enough practice, not [being] used to them…I am still trying to get used to it. I have to apply it, by conscious [thought], it’s not that deep in my thoughts, yet” (Participant E.10).

Participants in the control group also admitted need for practice, “It took time, I’d say. It wasn’t easy to find, or to change, a certain habit of having one approach…That transition to having different perspectives, being brought into my own perspective, was kind of difficult” (Participant C.9). Participant C.5 summarized the benefit of regular practice with newfound strategies, “The more I used it, the better I got at it…I was more aware of knowing when to ask questions, and how to approach someone when asking questions…Practicing that skill was important.” Evidently, practice was identified by participants as essential for learning new strategies and for developing metacognitive ability (Dignath & Buettner, 2008; Dignath et al., 2008; Salomon & Perkins, 1989, Tuomi-Gröhn & Engeström, 2003).

Overall, the participants reinforced several characteristics of the design: the need for metacognitive development to enhance focus and regulation of thoughts; incorporating audio recording in a social context; ensuring the presence of novel, difficult problems to facilitate monitoring and metacognitive thought; and incorporating repeated practice, over extended periods of time, to facilitate growth. These findings also supported the literature on: potential for metacognitive growth (McCabe, 2011); impact of dialogic, online measures of metacognition in a social context (Helms-Lorenz & Jacobse, 2008; Kramarski & Dudai, 2009; Schmitz & Perels, 2011); importance of including novel (Mevarech & Kramarski, 2014; Mevarech et al., 2010) and difficult (Mevarech & Kramarski, 2014; Mevarech et al., 2010; Salomon & Perkins, 1989) problems; and supported the literature on the inclusion of repetition (Salomon & Perkins, 1989, Tuomi-Gröhn & Engeström, 2003).

Characteristics of Participants' Learning

Throughout the interviews, participants within both groups shared details characterizing their preferred learning styles and general feelings towards the course experience. Participants from the control group reported mixed reactions to the process of learning in the lab. Several participants reported that they needed time to think questions through and organize their thoughts. Participant C.4 identified fears resulting from perceived familial pressure:

> Sometimes, when I'm in the exam hall or looking at questions, I would get so nervous and start biting my fingers. [I would] start looking up, down, losing focus. Then, I start getting concentrated again…[It] just goes on and on like that…I'm the first child in my family…I'm the one that's going to make the way for them…That's what really drives me when I'm in the exam hall….I'm working for my family.

Several participants of the control group identified that they enjoyed learning new skills with some anxiety during the learning process. Participant C.5 shared, "I really like learning things about myself or ways to improve myself…At first, I was annoyed when I couldn't solve the problem, but then, when I learned to deal with it somehow, it felt like I improved myself." Participant C.6 affirmed, "When something is not going the right way, I get panicked, and I feel [think], 'Where did I go wrong? I already did this much work. I don't want to go back.' I kinda get lazy sometimes, too." It was evident that learning for the control group was mixed between the joy of learning and anxiousness to perform based on perceived pressures.

Similar to the control group, experimental group participants also reported mixed feelings regarding learning. Participants were resistant to change,

> I don't like to change what I'm doing…If I found that halfway through reading one problem I was doing it completely wrong, I would just keep doing it…I didn't like to share how I would think, just because I would fear that maybe I was wrong …I still wouldn't like to restart a question purely because of the work I had put through it. (Participant E.1)

As the course progressed, this individual reported improvements in comfort with change. Participant E.3 reported, "There is a bit of stress…There is this new thing, I might not get it right." Conversely, Participant E.9 reported a strong desire to learn new strategies after initially taking time to, "go with the flow". This excitement to complete the problems efficiently, and to learn, was shared by several members of the experimental group. Finally, Participant E.10 reported a performance-approach motivation, "Sometimes you really want to get the better grade…so you are eager to do more questions without knowing your own mistakes." It was evident that, similar to the control group, the experimental group had mixed feelings about learning ranging from anxiety to joy; however, members also reported performance-approach goals (Elliot & Church, 1997).

Performance-approach goals were defined by their fear of failure in addition to their high-competency expectations; mastery-approach goals were defined by high-competency expectations and achievement motivation (Elliot & Church, 1997). Evidence of performance-avoidance goals as defined by Elliot and Church (1997) (i.e., low-competence expectations and fear of failure). Therefore, because of the participants' reported feelings regarding learning as a process, it was concluded that the participants for the experimental and control group displayed performance-approach and mastery-approach goals.

Distinct from the control group, participants from the experimental group shared their diverse characteristics pertaining to their educational background and learning styles. Participants of the control group were less forthcoming with in-depth knowledge of their learning style. Participant C.5 reported, “I don’t think much about how I think, because I’ve already discovered how I think… That’s how I’m proficient at doing stuff now…I know how much time I’m going to need…so I plan everything out before I start.” While an advanced strategy (i.e., planning) was mentioned, this lacked description or evidential application.

Uniquely, Participant E.8 of the experimental group self-declared as a graduate of the International Baccalaureate (IB) Diploma Programme. During the completion of the IB Diploma, the participant shared that they learned of metacognition previously while studying the Theory of Knowledge credit required by the Diploma, “I valued them [i.e., the strategies learned] a lot…I did take a Theory of Knowledge class…I just really liked learning. Learning new ways to help me learn better, you can’t go wrong with that.” Participant E.8 also seemed to understand personal preferences of learning (i.e., an auditory learner). Singularly, the individual engaged in regular self-evaluation of performance, “I would time myself based on first questions…I would quantify it [time]…to make sure I have an idea of how I’m moving along…It made me more efficient; it made me use my time more wisely.” The impact of the IB experience appeared to encourage thinking before acting. Participant E.9 reported that, during secondary school, the individual was lazy in thinking and turned to friends for support. Participant E.5 stated a personal preference towards verbal interaction to “cement” ideas. In summation, experimental group participants were more forthcoming about their learning preferences.

The experimental group displayed rich demonstrations of metacognitive personal knowledge. Participants from both groups were identified as possessing either performance-approach or mastery-approach goals (Elliot & Church, 1997). Further, while participants from both conditions reported mixed feelings of stress and joy during learning episodes, only participants from the experimental group identified specificity of learning preferences and varying comfort levels with their use of learning strategies. These differences suggest that this may have been a result of an increase in the experimental groups' metacognitive personal knowledge and evaluating metacognitive components, respectively. Therefore, the intervention may have enhanced participants' metacognitive personal knowledge and evaluating components within the domain of learning itself (Kramarski et al., 2013; Rotgans & Schmidt, 2009). This suggested the possibility of transferring evaluating and metacognitive personal knowledge components within the domain of generic learning (e.g., van Velzen, 2016), contrary to literature (e.g., Erickson & Heit, 2015; Winne & Muis, 2011; Vo et al., 2014).

Metacognitive Strategic Knowledge

Participants within both the experimental and control condition shared numerous strategies in their regular practice:

- compared solutions with peers;
- developed solution approaches with peers;
- applied knowledge developed from high school;
- applied solutions and models developed from class time;
- chunked, or broke, complex questions into smaller portions;
- listed knowns and unknowns in the question to identify solution pathways; and
- tried an approach before rereading questions to identify mistakes;

Distinctly, the control group reported that they:

- reduced calculator use through increased mental mathematics;

- searched for connections between all information and format when solving problems; and
- developed a more a serious approach to laboratories based on observing others.

One participant reported noticing a pattern between the laboratories and the order in which content was delivered to the students. Collectively, these strategies can be identified as belonging to the category of metacognitive strategic knowledge. Although participants in the control group reported learning these strategies before, the use of these strategies assisted in clarifying questions and increasing efficiency for solving the problems. All control group participants reported comfort with using the strategies listed above.

Similarly, the experimental group shared strategies employed while solving problems in the laboratory sessions, however, the content of these strategies fell into two categories: metacognitive strategic knowledge and self-regulated learning strategies. For metacognitive strategic knowledge, in addition to the strategies shared between both groups, the experimental group participants reported that they:

- searched for connections between all information and format when solving problems;
- checked answers for reasonability, readability, and comfort; and
- analysed questions before beginning to solve them.

It was noted that more than one member of the experimental group mentioned checking answers, and analysing questions prior to solving. This indicated that the experimental group employed more advanced strategies such as debugging and planning.

A distinguishing characteristic of responses from the experimental group was their identification of self-regulated learning strategies. For self-regulated learning strategies, the experimental group members reported that they:

- reviewed content from each laboratory;

- applied the metacognitive question tool to assist in debugging and problem-solving;
- chose to answer simpler questions before complex questions;
- minimized second-guessing by answering questions with increased effort;
- sought help from more experienced students;
- reviewed specific uses of equations and when to use them;
- explained concepts to other students to develop deeper learning;
- focused on targeted learnings, particularly those emphasized by the instructor; and
- worked ahead of the instructor to find original methods for concepts learned in class.

The only self-regulated learning strategy listed by the control group participants was regular practicing of problems to facilitate learning. Since self-regulated learning strategies were minimally reported by the control group, it was concluded that the intervention increased the development and use of self-regulated learning (Hessels-Schlatter et al., 2017; Özcan, 2015).

Also distinct from the control group, some members of the experimental group reported high comfort, while others reported that their learning was still in-process. This was substantially different from the control group members, who reported high degrees of comfort uniformly. Consequently, it was argued that the experimental group developed more reasonable evaluations of their performance, particularly in context of their experience, in comparison with the control group (Kramarski et al., 2013; Rotgans & Schmidt, 2009).

In conclusion, participants interviewed from both conditions reported the use of problem-solving strategies for the purpose of enhancing efficiency during the laboratory sessions. This finding aligned with a performance-approach orientation (Elliot & Church, 1997). Distinct from the control group, participants from the experimental group employed the use of more advanced (i.e., debugging) strategies. Further, the experimental group reported detailed use of self-regulated learning strategies. Therefore, the intervention positively affected the development and use of self-regulated learning (Hessels-Schlatter et al., 2017, Özcan, 2015). Finally, while the control group reported uniform comfort with the strategies, the experimental group provided more reasonable evaluations of performance, indicating that the intervention improved the evaluating and metacognitive personal knowledge components (Kramarski et al., 2013; Rotgans & Schmidt, 2009).

Impacts of the Intervention

Throughout the interview, participants shared the impacts of their learning journey, revealing enhanced benefits in overall metacognitive performance for the experimental group when compared with the control group.

Control group. The control group identified enhanced use of strategies but also shared that they did not learn about how they think. Participant C.10 shared, “We only learned how to think, how we solve, mathematical problems in Calculus. But, [we] *really* don’t know how we would think in other things [subjects]…For example, English, or Science.” Participant C.6 described this in more detail,

> I didn’t learn much, because I use [my thought processes] mostly all the time for solving problems in other classes, too. I already know how I think. I didn’t feel like I developed as much…It seemed the same to me…Maybe just new skills that I learned but not how I think.

Despite associating the course with only strategies, Participant C.6 independently reported developing metacognitive monitoring skills, “Before…I was…focusing on the strategies in the answer but, after the lab, I’m more aware that I have to develop the skills for doing the process before getting the answer…I have to practice that more." Participant C.10 also reported learning new strategies for success,

> Thinking one way, I started trying to solve in other ways that I never tried before…or I knew, but I don't like using those ways…For example, if I had a question, and there's two solutions, there is one that is one-step, and the other in two-steps. I would do the other one that's in two steps because I know that one, and I wouldn't learn the other way that was easier…I started practicing to learn other solutions, other ways.

Participant C.5 admitted no growth in new skills of learning but instead benefitted in refining the balance of social and academic performance,

> I feel like it did improve on how I think about how I learn. I was able to use parts of my brain simultaneously. I could use the social aspect of my brain…[and] I learned to focus on the problems when I'm learning something new. Rudimentarily I had that skill, but I hadn't practiced it, so because of the lab, those skills did improve, and that helped me learn more about how I think.

C.4 displayed the most advanced metacognitive development, from among the control group. The individual shared evidence of monitoring and planning development,

> Before, I would just get the questions, try to think for maybe 30 seconds, then just give up and ask my friends for the answers. Now, I get the question and try to think for five minutes, ten minutes, or twenty minutes…still thinking of how to get the answer…[If] I can't get it, then I ask my friends. When the destructive thoughts come to my mind [I say], "No, not the time. It's time to focus…Yo, Bro, you can't afford thinking of this right now, you have to focus." (Participant C.4)

Participants developed a diverse range of metacognition components independent from the intervention, ranging from metacognitive strategic knowledge to metacognitive monitoring. Such improvements in undergraduate populations were reported within the literature as possible, considering the room for growth available in undergraduates (McCabe, 2011).

The control group also reported enhancements to their use of self-regulated learning strategies, particularly in relation to study for the course and lab. Some participants reported developing study strategies, particularly for optimizing grades within a time limit, as summarized by one individual,

> Before the labs,…I wouldn't read the whole lab, and then start answering, I would just start question one and then do it…I used to get stuck on a question, and I wouldn't skip it. After the labs, I'd just read the whole questions and then start with the easiest question and then go to the hardest. (Participant C.10)

Other skills were even more specific to optimizing results under pressure,

> I was able to plan ahead…I'll do the questions as fast as I can…I can go over them after with other friends… Looking at the number of problems, I can decide how much time I am probably going to allot to each question. I usually just skim the problems before I start, so if I know that I have trouble with a certain problem during class, I could either skip it for now or particularly ask about that problem ahead of time. (Participant C.5)

Evidently, participants within the control group developed self-regulated learning strategies focused on optimizing assessment performance within the pressure of time. Such activity aligned with the literature regarding the aforementioned performance-approach orientation displayed by the students (Elliot & Church, 1997).

Experimental group. Similar to the control group, the experimental group also reported increases in their ability to use strategies but additionally recognized increased understanding of learning itself. Participant E.10 demonstrated diligence in attempting to apply the metacognitive prompts,

> You gave us the idea [of metacognition] and we were trying to apply it to the questions we had…I was trying to apply it to my life, and games, and stuff. For the [Calculus] questions, sometimes they would help but not all of the time. If you have no idea about the question at all, it won't help. You should have some basic understanding of the question. It's helpful to recall the skills and models you have learned from the class. It's like a guideline [to] help you search into your memories, and [to] help organize from all the math in your mind.

Inspection of the above quote illustrated the importance of having subject-specific knowledge in order to make use of the metacognitive prompts for understanding. Participant E.5 credited success to understanding, "How I'm supposed to approach a problem or how my brain works…would allow me to…use the skills to benefit myself more effectively." Participant E.8 identified the importance of understanding strategic knowledge, "During lectures, the professor would show methods of how to solve certain equations…and so on; it's not so much about doing that process…It's also knowing about when to apply it, and why you're applying it."

Participant E.1 described the benefit of using metacognitive strategies in building confidence in individual performance,

> Being able to understand how you're thinking, as well as implement the strategies that I have already learned (time management, better communication, and being able to express myself better), all of these combined help to…show you're a person who has something

> to offer…By being able to communicate, and knowing how your presence is affecting those around you consciously, you can change that and set it to the best state.

This individual valued a differentiating perception from potential employers based on performance in a work place. Evidently, Participant E.1 acknowledged the benefit of applying strategies and metacognition in developing such core abilities. While both groups applied strategies, there also appeared to be greater development on the process of learning for the experimental group when compared with the control group (Kramarski et al., 2013; Rotgans & Schmidt, 2009).

Members of the experimental group described specific enhancements in their use of self-regulated learning strategies in the areas of organization, study habits, and communication. Participant E.1 credited "actively thinking about my processes" to helping improve information managing,

> This exercise…It really got me thinking about how I process all the information that I get…When I start a question instead, I would examine it bit-by-bit to see what was important, what I need to do first, versus what was easy to do, and what would easily affect the rest of it.

Before, this individual admitted, "I'd just sit there," when stuck on a question, "I wouldn't want to start it over because it was a lot of work" (Participant E.1). Managing information precipitated action by providing a focused direction for sorting through the complex task. Participant E.1 engaged in cross-sensory study strategies as a result of the study,

> It [i.e., practicing metacognition] definitely got me thinking about how I think and learn. Before, I wouldn't take notes in class…I didn't really find that helpful, mostly because it took a lot of time and effort. After really thinking about *how* I learn, I found that doing

> something while hearing the lecture or the class, helped put them together so that I could recall them easier later.

Some identified learning more effective study habits beyond memorization, “I was never able to achieve results [using memorization]. Learning these types of new learning strategies within the Calculus lab, it made me realize how I learn.” (Participant E.5). When asked how the study impacted, learning, this individual reported that it developed, “Course approach [method] and communication with co-workers”. Others took more efficient notes, focusing on core understanding, time management, and organization. In summation, Participants from the experimental group identified improvements in self-regulated learning strategies, particularly with respect to study habits, organization and communication (Özsoy et al., 2009).

Distinct from the control group, participants from the experimental group reported significant impacts on their emotional state, including increased joy of learning and decreases in anxiety. The experimental group acknowledged excitement at learning. Participant E.8 commented on learning a new way of thinking, “I was grateful…I enjoyed it a lot because, although it’s terrible for someone to tell you that you’re wrong, it’s also really good for someone to correct you and help you change.” Participant E.5 identified new levels of understanding the self while monitoring thoughts in live settings,

> I had a conscious awareness of the way I thought. The brain is so complex. Understanding a little portion of the way I think while doing a problem makes [me] realize how my brain is working while doing a problem.

Some participants reported decreases in anxiety from the experience. Participant E.9 credited such a reduction to recognizing alternative pathways,

> I try to just calm down, so I don't feel overwhelmed. That way, I won't keep on overthinking myself and using up all that time trying to solve that one question, where I can either move on or ask for help from someone else.

Evidently, participants within the experimental group reported enjoyment of learning and decreases in anxiety. Decreases in anxiety were an expected outcome based on the literature (Legg & Locker, 2009; Kramarski et al., 2010).

The experimental group described increases in efficiency through effective planning when using strategies in a live setting. Efficiency was a recurring theme for participants, described by Participant E.5,

> What I learned during these lab sessions…would make me a more well-rounded student because I'm able to partition what I think according to what I need to learn…It's made me a lot more efficient in learning as well as being more aware….[For example], what I did during the lab sessions allowed me to…slowly break down a question in order to make bite-size pieces where I can slowly digest them and understand them fully.

For some, this increase in efficiency resulted in grade improvements,

> I realize(d), 'This isn't something I quite understand, how about I ask for clarification so that I can understand it better and use that to solve the problem'. Once I started thinking like that, it helped better further my success. I was starting to see the grades I moreso wanted. (Participant E.9)

The use of the metacognitive prompts to this effect was verified by Participant E.10,

> It makes me more efficient. Before I learned that, in high school, I would get the questions, I [would] read them, but sometimes I'm just confused. I don't have a step-to-step guide that I can go through. I have to figure out what to do. Sometimes, I can see the

> answer, but I can't find the method. Sometimes, I can find the method, but at some steps I would just get jammed. That guideline [i.e., the metacognitive prompt card] keeps me on track. "

Evidently, participants within the experimental group credited increases in efficiency through increased planning. This finding reinforced the literature regarding the effect planning on efficiency (Kramarski & Friedman, 2014) and the impact of interventions on planning (Kramarski & Friedman, 2014; Mevarech & Kramarski, 2014) and performance (e.g., Boekaerts & Cascallar, 2006; Mevarech & Kramarski, 2014).

The experimental group reported increases in their overall thought processes, particularly metacognitive monitoring, as a result of participating in the study. Participant E.1 experienced increased delayed awareness, "Even though I wouldn't always be actively thinking about how I'm thinking, it [i.e., the metacognitive intervention] did get me to start thinking about it more." This individual described delayed monitoring experiences, "After the sessions I'd also be thinking, 'I used communication here to better understand my teammate as well as portray what I am trying to say, and I implemented a lot of problem-solving skills here' " (Participant E.1). Because this behaviour was reported after, it was considered a delayed monitoring experience. "My brain has to turn on now," Participant E.3 acknowledged. Participant E.3 described in detail personal effects of the intervention,

> My mind almost got into an explorative state…It was looking for all these different things…'What's a new way I can approach this? This is a different type of question, what do I need to consider for it?'…The end result was pretty useful, because I ended up carrying knowledge of that later.

Some even attributed improvements in their grades as a result of being aware as described by Participant E.5, “Being more conscious of the way I learned allowed me to learn more effectively, and be more confident in the way I learn. With the [new] way I study, I am able to achieve good results in the tests.” Significantly, participants cited the use of the metacognitive prompts in directly affecting monitoring thoughts as demonstrated by Participant E.5,

> The cue cards…directed the way I thought a lot better…Those questions would make me think about how I’m going to approach the problem…It guided me in the way I was supposed to approach the questions, and the way I’m supposed to think about them… It forced me to develop that skill of rereading and going through the whole process of the way I approach the question.

Similarly, Participant E.8 credited the intervention directly for increasing personal focus during problem solving, “This research helped me focus on what I’m doing, why I’m doing it.” It was evident that the experimental group experienced improvements in metacognitive monitoring as a result of participating in the intervention. Such increases in monitoring were anticipated based on previous literature (Hessels-Schlatter et al., 2017; Kramarski & Friedman, 2014; Mevarech & Kramarski, 2014).

Participants from the experimental group also reported various debugging strategies. Participant E.9 shared a generalized heuristic for debugging problems when confidence was low by asking the questions, “Why am I failing? What is wrong with my methods?” Thinking of other methods for debugging problems also impacted confidence for this individual,

> It’s really given me, in a way, a newfound confidence. I’d really doubt myself before, and I would think that I don’t need…clarification. Now, I’m realizing I do need help

> sometimes, I do need clarification…I shouldn't be thinking so linear. I should stretch my thinking and think of other ways to solving a problem. (Participant E.9)

The final point by this individual, "I shouldn't be thinking so linear," demonstrated an increase in the complexity of metacognitive thought employed while debugging. Such non-linear approaches reflect advanced planning techniques (Hessels-Schlatter et al., 2017; Kramarski & Friedman, 20124). Some participants cited assessing their confidence in order to evaluate performance. "In a test, we had a very long one [function]…I have not done a derivative of an equation that long before. So I did take it slowly going into it," Participant E.8 shared. This member elaborated, "Once I finished,…I didn't have confidence to leave it there and move on…so I did go back to search and make sure everything was right" (Participant E.8). The above examples affirmed improvements in metacognitive debugging anticipated from known literature (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Mevarech & Kramarski, 2014). Overall, participants from the experimental condition reported increases in metacognitive debugging.

Several participants identified that they had not considered metacognition before. Participant E.9 commented on a debugging strategy used, "I never really thought myself, that I could think this way…that I could keep this going and realizing where there might be problems, and what are some ways I could go about solving those problem." Participant E.5, shared that the laboratory was a first conscious metacognitive experience, "It was…cool I guess, 'cause I never really think about how I am thinking. Having a little space, like two hours a week, where I know how I'm thinking and my thought processes, is interesting." Participant E.5 detailed, "I've never really thought about the way I've been thinking for the past 18 years." Participant E.10 reported learning to read problems for understanding as a plan during solving, "When I approach a question, first I should really understand the question. I didn't do that before. I learned that I have to be precise about what they are asking." Evidently, participating in the metacognitive intervention facilitated a first conscious metacognitive experience for some members. This reinforced the findings of Young and Fry on the positive effects of interventions on metacognition (Young & Fry, 2008).

Comparing conditions. In summation, the control group identified individual improvements in their use of strategies, ranging from no improvements to those focused more on metacognition. This reinforced the literature on metacognitive growth potential in undergraduate students (McCabe, 2011). By comparison, the experimental group described developments in their use of strategies consistently, also indicating improvements to their understanding of learning itself (Kramarski et al., 2013; Rotgans & Schmidt, 2009).

While both experimental and control groups reported improvements to their use of self-regulated learning strategies, qualitative differences were observed. The control group appeared to emphasize the importance of optimizing grades, which was connected to emphasis on a performance-approach orientation (Elliot & Church, 1997). The experimental group cited specific areas of improvement: organization, study habits, and communication with others (Özsoy et al., 2009). The experimental group also reported improvements in their emotional state, citing increases in joy of learning and decreases in anxiety (Legg & Locker, 2009; Kramarski et al., 2010).

Lastly, the experimental group indicated enhancements in several components of metacognition, including efficient use of resources from increased planning (Kramarksi & Friedman, 2014; Mevarech & Kramarski, 2014), monitoring (Hessels-Schlatter et al., 2017; Kramarski & Friedman, 2014; Mevarech & Kramarski, 2014) and debugging (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Mevarech & Kramarski, 2014). Members of the experimental group reported conscious metacognitive experiences for the first time during the intervention (Young & Fry, 2008). It was evident that the experimental group attributed participation in the study with enhancing metacognition, particularly in the advanced components of establishing plans and monitoring thoughts for approaching complex problems.

Transfer

Following the framework established by Salomon and Perkins (1989), transfer was differentiated into three categories based on distance: time (immediate/delayed), context (near, far), and exposure (routine/novel). As noted during the *Characteristics of Participants' Learning* (p. 171), novel and difficult problems facilitated the development of advanced metacognitive capacities such as monitoring and planning (Mevarech & Kramarski, 2014; Mevarech et al., 2010; Salomon & Perkins, 1989). Participants also reported the need for practice (i.e., in routine contexts) to enhance metacognitive development (Dignath & Buettner, 2008; Dignath et al., 2008; Mevarech & Kramarski, 2014; Salomon & Perkins, 1989). This supported previous researchers' claim that repetition facilitates near-transfer into related contexts (Salomon & Perkins, 1989, Tuomi-Gröhn & Engeström, 2003). Immediate transfer was examined during the *In-Course Analysis* (p. 97 above). Consequently, the routine/novel and immediate types of transfer were not examined here.

Motivation to transfer learning. Participants within the experimental and control groups reported interest in discovering transferability for their learning. Within the control group, participants indicated interest in applying their Calculus knowledge to other contexts. Participant C.5 acknowledged, "I like thinking about how the problem could be applicable in my everyday life, 'What's the whole point of this problem?'…Maybe in science…or a data experiment, that is where I would use this skill." In an effort to derive meaning from the problem at hand, this individual sought transferability. Participant C.5 imagined using social skills strategies learned from the lab presently as a volunteer, and in the future as a doctor. Participant C.5 specified, "I shadowed a doctor…How I learned to think simultaneously about the social skill…the time pressure, and solving the actual physical problem, that helped in areas like that." Participant C.5 also described transferring problem-solving strategies, "to help [other students] learn how to think about how they are learning in science," a sentiment which was also connected to everyday problems, future jobs, and family by other participants. This reflected a desire by the individual to consider others' problem-solving and metacognitive development.

Participant C.4 specified applications of problem-solving strategies to a, "business contract with someone, [or] maybe I have to design something. I will think of my own idea first, then try to build the parts…Go into research…Asking people for their ideas…to add their ideas to my own." Participant C.6 imagined applying, "these thinking strategies to Integral Calculus, Physics, and Chemistry. Outside…I'm not really sure," evident of a belief in possible near-transfer by the participant. In summary, control group participants were motivated to seek transfer possibilities, and also imagined far-transfer of learning into contexts beyond present circumstances. This affirmed that high-road transfer of metacognition took "what is [was] learned in schools to be used in situations outside" (Tuomi-Gröhn & Engeström, 2003, p. 33).

Participants within the experimental group reported motivation to use metacognitive strategies elsewhere. Participant E.10 saw applications to English classes in addition to the benefits of using metacognition with time-management, organization, and socializing with others,

> [Use the given] core idea. The problem, for me, is there is a high chance that I will misunderstand what they are talking about, and write a whole essay completely off the topic…I could try to break it down, read it, and understanding it better to avoid that off-topic thing.

It was evident that this individual applied heuristics into the construction of an essay. Participant E.10 recognized the greater function and demonstrated the application of planning into a distant context.

Participant E.1 acknowledged that, “The improvements that I saw after implementing them [i.e., self-regulated learning strategies] in Calculus motivated me to apply them to other courses.” Tuomi-Gröhn and Engeström (2003) specified the importance of successfully using and applying a model to effect such transfer. Upon reflection, Participant E.1 recognized the importance of using metacognition to improve social interaction while in a working context, “Being able to consciously think about how you’re acting really assists in giving off a better image, as well as the other learning skills, like time management and communication. All can assist in the workplace.” This quote demonstrated the individual’s advanced application of the concept to far-reaching contexts (Tuomi-Gröhn & Engeström, 2003).

Participant E.9 foresaw the application of self-regulated learning strategies (i.e, organization) into personal health, “Organize more time throughout the day…[by] figuring out how I can…live a better life, and not be so unhealthy…If I’m not able to take care of my body, than how am I supposed to take care of my mind?” The individual connected the impact of personal health on mental performance. Lastly, Participant E.5 imagined applications to school performance, “Scheduling…has been a lot more applicable now than before,” and also when working with others, “Team building…that was a crucial part of the lab and I’m sure it will be a crucial part of a job I get into in the future." Evidently, experimental group participants reflected on numerous transfer possibilities, citing transfer into various distant contexts. While the control group cited imagining using strategies in other contexts, the experimental group provided detailed circumstances for applying metacognition into far contexts, with a greater volume of non-academic contexts listed by the experimental group (Tuomi-Gröhn & Engeström, 2003). Therefore, it was concluded that the intervention facilitated the construction of forward-reaching transfer (Salomon & Perkins, 1989).

Delayed-transfer. The hypothetical Biology research problem was used to examine delayed and far-transfer simultaneously. Explorations of transfer of metacognition into delayed and related contexts are reported in *Near-transfer* (p. 196) below.

Experimental and control group participants demonstrated a diversity of metacognitive ability while completing the biology transfer task; however, some participants from both groups showed the transference of specific strategies during their solution. An approach was identified as novice if the participant completed the problem in the order presented (e.g., Schoenfeld, 1985). Approaches were categorized as advanced if the participant demonstrated signs of prioritizing the five considerations (i.e., focusing on the issues in order of importance: assessing the habits of at least two of the organisms, permissibility of conducting the research in Socotra, and factoring in the remaining considerations into an answer if time permitted), switching between considerations as-needed (e.g., Schoenfeld, 1985). Participants were evaluated on a scale from 1-10 by the researcher, using the rubric included in Table *33* below; evaluations of the participants' scores were included in *Table 34* below. While these quantitative scores provide a summary of the participants' relative performance, the descriptions which follow contextualize the values assigned.

Table 33
Rubric Used to Assess Metacognitive Performance

Score	1-2	3-4	5-6	7-8	9-10
Metacognition Observed	Little to none	Minimal presence	Low presence	Medium presence	High presence

Table 34
Score Summary of Participants' Performance on Hypothetical Task

Control Group		Experimental Group	
Participant	Score	Participant	Score
C.9	4	E.3	2
C.5	6	E.8	1
C.10	2	E.1	7
C.6	8	E.9	2
C.4	7	E.5	1
		E.10	6

During the solution of the hypothetical Biology research problem, a diversity of metacognitive ability was observed from the control group. Some participants approached the problem in a linear manner, addressing the five considerations listed in the problem from top to bottom. For example, Participant C.10 utilized information managing throughout, however no indications of planning, monitoring, or evaluating were demonstrated during the solution. Participant C.9 chose to solve the task generically without taking time to research any additional information. Field notes on the participant's solution indicated general answers with little thinking involved. Participant C.5 indicated some awareness during the solution, "I don't know how much time I'm taking?" Participant C.5 also showed some indications of planning initially when browsing information about the species of interest and governments' roles in Socotra; however, the individual reported difficulty with fully comprehending the task, "I didn't think it would take so much to research the place, 'cause the University just provides all that stuff for you." This indicated that the individual had not planned sufficiently how to best optimize time throughout the solution. Participant C.5 acknowledged a sense of learned helplessness (Seligman, 1972) from personal experience in University.

Participant C.4 indicated signs of planning when rereading the problem after its initial presentation. This individual also demonstrated signs of debugging when attempting to search for more details to answer the problem,

> I'm thinking of what to type on Wikipedia to bring out the information that would rhyme [match] with the answer…I'm looking at the questions. I'm trying to type the right words in the questions and see if I would get the right answer I need…I'm brainstorming on what to type…and if I don't get [what I need] I just ask someone… (Participant C.4)

An inspection of this quote in comparison to strategies cited by this individual indicated that there was remembrance of transferring the strategy of asking a friend for support. Participant C.6 demonstrated a strong use of metacognition during the solution by first prioritizing re-reading the question several times and planning the use of time through careful highlighting of the question. Monitoring and debugging were also visible during the solution, where Participant C.6 attempted to answer all five considerations in the time provided. Unique to the control group, Participant C.6 acknowledged transferring some metacognitive personal knowledge, "If I write everything out, I can visualize everything better." In summation, participants within the control group demonstrated varying metacognitive ability while solving the problem; transfer was observed for one instance of metacognitive strategic knowledge and personal knowledge each.

A diversity of metacognitive ability was also displayed during the experimental groups' solutions to the hypothetical Biology research problem; however, some participants showed transfer of specific strategies. Participant E.8 and Participant E.5 both demonstrated novice approaches to the problem, addressing the five considerations in a linear manner. Participant E.8 displayed minimal planning, while Participant E.5 showed no signs of planning, nor use of the resources provided to conduct research. Participant E.3 showed few signs of organization while solving, apparently addressing issues as-needed. While Participant E.3 provided a focus in contrast to Participants E.8 and E.5, the chosen focus on survival and travel indicated a lack of effective prioritization. No indications of monitoring or planning were observed for Participant E.3. Participant E.9 used a plural pronoun to summarize a linear approach to completing the problem,

> Look over all of our research, we're satisfied…We want to make sure we're on good relations with the communities. [We need to] make sure that the government knows that we are nearing our departure…Make sure there was no problem between both sides, that we didn't cause any commotion…within wherever we stay, in a shelter or camping out in tents, that we pack up our equipment…and that we get rid of any waste that we might have made, so that we don't leave it within the community or ecosystem…[We should be] making sure that we have all the samples for the trees, for the plant life and the chameleon, and that we are able to come back with efficient research that we can later on also study over time back at home.

An inspection of the answer described by Participant E.9, in comparison with the instructions provided, indicated a 'top-down' approach through the five considerations given in the question. Further, the answer provided was general in nature, with no indication of planning provided.

Beginning with rereading the question, Participant E.10 attempted to break down the problem into smaller pieces. Participant E.10 cited using this strategy in the course; this indicated that transfer of the strategy occurred during this activity. Participant E.10 attempted to engage in planning, focusing on survival and demographics of the region. Although quiet for most of the solution, observations of the Participant's note-taking and effort spent researching through Wikipedia indicated that Participant E.10 debugged throughout the solution. Field notes from the researcher also indicated that the efforts to plan provided room for Participant E.10 to consider many factors. While initially the individual focused on the leadership component of the problem, the eventual focus was shared near the end of the solution, "But he [i.e., an imagined person leading the hypothetical study] is also a researcher, so he should focus on the research. The three key areas I was trying to target is surviv[al], transport[ation], and the third one is the research."

Participant E.1 began solving the problem by rereading the question and taking time to plan. Participant E.1 demonstrated numerous instances of planning while self-talking during the solution of the task, "Okay, I'm going to stop. Think, 'What's the main goal?'…We're preparing the research project. To do that we're going to need location, supplies…climate would be a good factor…[and] habits of the organisms." It was evident that Participant E.1 also regularly revisited debugging throughout the solution. The focus of the solution was centered on organizing the research project, climate and government. Participant E.1 reported not using planning regularly throughout the course, yet in this instance planning was a significant theme for the participant; therefore, planning was considered a possible transferred strategy. In summation, participants from the experimental group also displayed varying metacognitive ability, with two participants indicating the transfer of a cited strategy.

In conclusion, participants within both the experimental and control groups demonstrated varying metacognitive ability. Transfer was observed within the control group for one instance of metacognitive strategic knowledge and personal knowledge each. Two participants from the experimental group described the transfer of a cited strategy. The explicit transfer of strategies by the experimental group participants was considered advanced as the participants explicitly presented the use of the strategies cited earlier in the interview. While it was evident that one control group participant applied metacognitive personal knowledge and another transferred strategic knowledge into the task, these were less direct. It was noted that, by design, participants were not encouraged directly in the instructions of the task to use metacognition. This was designed to assess whether metacognition would present itself as a habit by the participants in a delayed, unrelated context. Considering the diverse presentation of metacognitive skills by both groups, there were minimal differences in transferring metacognition. Given what was revealed earlier by participants regarding the importance of practice, it was evident that delayed-transfer of metacognition might require additional practice and explicit prompting before it would be presented as a habit.

Near-transfer. Also noted above while comparing the *Impacts of the Intervention*, participants within the experimental group indicated transference of metacognition to their learning process in the course of study (i.e., immediate, near-transfer). Participants from the experimental and control group reported applying various components of metacognition to other related subjects. Subjects such as those of a fundamentally mathematical or problem-solving nature were also considered within the domain of near-transfer. Contexts were considered delayed if they presented after the completion of the intervention. Contexts which presented with generality were considered as both immediate (i.e., ongoing) and delayed (i.e., post-intervention).

Control group: metacognitive strategic knowledge. Control group participants referenced applying metacognitive strategic knowledge for problem-solving into Physics and Chemistry. Because these were reported generally for the subject, the transfer was considered as both immediate and delayed. Participant C.9 reported applying the strategies to Chemistry,

> [I would] try to see what givens are in the question,…try to list them down, and narrow down all the equations to the certain givens that are in the question. [Then, I would] try to

> use a certain formula…to help me solve the question. [This] strategy…really helped me focus and stay on task during a problem.

This individual applied the strategy of breaking down questions into fragments to Chemistry problems to facilitate task identification. Participant C.4 reported applying strategies (e.g., trying questions, comparing with peers, etc.) to Engineering Mechanics and Linear Algebra. Participant C.6 described the transfer of strategies to Chemistry as well as Physics,

> I applied those thinking strategies to other courses. For example, …in Physics…I had to list out everything that I had, plan the process of what strategy I was going to use, and then work my way to the answer. Also, Chemistry…because word problems in there, too, had to be solved just like Calculus and Physics and I felt like they were all similar. It [i.e., applying the strategies] was a good impact because it helped organize the way I solved everything.

In summary, participants within the control group reported evidence of transferring metacognitive strategic knowledge (i.e., self-regulated learning strategies and problem-solving strategies) to near contexts generally.

Experimental group: metacognitive strategic knowledge and self-regulated learning. Experimental group participants also identified transferring metacognitive strategic knowledge generally into similar academic contexts. For example, Participant E.9 acknowledged that, "I am able to use it [i.e., the learning strategies] in other labs as well." Participant E.5 specified the application of a self-regulated learning strategy (i.e., dialoguing with others) to assist solving complex problems in the course,

> Taking the derivative with respect to variables is a little bit more tedious than taking the derivative of anything…Going through that whole dialogue about what I think and what

> he thought…made me realize that the way I was doing it previously was wrong. (Participant E.5)

Participant E.3 reported applying the self-regulated learning strategy of finding new processes to, "Linear Algebra, where you have to understand Gram-Schmidt orthogonalization or trying to understand what normalization is." Participant E.8 also cited using,

> Organization and being able to communicate. In Linear Algebra, there are a lot of numbers, a bunch of matrices; you can carry your mistakes on and on…Before, I would go back and try to redo it [a question], and see if I got the same errors. If I did get the same error, I would have a constant error and I could fix it. Now…I found a way to write down my numbers much more clearly…Instead of being…not exactly discouraged, by all the numbers in that little square or rectangle…I would try to focus on one number at a time and apply my transformation to get…row reduced form.

Evidently, Participant E.8 combined organizational strategies with monitoring to manage the complex clerical task of matrix transformations in Linear Algebra. Similar to the reported examples of transfer in Chemistry and Physics, the transfer to Linear Algebra was general, and thus considered as both immediate and delayed.

Interestingly, in an Economics course where memorization was reported as a significant component of learning, some participants reported minimal influence from the course, as summarized by Participant E.10, "The guidelines won't help about memorizing for me." Metacognition did not appear to transfer to contexts which relied on such memorization, as perceived by the individuals.

Within Algorithms I, a computer programming class, Participant E.3 connected new processes to those learned in the course, "[I was] trying to organize everything into something that works and doesn't crash your program. That was similar to how I developed related rates or deal[t] with this new type of derivative." As this was a general component to the course, this transfer was considered as both immediate and delayed.

Participant E.1 applied time management to a mechanics course (i.e., near context), citing the impact of the intervention on a midterm performance (i.e., immediate context),

> The time management really helped me set aside specific times when I would do work for this course. This all happened after the midterm. Before the midterm, I would go to class, go to the labs, and leave that as the work I would do for that course. The midterm was a very hard midterm, and I just barely passed. I knew I had to change something… Working with others, and explaining my thought process, really solidified how I was doing the questions.

This member also detailed a strategy for solving novel problems (i.e., general context),

> A big one for this course was the changing factors. We wouldn't get a lot of questions that we hadn't already done in class. When it would come to the test or midterm, the questions would be things you had never thought of before. One really big one, that stuck with me, was on the midterm itself. It was a question that dealt with finding the forces in a system…you would have to find the reaction forces, how the system was reacting to it. In the exam, he gave us the reaction forces, and asked us to find the output forces. You'd have to reverse your thought process. After that, I really tried [thinking], 'How can I look at this question in a different way? What factors can I change? Let's say he doesn't give me this or he says this instead of that,' I tried to do those questions that way. That really helped on the final, where it bumped my mark 20% at the end. (Participant E.1)

This individual credited thinking of alternate approaches to problems (i.e., debugging strategies), in combination with time management, for an increase in performance in the Mechanics course.

Participant E.9 applied self-regulated learning strategies to, manage "…information that was provided to me, [that] I didn't quite understand what to do." The member introspected in such situations, "Why don't I ask the TA for help and for clarification: what variables to use; what method should I be using?" In this situation, the individual employed help-seeking behaviours to meet the challenge of confusing information in an immediate context. Time-management strategies were applied by Participant E.1 in the subsequent semester to "Chemistry, Physics…Integral Calculus, as well as Thermofluids." This example illustrated the transfer of metacognition into near, and delayed, contexts.

Participant E.5 also reported applying study and test strategies into a near, delayed context, with a Mechanical Engineering course,

> During my mechanics final, I was aware of how many problems I had been doing and the math of everything. It allowed me to…think about each question fully. It allowed me to partition my time easier…because I was developing those skills of repetition of questions and applying a skill.

During an exam, which occurred after the completion of the intervention, this individual specified effective time-management during a test, "I would be able to fire the easier questions off first so I could have more time for the questions I wasn't as confident in." Therefore, participants within the experimental group reported applying various metacognitive strategies and self-regulated learning to near and delayed academic contexts (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017).

Other metacognitive components. Experimental group participants also applied other metacognitive components to near contexts. Participant E.10 applied the metacognitive prompts, as a planning heuristic, during problem-solving in Physics,

> It's like Calculus but more object-involved. We're talking more about some *thing*, instead of some theory. But, [there] is not much difference, so I can just use the same method I use in the labs. I first set up the few guidelines [i.e., metacognitive prompts]. I would write down the things they want us to know…and the things that they have given us. For physics you get a formula sheet. When I'm doing the questions…after you get a few components, you can just take [use] the formula sheet...[This is] because all the components match and such, [which] makes it a lot easier.

Participant E.9 applied metacognitive debugging into a Computer Science course,

> It really helped in my other courses…During my coding labs, I would think, 'Okay, here's the task at hand, this is the program they want us to make, What if I do this?' I would code out about 30 lines of code and think, 'Why it's not working?' I would look at my code and think, 'Where did I go wrong? Is there anything I might have missed? Did I not put in a bracket here or did I use the wrong variable here? Am I making sure everything works?'…it helped me think, 'What other methods are there, that I can use? Why don't we try putting in *this* variable? Why don't we try having it set to *this?'* instead of it just ending there.

The above quote illustrated the individuals' application of finding alternate solutions to problems while attempting to debug computer programming code. Distinct from the control group, metacognitive planning (e.g., Hessels-Schlatter et al., 2017) and debugging (e.g., Kramarski & Dudai, 2009) were transferred into near contexts by the experimental group.

Both control group and experimental group members reported transferring metacognitive strategic knowledge to near academic contexts. This finding supported what was found in the literature regarding the transferability of metacognitive strategic knowledge and self-regulated learning (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017). Distinct from the control group, participants who experienced the intervention reported the transfer of other metacognitive components (i.e., debugging, planning) into near contexts. The impact of the intervention aligned with previous findings on the potential transferring of planning (Hessels-Schlatter et al., 2017; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008) and debugging (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014). A single instance of monitoring, combined with organizational strategies, reinforced the potential for monitoring transfer (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008; Tajika et al., 2007). It was concluded that experiencing the intervention increased the depth and breadth of transferred metacognition for the participants.

Far-transfer. Although participants from both the experimental and control groups identified metacognitive components for transfer to "far" domains, distinctions were found between the types of skills transferred.

Control group: metacognitive strategic knowledge. The control group reported the transfer of metacognitive strategic knowledge to other subjects. In the following quote, the "strategies" referred to by Participant C.6 included: learning strategies (e.g., practicing questions), and problem-solving heuristics (e.g., writing out unknown and known variables), "I felt that they (the strategies) were really helpful to solve the problems that I did in the lab. They also helped in other classes too, like Physics." Participant C.9 understood the importance of applying multiple methods into other situations,

> Taking what I do in the lab into real life approaches, for example, I shouldn't be as closed-minded…I'd see that different approaches lead to better results, and I'd use that approach in the lab…to have a broad view of the question or problem…It boosted my grades, per se, as it helped me think clearly rather than having everything jammed into one…view. I would try to keep my thoughts organized…to try to solve the conflict.

This individual connected the recognition of open-mindedness to grade improvement. Some within the control group specified transfer of strategies to Biology, Business, and Writing. Participant C.5 applied social strategies (e.g., self-regulating behaviour to the group) to a biology laboratory,

> I would have to understand the question…Then I would have to ask a certain GA [i.e., Graduate Assistant], because I knew one GA would take too much of our time… I would have to time my questions…I would have failed my labs if I didn't do that.

Participant C.10 read items for case studies in Business at home before attending class and took more detailed notes in class. In summation, control group participants transferred metacognitive strategic knowledge (i.e., self-regulated learning strategies) to far-reaching academic contexts (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017).

Experimental group: transfer of concepts. Participants from the experimental group reported extensions of metacognitive strategies with demonstrations of transferred concepts. Participant E.1 transferred the concept of variables to language for trigonometric identities,

> During one of the labs…I stopped thinking of it as, 'Just keep subbing in identities,' and I started thinking of it as a mathematical equation. I treated them, instead of [as] just

> random words, I treated them like variables…That is where my entire process just changed. By having sin(x) and tan(x) as if they were x and y, I could work through it more algebraically, in my head at least. That made it much easier to get to the final step where I would sub in all the right values and identities, and it would come out.

By abstracting the content to variable placeholders, the individual was able to resolve the complex task of trigonometric identities which were always “just one step away” from a solution previously.

Participant E.10 also abstracted a method of learning Calculus as analogous to learning models,

> It is just about models [i.e., formulae, procedures]…I start[ed] to get used to it. I start[ed] to…[realize] it’s not Calculus any more, it’s becoming model studies, because there’s just different models….I was realizing that we were just trying to remember all the models but not understanding the theories behind them…That is not going to help you further [understand] the theory.

By abstracting the course to model construction, Participant E.10 recognized the importance of understanding theory to deepen learning and assist with applying theories into problems.

Participant E.5 also applied models into a design course in order to resolve visual designs from two dimensions (i.e., 2D) into three dimensions (i.e., 3D),

> In our design class…we had to create orthographic projections…if a 3D object was given to us, we had to convert into 2D…[Being] able to reason out that it doesn’t look like…I’d model it out…It would be with one of the five senses. [For Example, I could]: use a different object in real life with it or build it out with my pencils.

The individual created representations of objects to facilitate drawing detail accuracy.

Participant E.8 applied metacognitive thinking into social contexts, "In order to understand someone, you need empathy…When people would explain their thoughts and processes…it's easier to feel, '…I would do the same, if I was in your shoes.'…It's being…able to analyse situations in different points of views." This individual elaborated with an example of a friend explaining a new way of thinking in politics,

> I wouldn't have agreed with him if I didn't feel like he was right. The only way I felt he was right is if … I would feel the same way about it…I tie that into a more general way of empathy…being able to see their [i.e., others'] side of everything. (Participant E.8)

Participant E.5 also commented on the application of metacognitive thinking to the realm of communication with others at work and at home. Specifically, "Being able to communicate with others about exactly what's wanted, or what we need to do, is another skill which has been reflected through the labs because it's helped me communicate with them better." Evidently, participants within the experimental group demonstrated the transfer of concepts into various distant contexts. Therefore, some of the evidence suggested that the intervention facilitated the development of metacognitive strategic knowledge to transfer towards general learning (Kramarski et al., 2013; Rotgans & Schmidt, 2009; van Velzen, 2016).

Both groups: self-regulated learning. Control group participants reported applying self-regulated learning strategies into non-academic contexts. Participant C.9 applied time management into family life. Participant C.10 looked at different solutions to a problem during a driving test by skipping questions. Participant C.10 also applied time management strategies into personal life contexts, "I used to come late for my lectures or right on time. Now, I start to manage my time more…coming for the lecture 15 minutes, half an hour (early)." "Before the labs, I would just watch the video…without practicing,” Participant C.4 reported paying deeper attention and incorporating practice after participating in the study,

> I watch Youtube videos on how to play the piano. When I see them playing things, I would try it on the piano in my room. That’s like me jotting down stuff. When I go to church and play…I would visualize the video I was watching and remember what he actually did and how it sounded like. I think that improved my piano playing skills.

Participant C.4 illustrated transfer of information management, from the Calculus course practice into musical performance practice. Evidently, control group participants found varied and distant applications of numerous self-regulated learning strategies, indicating the transferability of metacognitive strategic knowledge (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017).

Despite the successes of peers, Participant C.6 acknowledged no impact from the laboratory sessions outside of Calculus, “It didn’t impact at all…The thinking strategies that I used in Calculus were more focused on problem-solving. I don’t think it helped me in real-life problems…It’s completely different…how you think for a Calculus (compared to) a real-life problem.” An inspection of this quote revealed Participant C.6’s view that learning was only transferable if it involved in direct application. This need for direct application indicated growth potential for both metacognitive instruction (McCabe, 2011) and the transferability of learning to other areas for the individual.

Participants from within the experimental group also identified applications of self-regulated learning strategies to non-academic contexts. Participant E.1 cited several transfer contexts of various skills,

> Time management helps me a lot with managing my social life, my school work, [and] my personal health as well. Collaboration and teamwork really goes into how I interact

> with other people, making me a little bit more open to discussions and meeting new people. I find that they've really improved my daily life. Changing factors gets me to think of things in a different way with a different view. I find it hard to empathize a lot; it's a stretch, but it does give me a bit of a perspective in that field. I'm more able to put my thoughts into words.

Participant E.1 had varying values assigned to each of these skills, "Explaining would have mid-value. The teamwork and looking at different factors I find very valuable for both school work and social life…Time management was a really big benefit for my daily life." Evidently, participants from both conditions were able to apply self-regulated learning strategies into multiple non-academic contexts (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017).

Participant E.10 cited using self-regulated learning strategies to assist what are considered distant contexts (i.e., basketball and video games),

> [While] playing a game, there is a lot of information that comes in from the screen. 99% of people, I'm sure, ignore a lot of the information. Even if they do get the information, because the quantity is a lot, sometimes it's just hard to process it. That kind of guideline [i.e., the metacognitive prompts] will also help to organize that, to help getting better at doing things with a lot of information.

The theme of organizing time was shared by others. Participant E.3 described the effect of this on personal life,

> Realizing what makes me happy…This I enjoy… this I don't enjoy…(I would say to myself,) 'Let's split my time up so that if I have free time, why don't I do this thing that I enjoy?'...Any hobbies that I had…(I) honed them in more, focused more on them.

Evidently, this individual learned to balance personal free time from the experience. Participant E.1 shared that a time-management strategy improved overall personal health because it, "Gave me a lot more will-power…It gave me the ability to stick to my decisions, which was a problem before." While both groups displayed transfer to far contexts, distinct from the control group, participants from the experimental group transferred numerous self-regulated learning strategies into distant, non-academic contexts (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017). Therefore, the intervention, which incorporated implementation and proliferation of metacognition into regular practice (Tuomi-Gröhn & Engeström, 2003), ultimately facilitated high-road, and subsequently, far-transfer (Salomon & Perkins, 1989).

Experimental group: planning. Distinct from the control group, individuals in the experimental group reported applying other metacognitive components to distant contexts. Participant E.9 identified improvements in overall work-ethic and mood when transitioning from working in a fast-food restaurant to a social night club. When job performance was poor, the individual reported applying planning as a debugging strategy to overcome the challenge,

> I learned to calm down, take a breath, figure out, 'What problems are going on at the moment?', and order them from least to greatest…'Who is around that can help me? Who is not doing anything and who can help me solve my problems that everyone else has given me?' I would ask for help from my other coworkers…we would go on to make sure that…if anyone had a problem with anything they got the help they needed. (Participant E.9)

This individual acknowledged a deepened commitment to teamwork as a result of seeking help from peers. An inspection of the above quote revealed the prompts being used to deescalate anxiety and to formulate a plan to solve problems within a working context. Participant E.10, as will be discussed in detail later, applied metacognitive planning into a video game context. Thus, it was evident that the experimental group transferred metacognitive planning into distant contexts (Hessels-Schlatter et al., 2017; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008).

Experimental group: monitoring. Experimental Group members also transferred metacognitive monitoring into distant contexts. Participant E.10 also reported the use of monitoring in the personal life contexts of work-ethic and maintaining personal friendships,

> For example, in the morning…I just want to chill in bed…Sometimes it's good, but doing too much I think, is lazy. One day, I realize that I am really lazy. And, I didn't even know I'm lazy, I'm just following what I wanted to do. Other times, on my mind…when I walk on the street, I go to class, I see [a] girl [and think],'Oh, she's really pretty,'. One day I realized…I don't need to think in that way because it's a waste of time and energy …Thinking about that won't change anything. I will quickly forget that girl, after time….That's not so cool, to think about, while you have a girlfriend. So, I will stop think[ing] about that because I feel stupid for how I was thinking.

This quote revealed two applications of metacognitive monitoring in order to adjust undesired behaviour.

Participant E.5 also acknowledged applying metacognitive monitoring in a writing course, "In the Engineering Profession Class…reading my essay out loud allowed me to catch little grammatical mistakes." Participant E.5 also shared the benefits of metacognitive monitoring within recreational athletic performance of Ping Pong. The individual spoke about the act of, "Focusing my attention,…having that repetition and discipline towards it, and being aware I'm making a mistake (of the way I hit the ball and how I have to approach), it's making me a better Ping Pong player" (Participant E.5). Evidently, monitoring facilitated improved recognition of effective progress and evaluation for this individual.

Participant E.8 described enhancements to mindfulness resulting from using metacognitive monitoring,

> Being self-aware…reflects everyday life … I used to do a lot of stuff just to please others, and less focusing on myself. This past year, I thought…to think more about myself…When I do make decisions…I wouldn't just give them the answer they want to hear. I would try to think about it first, 'Do I want to do it myself or am I just doing it for them?'

Participant E.9 concluded a desire to think, "What problems am I faced with in everyday life, and how can I go about solving that problem?" This desire was extended to empathy for those whom the individual cared, "Making sure that everyone in my life that I care about is doing okay and that they aren't having any problems themselves." Evidently, metacognitive considerations and problem-solving led to not only self-improvements but also modifications in the empathy actions of Participant E.9. This individual specified several considerations to this effect with family: cleaning, helping with moving, renovations, and financial assistance. Overall, members of the experimental group reported transfer of metacognitive monitoring into distant contexts (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008; Tajika et al., 2007). Members reported improvements in performance in the transferred domains.

Control group: debugging. The only instance of debugging transferred from the Calculus labs for the control group was Participant C.4's account of applying an open-minded approach to essay composition,

> The same way I would think of the different equations to try to solve the question, that is the same way I would, if I'm writing an essay (i.e., in Engineering Profession). (I) think of different things to write down and see if… it's going to make sense… When you get a topic of an essay, you think of the points to write first, before you start writing your paragraph. ...Like, if I am talking about women, will I be mentioning men?...I will write that down, and then read it, and look at it, "No, that doesn't make sense writing this." So, I take it off and try another thing. I then make research on the Internet about the point I found.

The above quote revealed that debugging successfully transferred to a distant subject (i.e., Essay composition). Although this was the only cited instance, such occurrence provided support to the literature regarding the transferability of debugging into far contexts (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014).

Experimental group: debugging. Individuals from the experimental group reported the use of debugging in varied and distant contexts. Participant E.10 cited the use of debugging to troubleshoot performance in video games,

> I learned to review…my thoughts, how I did it, and most importantly, how I failed, how I got it wrong…Before I learned these methods, when I got a question wrong or when I lose a game, I would just [think], "Oh fuck, I screw[ed] up." I would get depressed, not thinking about what I have done wrong. This metacognition has helped me to rethink which part [has] gone wrong, which part I can do better…This is so helpful, and so important.

Participant E.10 reported, "The guideline [i.e., metacognitive prompts] I used for…my games. I would get my diary book, with one page just for that…I would read it while I proceed[ed] through the game," as an aid to help thinking during a game performance. Participant E.10 also detailed a specific application of a debugging analysis into recreational basketball,

> Helped me to start to realize, that basketball is a game that [where] you're not only following where your mind tells you to…you can also read your opponent. By reading your opponent, you can break it down to: his feet, his sight, his facing, and his centre of gravity…When they're trying to block you, [their] center of gravity is high, and by dropping down, it takes time. You've got the advantage that you are …a step ahead, so you can just drop your centre of gravity before he's realizing it. After he realizes it, it's too late, because you've already made the next move. It breaks it down into different parts. Before…a defender before me is a person standing. After thinking about that [metacognition], there are different foot setups, different data [setups], for example. It's [i.e., metacognition]…use[ing] different methods…After we learned that [metacognition]…I tried to figure out what I did wrong.

Inspection of the above quote revealed that Participant E.10 implemented deep analysis into the game of basketball in order to determine optimal performance. This debugging through compartmentalization of concept resulted in insights into the game itself.

Participant E.1 applied the debugging process to a social context after an incident with a friend,

> Last semester, a friend of mine was having issues in her relationship…It was just her venting, and not wanting to improve anything about it. At that point, I didn't really want to continue the conversation, so I ended the conversation…Afterwards, it disappointed her, made her feel bad. I reflected on it the next day and thought it wasn't really how I

> should have gone with the situation. I wouldn't have really thought that, I would just go with how it went, before the course where I was encouraged to think about how I think.

This individual credited the course with inspiring self-reflection after perceiving unsatisfactory results in a personal relationship. Numerous examples of debugging from the experimental group members illustrated the transferability of metacognitive debugging into varied, distant contexts (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014).

Comprehensive example of far-transfer. The most surprising description of transfer was provided by Participant E.10 regarding the application of metacognition into the first-person-shooting video game, *Overwatch*, Participant E.10 connected the game to the Calculus course:

> The whole game is like a model for Calculus. If I applied the method I'm using in Calculus, the first one is to read the question out. By that, in the game implies…what's the objective? What's the thing that you must get to win? The game I play is a shooter game…Because of metacognition, I started to try to understand what the game is about, not just shooting people. There's a lot of things that people don't think of unless they try to understand the game. For example, regroup…after you lose a teammate, why would you initiate a fight?...Not even diamond [i.e., the next level of] players realize that. Before, I wouldn't think about it when my teammate is down…It helps me to understand the game better.

Participant E.10 considered the essence of the game in a similar manner to assessing the essence of a problem. This demonstrated the application of debugging and metacognitive strategic knowledge specific to the game. Participant E.10 connected the information regarding the maps of the game to problems within Calculus,

> From metacognition, I tried to understand what everything is about, not just doing them…[I] understand what I should do to get the most efficient ways I can do in that thing…I tried to organize the information…For Calculus problems, [I] think about the methods, 'What other methods do I have?' I understand the map first. There [are] some maps that have a lot of high ground, but there are maps that don't have as much high ground. You should play differently accordingly to the maps…You have to try to understand every part of the game.

The concluding statement revealed the individual's interest in mastering all parts of the game through a metacognitive lens. Participant E.10 specified how metacognition monitoring and debugging affected live performance,

> When I used to play, I don't even think about those things. It's amazing how it changed my method of thinking. It also helped me to organize what information [I can] get from my screen. The information I used to get is: 'Where I am? Where are the enemy[ies]? What should I do? I should run or I should go?' I start[ed] to break the game into parts…and I start[ed] to figure out…more information from my screen. For example, how many high-grounds are on this map? On this map, how will the enemy take advantage of their composition and the high ground? So, I can tell my teammates to control the high-ground first, and it's better than before.

It was evident that the individual employed information management skills to critically assess strategic advantage during the performance. Participant E.10 described the debugging process after completing a game,

> [I would[think about, 'What leads to the game loss?' And, break it into smaller parts, 'What led to the loss of the team fight?' And, even smaller, 'What could you do better in

> *that* team fight to help your team to win?' …You have to figure out, 'What killed me this time? What am I doing wrong? What will help me survive next time?' If you survive…you can change the course of the fight.

Finally, Participant E.10 shared with enthusiasm, "I figured out that's [i.e., metacognition is] what the pros are doing." The individual specified, "They [i.e., professional players] are doing the same thing; they are thinking about what high-grounds can do, where they can go in their next step, and they are reviewing their gameplay. They are using this method without knowing (they) are using it." Evidently, metacognition was applicable into the distant context of a video game for Participant E.10, who applied planning, monitoring, debugging, and metacognitive strategic knowledge to increase performance in a similar manner of a professional within the gaming community. This example illustrated the furthest context (i.e., video game performance), and the most detailed account, of transferred metacognition.

Comparison of groups. Control group participants transferred metacognitive strategic knowledge into the far-reaching academic contexts of Biology, Business, and Writing. Participant C.6 revealed the need for metacognitive instruction and transferability of learning for some individuals. The implicit application of metacognitive strategic knowledge to far academic contexts demonstrated the implicit transferability of self-regulated learning skills across subjects. This supported what was found within the literature on the potential of transferring self-regulated learning skills (Hessels-Schlatter et al., 2017).

While participants from both groups described the transfer of self-regulated learning strategies into non-academic contexts, experimental group participants reported transfers into more distant contexts. Control group participants cited transfer of self-regulated learning strategies into personal life contexts and into learning music recreationally. This supported the transferability of self-regulated learning found within the literature (Hessels-Schlatter et.. al, 2017). This also supported previous research by Mevarech and Amrany (2008) who demonstrated that metacognitive strategic knowledge (i.e., self-regulated learning strategies) may not differ greatly between novice and advanced individuals. It should be noted however, that the experimental group members also reported transfer into personal, work, and social contexts. This illustrated the impact of the intervention in extending transfer, through implementation and proliferation (Tuomi-Gröhn & Engeström, 2003), into further contexts (Salomon & Perkins, 1989, Tuomi-Gröhn & Engestrom, 2003).

Distinct from the control group save for a single example of transferred debugging, experimental group participants reported numerous instances of transferring the planning, monitoring, and debugging components of metacognition into various non-academic contexts (i.e., personal life, professional life, recreational athletics and video games). This supported the literature on the transfer of, planning (Hessels-Schlatter et al., 2017; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008), monitoring (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017; Kapa, 2007; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008; Tajika et al., 2007) and debugging (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014) into far contexts.

Uniquely, Participant E.10 detailed an account of transferring planning, monitoring, debugging, and metacognitive strategic knowledge into the distant context of a video game, mirroring the behaviour of professionals in that field. Participants from the experimental group also reported the transfer of concepts of learning into distant academic and non-academic contexts (Kramarski et al., 2013; Rotgans & Schmidt, 2009). Therefore, the intervention appeared to increase the depth, and distance, of transferred metacognition into far contexts for the participants.

Impact of Interview

Although the interview was designed as an instrument to measure metacognition, the process of the interview itself had surprising impacts on the participants for both groups. As evident above, participants provided detailed accounts of their metacognitive thinking processes. In turn, deep insights into participants' metacognitive strategic knowledge, planning, monitoring, debugging, and evaluating were presented. One such example was Participant E.3, who described the management of information,

> Those [the labs]… were all open-book…The labs cater towards a specific unit or subject of Calculus that we had to address…If I was doing derivatives, the part of my brain that would focus on limits,…[it] would completely go away and go straight to that part…I don't really think too much, how my brain manages all of it, it gives me a headache if I try to…The brain is…wild. It's almost like I had a math library…and each specific type of unit, it would just reach out to a specific book catered to just that concept…I never really processed it like that [description before]…[I] still usually don't think about how I managed information, I guess it just happens…For some sort of information to stick…it's almost like it needs a double check or another example…'Okay, this strategy worked, let's see if it applies to a similar type of question in this field. If it does, I can safely place it here.'

This member cited applying this strategy to related rates. Note, that the individual also acknowledged the demanding cognitive load involved with advanced metacognitive skills such as monitoring with, 'it gives me a headache'. This reinforced previous literature identifying monitoring as an advanced task (Kramarski & Dudai, 2009), and the importance of scaffolding to reduce cognitive overload when instructing for the purpose of transfer (Salomon & Perkins, 1989). Such detail was facilitated by the semi-structured interview format.

Participant E.5 provided an accurate description of metacognition, saying, "The voice recordings allowed me to think about how I'm thinking…Being conscious of how I'm thinking, that also helped me because now I can think about, 'Oh, does this sound right or not sound right?' " This articulation connected consciousness of thought with the verbal learning style as an evaluative strategy. Participant E.10 detailed use of the metacognitive prompts, "We had the card that said, 'First, read the questions, and second, think about the questions'. That's the guideline for me." The prompts which were most helpful were, "Have I seen any familiar question from this?" and "Is there any other way that you can solve this question? *That* [last question] helps a lot in the test." This individual evaluated, and specified, the most valuable metacognitive prompts based on personal benefit.

Participant E.3 described a debugging strategy in a recipe-like fashion, "If it doesn't work, discard it. Just keep going until something does work, and then just go with it…If it doesn't work, it's gone." When asked about what the individual learned about the process, the individual responded,

> It's very automated…It's almost like my brain goes immediately to certain processes that it's comfortable with and it fires them off [to determine if they work]…If it doesn't, that's when the thinking mode begins. Take this [i.e., strategy] from a previous thing, 'Does this work?'…Ask somebody else, see what they have in mind…It's almost like a giant checklist or algorithm. (Participant E.3)

When asked how Participant E.3 found this approach, the response was, "Now…It's just hindsight." The above examples illustrated that the interview facilitated a rich collection of data for analysis. This was an anticipated outcome based on work by Pintrich et al. (2000) who affirmed that online measures of metacognition provide greater resolution of data.

Participants from both conditions reported that the experience of the interview was their first time engaging in metacognition. Participant C.10 admitted to this being a first experience of conscious metacognitive thought, "This interview, I thought about things I never thought, like how I think, and other strategies. I never sat down and thought of what I learned." Participant C.5 echoed this sentiment,

> I didn't really think too much about how I was thinking until this interview…Now that I'm more aware of how I'm using my thinking, it probably will be easier to adapt that to different situations, for example, a different class or if I'm talking to different people…I can have confidence in the fact I'm able to react to situations simultaneously and figure out a solution to the problem. I'm aware that I'm able to do that.

Despite being exposed to metacognitive prompts, Participant E.5 reported that, before the interview, the individual had not "thought about thinking". This was unsurprising, considering that new metacognitive experiences were anticipated for this population given the opportunity to practice metacognition (Dignath & Buettner, 2008; Dignath et al., 2008; McCabe, 2011; Young & Fry, 2008). Participant E.5 acknowledged the reinforcement of learning from the course due to participation in the interview,

> It's made me think how the whole lab has taught me even more. Talking about it again…made me go back to how much it has impacted me…It [i.e., the lab] might have impacted me, but I haven't been quite fully aware of it. Talking about it and going

> through this whole interview process has made me more aware of it [i.e., the impact] as well.

An inspection of the above quote illustrated an honest assessment of potential loss of the skills learned in the laboratory which were then reinforced through the interview.

Participant E.10 elaborated on this experience, “It [the interview] let me speak out what I was learning for the past few months, and that is very cool…If I tell this to my roommate, he do[es]n’t understand what I am talking about.” Participant E.10 revealed the challenge of practicing metacognition in a social context without access to a qualified colleague or instructor. Participant E.9 characterized the issue of developing metacognition, which operated in the background (i.e., unconsciously),

> If I were to try and do this on my own, I wouldn’t really admit…that I have these problems, that my way of thinking before wasn’t as effective as my thinking now…That thought would be in the back of my mind, …that I was stuck in this way of thinking but I didn’t want to act upon it….I realize now that, …I have this confidence, I have this new way of thinking. This interview in this way forced myself to think more critically, it’s really helped.

Participant E.9 also acknowledged the importance of being present to a competent listener in order to admit growth areas metacognitively. Participant E.10 specifically discussed the benefit of verbalizing thoughts, “Your mind is always working on…something. If you say it,…your brain is going to remember it better, and it’s going to work on it… It helped me to understand it better.” Participants’ acknowledgement of having an individual to dialogue with (i.e., in a social context) about metacognition supported the literature (Cuneo, 2008; Helms-Lorenz & Jacobse, 2008; Kramarski & Dudai, 2009; Schmitz & Perels, 2011).

Participant E.10 concluded on the potential application of metacognition into life beyond the interview,

> Today, you're asking me questions…and by that, I start[ed] to recall what I was doing. I start[ed] to understand more what I was doing. I think…if I find a method, I can start to ask question[s] to myself, to help me understand everything better.

It was evident that individuals, regardless of their exposure to the intervention, experienced metacognitive growth from participating in the interview itself. This distinguished the interview as its own form of intervention.

It should be noted that some participants, like Participant C.6, experienced, "No impact in particular," which identified that this interview had room for improvement as an intervention. Participant E.3 provided evidence of inexperience with metacognition, "It seems like a relatively new thing, at least in my life experiences…In the classrooms that I had, there's not a whole lot of attention to, 'What are your thinking processes during this problem' " (Participant E.3). Such inexperience may have resulted in increased cognitive load. This individual elaborated on the effect of cognitive load on metacognitive performance,

> It's fascinating…When you're trying to figure out trig identities for the first time, that's [metacognition is] not a main thing. There [are] different tricks that you learn…With Metacognition,…I feel like focusing on it in your day-to-day life is going to be so draining, and not needed. (Participant E.3)

This individual connected a perception of metacognition's lack of benefits with effort. This was an important distinction, as it revealed the importance of advocating the benefits of metacognition in order to motivate prolonged effort. This finding supported metacognitive monitoring as an advanced skill (Kramarski & Dudai, 2009), that required practice (Dignath &

Buettner, 2008; Dignath et al., 2008; Tuomi-Gröhn & Engestrom, 2003). Such a distinction was made possible through this higher-resolution online measure (Pintrich et al., 2000).

Some individuals reported refreshing previous knowledge. When asked about the effect of the intervention, Participant E.8 reported that,

> I enjoyed it because I don't usually have questions of such, to ask. No one asks me questions like this because these are very theoretical, philosophical, and psychological, so it requires a lot of thinking. It...refreshes me and makes me think about what I do, why I do it, and a bit of who I am as well…This was more of a refresher of the way I think, and the way my attitude towards school, and how I act…from back in high school when I used to do IB.

Evidently, previous experience with metacognition, as this individual reported from the International Baccalaureate (IB) Programme, was reinforced by the intervention. Overall, while many participants reported premier metacognitive experiences as a result of the interview, modifications to the process may improve the impact of the interview as an intervention. This finding also suggests that exposure to metacognitive prompts and discourse over a longer time may be helpful in participants' development of metacognition (e.g., Dignath & Buettner, 2008; Mevarech & Kramarski, 2014).

Given the depth of analysis offered by the interview data, the interview operated appropriately as an instrument of high resolution. Further, analysis of the data revealed metacognitive growth in both experimental and control group participants as a result of experiencing the interview. Therefore, the interview operated simultaneously as both intervention and instrument of metacognition. As "there is no one 'perfect' measure of metacognition" (Pintrich et al., 2000, p. 88), metacognition measurement research would benefit from the analysis of such a high-resolution instrument. As an intervention, further quantitative and qualitative data would need to be collected, to determine if the experience has generalizable effects on the population.

CHAPTER SEVEN: TRIANGULATION OF DATA

A concurrent, triangulated, mixed-methodology (Hanson et al., 2005) was used for analysis. Consequently, once data were analysed independently, interpretation of the data was conducted in search of the convergence of themes. Five themes converged:

- multiple forms of data reinforced the emergent themes, corroborating the findings of this study;
- an intervention targeting the explicit instruction of metacognition and transfer in post-secondary students affected students favourably;
- metacognitive growth and transfer were detailed in near, far, immediate, and some delayed contexts;
- transfer was facilitated into various contexts through the incorporation of metacognition into routine, novel, and difficult learning experiences; and
- it was also discovered that the interview operated as both instrument and intervention of metacognition.

Each theme was explored individually.

Reinforcement of Intervention Design

The in-course data analysis revealed that the experimental and control groups expressed infrequent monitoring behaviour as a result of awareness of being recorded. Further, independent of time and ability, complex, non-routine, and unfamiliar problems enhanced the metacognitive components such as planning, monitoring, and strategic knowledge, matching what was known from the literature (Mevarech & Kramarski, 2014; Mevarech et al., 2010; Salomon & Perkins, 1989). Although limited in diversity, prompts facilitated behaviours intended by the questions

(Mevarech & Kramarski, 1997; Mevarech & Kramarski, 2014). Conversation quality gained depth for the experimental condition when prompts were used.

The above findings were corroborated by the participants during their interviews. Participants reinforced the need for metacognitive development to increase focus and regulation of thought. Members of both conditions reported enhanced metacognitive thought from being recorded in a social context. The use of novel problems was corroborated by the participants' acknowledgement of metacognitive growth. The participants reported that difficult problems facilitated monitoring behaviours. Finally, participants acknowledged the importance of practice over time for metacognitive growth (Salomon & Perkins, 1989, Tuomi-Gröhn & Engeström, 2003).

Therefore, triangulation of both forms of data affirmed the design of the present study. First, the inclusion of complex, non-routine, and unique problems facilitated enhanced metacognitive performance; the act of recording participants facilitated metacognitive monitoring and metacognitive thought (Helms-Lorenz & Jacobse, 2008; Kramarski & Dudai, 2009; Schmitz & Perels, 2011); and, the metacognitive prompts, arranged to be developed over time, facilitated the outcomes intended by the guiding questions. In conclusion, the design of the present study was affirmed to match the outcomes intended by the intervention regarding the enhancements and assessment of metacognition.

Participant Characteristics

Analysis of the in-course data revealed similar composition of the participants' membership characteristics. Participants began conversations with diverse metacognitive topics, followed by a focus on metacognitive task knowledge, debugging, and evaluating components for the experimental group (27.4%, 25.5%, and 11.5%, respectively) and the control group

(29.9%, 23.8%, and 12.4% respectively). This reaffirmed what was found within the literature, which also noted a lack of diversity in metacognition for younger populations when solving familiar problems (e.g., Mevarech et al., 2010); particularly the novice skills of metacognitive task knowledge (e.g., Mevarech & Amrany, 2008), evaluating (e.g., Kramarski & Dudai, 2009), and debugging (e.g., Kramarski & Friedman, 2014) when solving familiar problems. Further, both groups displayed diverse metacognitive abilities, including the presentation of higher levels of cognition and advanced metacognitive components (i.e., planning, monitoring, and debugging). Both groups showed strong teamwork capacities. In summation, in-course data analysis revealed similar attributes in the composition of group membership for experimental and control conditions.

Analysis of the interview data corroborated some of the findings of similarity from the in-course data with increased resolution. Such resolution identified differences between the conditions regarding participants' experiences. While participants from both conditions reported mixed feelings of stress and joy during learning experiences, experimental group participants identified varying comfort levels with the use of strategies. This was interpreted as enhanced metacognitive personal knowledge for the experimental group when compared with the control group, who expressed uniform comfort with little detail to support such claims. This increase in metacognitive personal knowledge was corroborated by it being used fourth-most frequently by the experimental group (5.5%) and sixth-most frequently by the control group (3.9%). Therefore, participants who received the intervention experienced some increase in metacognitive personal knowledge, which in turn developed more reasonable evaluations of performance when compared with the control group. It was concluded that the intervention may have slightly enhanced participants' metacognitive personal knowledge and evaluating components within the context of general learning (Kramarski et al., 2013; Rotgans & Schmidt, 2009, van Velzen, 2016). This contradicts the findings of other researchers regarding transfer of metacognitive personal knowledge (e.g., Alexander et al., 2011) and evaluating (e.g., Erickson, 2015; Winne & Muis, 2011; Vo et al., 2014), providing further evidence to support general transfer of the metacognitive components into far, immediate and delayed, contexts.

Metacognitive Strategic Knowledge

Analysis of the in-course data revealed that participants' achievement goal-orientation (Elliot & Church, 1997) affected the use of self-regulated learning skills (Hessels-Schlatter et al., 2017, Özcan, 2015). Rooted in a performance-approach, participants from both conditions engaged in the use of the skipping question and comparison strategies. These strategies, which were not always effective, emphasized performance over learning (Elliot & Church, 1997).

Participants from both conditions enumerated many problem-solving and information-management strategies during the interviews. Analysis of the participants' use of the strategies indicated emphasis on efficiency and question clarification, in alignment with a performance-approach to learning (Elliot & Church, 1997). This was further corroborated during the interviews by the control groups' focus on optimizing assessment performance within the pressure of time.

Participants who received the intervention also cited debugging strategies and analysing questions prior to solving. Participants from the experimental group also appeared to be more focused on the process of learning when compared with the control group, indicating that the intervention enhanced general learning (Kramarski et al., 2013; Rotgans & Schmidt, 2009, van Velzen, 2016). The use of advanced strategies, and the development of the learning process, supported the conclusion that the intervention enhanced metacognitive strategic knowledge development (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017).

The quantitative analysis conducted from the in-course data also appeared to align with the experimental group's enhancement in metacognitive strategic knowledge. Metacognitive strategic knowledge was the fourth-most used component (7.2%) of metacognition by the control group. Metacognitive strategic knowledge was sixth-most used (4.9%) by the experimental group. The findings resulting from the statistical analysis, interpreted with caution (Harrison & Vallin, 2018), were just short of significance for change over time for conditional (i.e., strategic) knowledge and information managing, with a tendency for the intervention group to maintain their strategic knowledge from pre-intervention to post-intervention. In other words, the intervention may have helped maintain, or enhanced understanding of, existing levels of metacognitive knowledge which reinforced previous findings (Mevarech & Fridkin, 2006). This aligned with the use of advanced techniques, such as debugging and analysis, employed by the experimental group in comparison with the control group (Kramarski & Friedman, 2014).

Furthermore, during the interviews, only participants from the experimental group reported self-regulated learning strategies, in addition to metacognitive strategic knowledge in problem-solving. These strategies were focused in the areas of organization, study habits and communication (Özsoy et al., 2009). These strategies aligned with a performance-approach to learning (Elliot & Church, 1997). While both groups professed a performance-approach to learning, it was only evident that participants who received the intervention were able to express the use and development of strategies dedicated to the targeted outcome. In conclusion, the intervention enhanced metacognitive strategic knowledge development (Chi & Van Lehn, 2010;

Hessels-Schlatter et al., 2017) and facilitated general learning (Kramarski et al., 2013; Rotgans & Schmidt, 2009; van Velzen, 2016) in addition to performance goals.

Transfer

Transfer was separated into three categories of distance: time (immediate/delayed), context (near, far), and exposure (routine/novel). Participants' motivation to transfer was an additional theme which emerged from the data. Each theme expressed itself through unique forms of data. Consequently, each was examined independently.

Motivation to transfer learning. The interviews revealed that control group participants were motivated to find transfer opportunities. They also imagined far-transfer of learning beyond immediate circumstances. This was interpreted as forward-reaching transfer (Salomon & Perkins, 1989). Although experimental group participants also cited potential transfer of learning into various distant contexts, the examples provided were more detailed, with a larger volume of non-academic contexts cited. In summation, the intervention appeared to affect participants' motivation to transfer learning, (Tuomi-Gröhn & Engeström, 2003). In particular, it was evident that participants in the experimental group were able to imagine detailed, more distant contexts in which to apply metacognition. Therefore, instructing individuals explicitly for transfer likely enhanced intrinsic motivation for seeking transfer, which in turn affected far-transfer applications.

Routine-transfer. Participants from the experimental group affirmed the importance of practicing metacognition in order to facilitate metacognitive growth (Mevarech & Kramarski, 2014; Salomon & Perkins, 1989). Such practice resulted in reductions of cognitive load, necessary for developing metacognitive automaticity (Salomon & Perkins, 1989). Therefore, the intervention supported the transference of metacognitive knowledge and regulation into routine, related contexts through the process of regular practice (Salomon & Perkins, 1989, Tuomi-Gröhn & Engeström, 2003).

Novel-transfer. Both in-course and interview data corroborated the transfer of metacognition into novel contexts for both conditions. In-course data analysis revealed the impact of complex, non-routine, and unfamiliar problems soliciting advanced metacognitive behaviours such as monitoring, planning, and strategic knowledge (Mevarech & Kramarski, 2014; Mevarech et al., 2010). Interview data reinforced the solicitation of metacognitive growth in novel contexts, particularly for the monitoring component. Therefore, the introduction of novel contexts facilitated the use and transfer of metacognition.

Immediate-transfer. Immediate-transfer was analysed during the in-course data, given this formed the immediate context for potential transfer by the participants. Although low in overall use, transfer was identified slightly more for the experimental group (i.e., 1.2%) when compared with the control group (0.3%). These forward-reaching transfer moments (Salomon & Perkins, 1989) decreased over time (i.e., 2.1%, 2.1%, 1.4%, 0.8%, and 0% for weeks 1 to 5, respectively); this decrease was associated with the need for practice (e.g., Dignath & Buettner, 2008; Mevarech & Kramarski, 2014). It was thus concluded that the intervention, through explicit use of the prompts, solicited the transfer of metacognition into immediate (Mevarech & Kramarski, 2014; Mevarech & Kramarski, 1997) and future moments (Salomon & Perkins, 1989). The cause of this was attributed to a combination of participants becoming aware of the purpose of transfer through their involvement in the study, and the effect of increased metacognitive diversity promoted by the use of the prompts. In summation, prompts enhanced metacognitive diversity, which in turn facilitated immediate-transfer of metacognition into general learning (Kramarski et al., 2013; Rotgans & Schmidt, 2009; van Velzen, 2016). The infrequency of these distinctions, however, led to the conclusion of limited transference into immediate, near contexts.

Delayed-transfer. During the interview, a hypothetical biology transfer task was used to assess delayed-transfer. This task revealed a diversity of metacognitive ability for both experimental and control group participants. Some participants, from both groups, displayed the transfer of specific strategies during their solution. Specifically, members of the control group displayed one instance each of transferring metacognitive strategic knowledge and personal knowledge. Unique to the experimental group, two participants demonstrated the transfer of a previously cited strategy.

Participants' responses to the task from both conditions were assessed using the rubric in Table *33* (p. 192). Not all interview participants completed the Metacognitive Awareness Inventory (MAI) pre-test and post-test. For comparison, z-scores were tabulated from the entire dataset collected post-intervention. A summary of this comparison is included below in Table *35* below.

Inspection of the metacognitive knowledge and regulation scores for the control participants appeared to indicate some alignment: Participants C.5 and C.6 displayed advanced metacognitive strategies, with above-average z-scores (1.83 and 2.06 z-scores, respectively) in metacognitive regulation and metacognitive knowledge (1.82 and 0.96 z-scores, respectively). The magnitude of the score, however, did not correspond with the overall performance. Similarly, Participant C.10 performed with low metacognitive skill, and reported below-average performance in knowledge and regulation (-0.51 and -0.39 z-scores, respectively). It was noted that two of the control participants, C.9 and C.4, did not complete the metacognitive awareness inventory, thus restricting total possible analysis.

Table 35
Comparing Quantitative Scores of Solutions with Metacognitive Z-Scores

Condition	Participant	Rubric Score	Metacognitive Knowledge		Metacognitive Regulation	
			M (SD)	MK Z-Score	M (SD)	Z-Score
Control (n = 14)	C.4	7	n/a	n/a	n/a	n/a
	C.5	6	4.49	1.82	4.47	1.83
	C.6	8	4.17	0.96	4.56	2.06
	C.9	4	n/a	n/a	n/a	n/a
	C.10	2	3.62	-0.51	3.59	-0.39
	Overall		3.87 (0.56)	n/a	3.70 (0.53)	n/a
Experiment (n = 17)	E.1	7	3.4	-0.84	3.30	-0.75
	E.3	2	3.81	-0.11	3.67	0.30
	E.5	1	4.24	0.65	3.60	0.22
	E.8	1	4.10	0.40	3.80	0.19
	E.9	2	4.22	0.22	3.48	-0.41
	E.10	6	3.43	-0.99	3.38	-0.94
	Overall		3.81 (0.38)	n/a	3.75 (0.39)	n/a

Note. MK = Metacognitive Knowledge; MR = Metacognitive Regulation

In contrast, the experimental group displayed advanced metacognitive skills in opposition of reported metacognitive knowledge and regulation. Participants E.1 and E.10 reported below-average metacognitive knowledge (-0.84 and -0.99, respectively) and regulation (-0.75 and -0.94, respectively). The remaining participants from the experimental group displayed minimal use of metacognition, despite slightly above-average reports of metacognition (i.e., z-scores not exceeding 0.65 for metacognitive knowledge and 0.30 for metacognitive regulation).

Therefore, metacognitive knowledge and regulation as reported by the Metacognitive Awareness Inventory did not appear to predict the use (i.e., delayed-transfer) of metacognition in completing the biology task. While control group participants’ use of metacognition aligned with reported scores, experimental group participants’ use of metacognition did not. This conflict in outcomes aligned with what was found in the literature on possible inaccuracies in self-report methods (Panadero et al., 2015).

Consequently, corroboration was sought from the qualitative analysis of participants' answers to the hypothetical task, also recommended by other researchers (e.g., Dinsmore et al., 2008; Winne & Perry, 2000). Most participants, from the experimental and control group, offered 'linear' (i.e., 'top-down' approaches to the considerations) solutions, indicating low use of metacognition. One participant from the control group displayed the transfer of metacognitive strategic knowledge (i.e., Participant C.4) and another individual from displayed the transfer of metacognitive personal knowledge (i.e., Participant C.6). Two participants from the experimental group (i.e., Participants E.1 and E.10) displayed transfer of specific strategies.

Therefore, inaccuracies in students' self-reported metacognitive knowledge and regulation was verified by the triangulation of data between the forms (Panadero et al., 2015). Considering that there were few distinguishing differences in performance between the experimental and control groups, the intervention did not facilitate transfer into a far, delayed context. All participants displayed at least some use of metacognition during their solutions, but few referenced the use of newly acquired skills. Interestingly, Participant E.8, who reported previous experience with learning metacognition during completion of an IB Diploma, demonstrated novice skills (i.e., solving the problem in a linear fashion); having metacognitive knowledge did not ensure learners' regulation of cognition (Mevarech & Amrany, 2008). An examination of the question itself revealed that, although delayed-transfer was adequately assessed from the activity, no metacognitive prompts were provided to encourage use or transfer, by design. Considering participants' aforementioned acknowledgement regarding the importance of repeated practice, supported by the literature (Tuomi-Gröhn & Engeström, 2003), it was concluded that delayed-transfer of metacognition requires prompting until it cements itself as a habit for an individual.

Near-transfer. When used properly, prompts facilitated diverse metacognitive behaviours, including transfer, as evident during the in-course data analysis. As was reported under *Immediate-transfer* (above), the use of prompts solicited transfer of metacognition for the experimental participants into the course of study (i.e., a near context). This was corroborated through the interviews, where participants from the experimental group reported increases in debugging, evaluating, monitoring, and planning as a result of participating in the study (e.g., Mevarech & Fridkin, 2006; Mevarech & Kramarski, 2014). Further, experimental group participants cited enjoying the process, with decreases in anxiety (Legg & Locker, 2009; Kramarski et al., 2010). Some individuals reported engaging in metacognition for the first time.

During the interviews, experimental condition participants identified enhancements in self-regulated learning strategies (Hessels-Schlatter et al., 2017) focused in the areas of efficiency, organization, study habits, and communication (Özsoy et al., 2009). Further, participants from the experimental group also showed greater development in the process of learning (Kramarski et al., 2013; Rotgans & Schmidt, 2009). Therefore, it was concluded that the intervention enhanced metacognitive diversity, self-regulated learning strategies, and the process of learning, ultimately facilitating the transfer of metacognition into near contexts (i.e., the course of study).

During the interviews, participants from both the experimental and control groups also reported applying various metacognition components to other related subjects. Control group participants identified transferring self-regulated learning strategies and problem-solving strategies (i.e., metacognitive strategic knowledge) into multiple near contexts such as Linear

Algebra, Physics, Chemistry, and Engineering Mechanics. Similarly, experimental group participants reported transferring metacognitive strategies to near contexts considered as both immediate and delayed (i.e., Linear Algebra, Chemistry, Physics, Mechanical Engineering courses, and Thermofluids). Distinct from the control group, participants also reported transferring metacognitive debugging and planning into near, immediate, and delayed contexts (i.e., Computer Science and Physics).

Therefore, exposure to the intervention also appeared to facilitate transfer of metacognitive debugging (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014) and the advanced component of planning (Hessels-Schlatter et al., 2017; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014; Kramarski et al., 2013; Mevarech & Amrany, 2008) to near contexts. It was further concluded that metacognitive strategic knowledge, such as problem-solving strategies and self-regulated learning strategies, transferred to near, immediate, and delayed contexts. This finding was observed independent of exposure to the intervention. Futher, this expanded on what was found in the literature regarding the transferability of metacognitive strategic knowledge, and in particular the application of problem-solving and self-regulated learning strategies into varied contexts (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017). In summation, while metacognitive strategic knowledge appeared transferrable regardless of exposure, participants who received the intervention transferred metacognitive debugging, and planning into near, immediate and delayed, contexts.

Far-transfer. Analysis of the interviews identified distinct differences in the components of metacognition transferred into far domains between the experimental and control group participants. Participant C.6's need for direct relatability indicated the importance of metacognitive instruction (Pólya, 1945; Schoenfeld, 1985; Mevarech & Kramarski, 1997;

Verschaffel, 1999; OECD, 2010). Control group participants reported the transfer of metacognitive strategic knowledge (i.e., self-regulated learning strategies) into far academic contexts such as Biology, Business, and writing courses. These strategies were also transferred into non-academic contexts: time-management, a driving examination, and learning music recreationally. This expanded on previous research on the transferability of metacognitive strategic knowledge (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017)

Participants from the experimental group reported the transfer of advanced metacognitive components such as debugging, planning, and monitoring to various distant contexts. These individuals reported applying metacognition into their personal life, professional life, recreational athletics, and video games. Participant E.10 provided a detailed account of applying debugging, monitoring, planning, and metacognitive strategic knowledge to increase performance within the gaming community. Participant E.10 also recognized that these same skills were employed by professionals within the community.

Therefore, the intervention appeared to have improved the transferability of metacognition into far contexts, both academic and non-academic in nature. Previous research indicated that innate metacognitive knowledge in novice learners may make interventions unnecessary (Mevarech & Amrany, 2008); this was given increased detail by the present study, particularly by the examples listed by the control group. Both conditions supported the transference of metacognitive strategic knowledge to alternate domains (Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017). This suggests the possibility that metacognitive strategic knowledge may transfer implicitly, further increasing its value as an incorporated element to learning. Further research is recommended to examine the implicit transfer of metacognitive strategic knowledge. As noted under *Metacognitive Strategic Knowledge* (above), the intervention extended the distance of transfer to even further contexts, with applications to general learning, an original contribution to the literature.

Regarding metacognitive regulation, participants who received the intervention indicated transfer of metacognitive debugging (e.g., Kramarski & Dudai, 2009; Kramarski & Friedman, 2014) , planning (e.g., Kramarski et al., 2013; Mevarech & Amrany, 2008), and monitoring (e.g., Chi & VanLehn, 2010; Hessels-Schlatter et al., 2017; Tajika et al., 2007) to distant academic contexts and non-academic contexts; This illustrated the versatility of metacognition for daily life, fulfilling transfer as described by Tuomi-Gröhn and Engeström (2003). To the best knowledge of this researcher, this is the first time the transfer of all components of metacognition to such distant contexts has been observed. The high resolution of the data provided ample justification for future research to confirm the present findings. In summation, the intervention positively impacted participants to effectively transfer metacognition into distant contexts.

Impact of the Interview

Analysis of the interview data resulted in an unexpected impact of the interview process on both experimental and control group participants. First, as was evident during the analysis, the examples provided by participants illustrated the facilitation of rich data collection by the interview (Pintrich et al., 2000). Detailed accounts of understanding, and use of metacognition, were collected as a result of using the interview to assess metacognition in the participants. Further, participants from both conditions reported the interview as a premier conscious experience of metacognition, being given the opportunity to practice (Dignath & Buettner, 2008; Dignath et al., 2008; McCabe, 2011, Young & Fry, 2008). It was therefore evident that, regardless of exposure to the intervention, participants experienced metacognitive growth from the process of the interview itself.

Conclusion

The purpose of the present research was to investigate the transfer of metacognition to other domains from mathematics, with two intended outcomes:

1. identifying and describing the transference of metacognitive strategic knowledge and regulation to other domains from mathematics; *and*
2. validating (or calling into question) the generality of metacognition and its transferability into other domains.

Participant characteristics, intervention design, and metacognitive enhancement were verified in order to answer potential transfer differences. Characteristics of the population emerged which matched those found within the literature. All participants, regardless of condition, increased in performance of self-regulated learning strategies (i.e., metacognitive strategic knowledge and information-managing); however, participants within the experimental group generally demonstrated the development of more advanced strategies. The experimental group also reported detailed and diverse self-regulated learning strategies, with diverse confidence in comparison to the uniform comfort expressed by the control group. Collectively, the design of the study was reinforced by the triangulated data, including: the use of explicit metacognitive instruction to focus and regulate thoughts; the recording of participants in a social context; the presence of novel, difficult problems to facilitate metacognition; and the incorporation of repeated instruction to facilitate growth.

The intervention had numerous, positive impacts on the participants. The experimental group demonstrated diverse use of self-regulated learning strategies, and reported increases in learning satisfaction with decreases in anxiety. The intervention enhanced metacognitive personal knowledge for members of the experimental group, resulting in transfer to general learning (e.g., van Velzen, 2016), which contradicts findings from other researchers (e.g., Alexander et al., 2011). Several participants reported using metacognition consciously for the first time. The metacognitive prompts solicited diverse metacognitive behaviours from the participants in addition to transfer. The above findings provided adequate ground to affirm known attributes of the population, that the intervention was appropriately designed, and that it enhanced metacognitive knowledge and regulation. The enhancement of metacognitive knowledge and regulation found in this study supported the literature on the transference of metacognitive strategic knowledge (e.g., Hessels-Schlatter et al., 2017) and regulation (e.g., Hessels-Schlatter et al., 2017; Mevarech & Amrany, 2008) into near and immediate contexts.

Transfer identified from both experimental and control group participants characterized expected applications of metacognition. All participants reflected on numerous transfer possibilities. The experimental group imagined applications of metacognition into far contexts, with greater volume towards non-academic contexts. Thus, the intervention affected intrinsic motivation of transferring metacognition to ‘real-life’ contexts (Tuomi-Gröhn & Engeström, 2003). Novel, difficult contexts facilitated metacognitive development. Participants in the experimental condition expressed limited transfer in delayed contexts. Convergence of the data corroborated the importance of incorporating metacognition into routine practice to facilitate growth and transfer to delayed contexts.

Participants from both conditions transferred metacognitive strategic knowledge (i.e., self-regulated learning strategies and problem-solving strategies) to academic subjects (e.g., Physics, Chemistry, Engineering, etc.) considered as near contexts. Participants who received the intervention demonstrated transfer of metacognitive monitoring, planning, and debugging. Metacognitive strategic knowledge also transferred to far academic contexts for participants in both conditions (e.g., Business, Writing, etc.); however, participants from the experimental group transferred metacognitive strategic knowledge to distant, non-academic contexts. Participants who received the intervention demonstrated the transfer of advanced metacognitive components (i.e., debugging, planning, and monitoring) into distant contexts (i.e., personal life, professional life, recreational athletics, and video games). Collectively, the evidence revealed varying impacts of the intervention on each type of transfer, summarized in *Table 36* below.

Table 36
Types of Transfer Identified During the Present Study

	Exposure		Near		Far	
	Routine	Novel	Immediate	Delayed	Immediate	Delayed
Metacognitive Knowledge	✓$_E$					
Personal			✓$_E^{*b}$		✓$_E^{*b}$	✓$_B^{*b}$
Task						
Strategic		✓$_B$	✓$_B$	✓$_B^{*a}$	✓$_B$	✓$_B^{*a}$
Metacognitive Regulation	✓$_E$		✓$_E$			
Planning		✓$_B$	✓$_E$	✓$_E$	✓$_E$	✓$_E$
Monitoring		✓$_B$	✓$_E$		✓$_E$	✓$_E$
Debugging			✓$_E^{*a}$	✓$_E^{*a}$	✓$_E^{*a}$	✓$_E^{*a}$
Evaluating			✓$_E$		✓$_E^{*b}$	✓$_E^{*b}$
Self-Regulated Learning			✓$_B$	✓$_B^{*a}$	✓$_B$	✓$_B^{*a}$
General Learning			✓$_E$	✓$_E$	✓$_E$	✓$_E$

Note. Transfer was identified based on triangulation of all three forms of data; $_B$ = both groups; $_E$ = experimental group only; ^{*a} = novel contribution to the literature; ^{*b} = novel and contrary to some literature.

Inspection of *Table 36* revealed ample support for previously reported transfer of metacognitive strategic knowledge, self-regulated learning, general learning, and metacognitive regulation (i.e., planning, monitoring, and debugging). Novel to the literature, the present study provided high-resolution data illustrating the strengthening effect of the intervention on metacognition. Qualitatively, the present study explicated what were considered 'further' transfer contexts (e.g., personal life, working life, recreational sports, and video games) than were previously found in the literature. Therefore, the transferability of metacognition may be more general than was previously thought (e.g., Kelemen et al., 2000). Evidence supported distant transfer of metacognitive personal knowledge and evaluating components into general learning contexts (Kramarski et al., 2013; Rotgans & Schmidt, 2009), contrary to other researchers regarding metacognitive personal knowledge (e.g., Alexander et al., 2011) and evaluating (Erickson, 2015; Winne & Muis, 2011; Vo et al., 2014); however, the high resolution of the data collected justified the finding. Original contributions to the literature also included examination into (near and far) delayed-transfer of metacognitive strategic knowledge and self-regulated learning.

Analysis of the results from the systematic literature review revealed an opportunity for further investigation regarding the explicit transferability of the debugging component of metacognition (See *Debugging*, p. 53). This was attributed in part to the uniqueness of Schraw and Dennison's (1994) metacognitive model which extended Brown's (1987) metacognitive model to include debugging. Although differences between the experimental and control groups could be attributed to a small pool of participants examined, the high-resolution data of the present study illustrated explicit, triangulated data supporting the transferability of metacognitive debugging into (near and far) immediate and delayed contexts. Therefore, the present study contributed original, explicit, qualitative data regarding the transferability of metacognitive debugging in support of previous researchers (Chi & VanLehn, 2010; Kramarski & Dudai, 2009; Kramarski & Friedman, 2014).

Analysis of the interview data revealed the surprising impact of the interview on participants' metacognition. The interview facilitated the collection of qualitatively rich metacognition data for analysis. Further, numerous participants attributed the interview to instigating premier conscious metacognitive experiences. Individuals from both conditions experienced metacognitive growth through participation in the interview itself; thus, the interview operated as a form of intervention worthy of further study.

In summation, an intervention targeting the explicit instruction of metacognition and transfer affected post-secondary students positively; transfer of metacognition into near, far, immediate, and some delayed, contexts was affirmed. The evidence revealed the need for novel, difficult contexts to facilitate advanced metacognitive behaviours. The necessary incorporation of metacognition into routine learning experiences in order to facilitate transfer towards delayed contexts was affirmed. A surprising finding worth reporting was the simultaneous outcomes of the interview, intended as an instrument of measuring metacognition, also operating as an intervention itself.

Limitations & Recommendations

Given the potential effects noted during the study on the experimental group participants' metacognitive personal knowledge, further study is recommended regarding the impact of metacognitive interventions on students' metacognitive personal knowledge (i.e., knowledge of personal learning needs). In particular, research should focus on the potential transference of such knowledge into near (immediate and delayed) contexts.

Examination of the literature revealed conflicting evidence regarding the domain-specificity (e.g., Erickson & Heit, 2015; Winne & Muis, 2011) and domain-generality (e.g., Schraw, 2001) of metacognitive evaluating. The literature review conducted for the present study revealed a need for identifying elements of metacognitive evaluating which are transferable (Gutierrez et al., 2016); some studies indicated the possibility for increased evaluating for generic learning (e.g., Kramarski et al., 2013). While metacognitive evaluating was reported when observed, given such conflict regarding its transferability, metacognitive evaluating was determined to require its own independent examination separate from the present study.

Future study of the interview method employed in the present research is recommended. For example, while the interview method positively impacted growth on the participants, regardless of condition, correlation was inconclusive between the interview and other quantitative measures of metacognition. In particular, examination should focus on the potential for this interview method to operate as an intervention, measuring possible effects and impacts from the process. Lastly, should positive effects and impacts on metacognitive growth be affirmed, a study which examines the incorporation of the interview into instructional time might demonstrate the benefit of infusing regular metacognitive dialogic discussion into course design.

Several limitations restricted the ability to generalize the conclusions within this study to a general population. First, the requisite depth of qualitative analysis required for the in-course and interview analyses restricted the generalizability of the data. Insufficient numbers of participants for the survey data ($n = 23$) restricted the possibility of finding significance for the effects of time and treatment across the ten subscales of the Metacognitive Awareness Inventory, (i.e., n = 128, as suggested by G-Power). Further, the in-course data (n = 8) and the interview data (n = 11) were chosen for increased resolution of analysis, limiting generalizability of the conclusions. Caution should thus be employed before conclusions are applied to any general population.

Therefore, it is recommended that future studies examine the generalization of transferring metacognition within post-secondary populations. Given previous research on the impact of complex, unfamiliar, and non-routine contexts on the development of metacognition, and the importance of practice in developing metacognition explicitly (e.g., Mevarech & Kramarski, 2014), transfer into novel and routine contexts were affirmed by the present research. Consequently, it is recommended that future studies examine the generalizability of transfer of metacognition in immediate, near, and far contexts. Such studies are recommended to include mixed data, with sufficient sample sizes for quantitative analysis, and also to include high-resolution qualitative analysis to corroborate potential findings. Additionally, while the present research identified potential transfer in a delayed context, it was evident that additional practice and explicit reinforcement were needed for more distinguishing results. Thus, a study which reinforces metacognitive development explicitly over a longer period of time may clarify the transferability of metacognition into delayed contexts.

As revealed during the in-course data, increases in conversation quality for both the experimental and control group participants' were recommended. Participants' tendency to speak with off-microphone individuals emphasized the need for restricting conversations of participants to recorded individuals exclusively. Based on the frequency counts of the in-course data, the combined topics of personal, procedural, or silence for the experimental group accounted for 9.7% of all discussed topics compared with 16.6% for the control group. These distractions of the participants indicated the need for engaged instructors. A detailed account of the mechanics of the study, paired with instruction on think-aloud protocols for participants, is recommended for minimizing silence and increasing the resolution of observing of metacognitive behaviours. Overall, the following recommendations are made for future iterations of the present intervention: explicit instruction of think-aloud protocols for all conditions; the incorporation of highly-engaged instructors; and participants' conversations restricted to those within any future study.

The frequency of prompt-use decreasing over time during the in-course data was corroborated by participants' own admittance to requiring practice, as evident during the interviews. Therefore, it is recommended that future studies include semi-frequent prompt instruction, scaffolded for enhanced development (Teeuwen & Salinitri, 2019), with gradual release of responsibility.

Overall, while the present research affirmed the transfer of metacognition into near, far, immediate, and some delayed, contexts, further research generalizing this finding to a post-secondary population is recommended. Recommendations for such a study include: restricting participants to conversations with audio-recorded individuals only, explicit instruction of think-aloud protocols, and engaged instructors to scaffold metacognitive prompts to participants, with gradual release of responsibility. A study dedicated to the examination of delayed-transfer of metacognition is recommended to affirm the optimal conditions for instruction listed in the present study.

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APPENDIX A – METACOGNITIVE AWARENESS INVENTORY QUESTIONNAIRE

*Note: this survey was delivered online using Qualtrics.com.

Title: Investigating the Transfer of Metacognition to Another Domain from Mathematics

Please verify that you are a student enrolled in *0362-140: Differential Calculus* at the University of Windsor in the Fall Semester.

- [Captcha button included]

Twice this semester, the Mathematics Department is conducting an assessment of a piloted teaching strategy in some of its laboratories. To determine its effectiveness, we will be assessing students' metacognitive awareness through a survey. Metacognition is understood as "thinking about thinking", and has potential impact on learning, such as particularly during problem-solving. 75 participants will receive a $10 gift card to either the University of Windsor Bookstore or Amazon (participants' choice). Participation is entirely voluntary and will not impact your performance in the course whatsoever. This survey data may be used for research projects. Such use would only occur with approval from the Research Ethics Board of the University of Windsor.

- I understand and consent to participate in this survey. [If selected, participant proceeds to the next question].
- I do not consent to participate in this survey. [If selected, the survey concluded].

1. Please indicate your age:
   - 17
   - 18
   - 19
   - 20
   - 21
   - Other, please specify: __________

2. Please indicate your gender:
   - Male
   - Female
   - Other, please specify: ___________
   - Prefer not to answer

3. Please identify your highest completed level of education (Select one):
   - High School Diploma
   - College Diploma, please specify: ____________
   - University Degree, please specify: ____________
   - Other, please specify: ___________

4. Please identify your most recent math course in the last 12 months (Select all that apply):
   - I am repeating this course
   - I have taken another Math Credit at a university
   - I have taken a Math Credit at a college

- Grade 12 Advanced Functions (MHF4U)
- Grade 12 Calculus and Vectors (MCV4U)
- Mathematics of Data Management (MDM4U)
- Other, please specify: ___________

5. Please state your enrollment in University:
   - Part-time (1, 2 or 3 courses)
   - Full-Time (4 or more courses)

6. Please identify your faculty:
   - Faculty of Arts, Humanities and Social Sciences
   - Faculty of Education
   - Faculty of Engineering
   - Faculty of Graduate Studies
   - Faculty of Human Kinetics
   - Faculty of Law
   - Faculty of Nursing
   - Odette School of Business
   - Faculty of Science
   - Undeclared

Please consult with your Student Information System (SIS) to answer the following two questions:

7. State the name of the program in which you are enrolled: ___________

8. In which lab section are you enrolled for this course?

Labs are listed in order of their occurrence in the week. Please consider your room and section number correctly.

Section:

- 51, Mondays, 4-5:50pm, DH 353
- 57, Mondays, 4-5:50pm, DH 256
- 65, Mondays, 4-5:50pm, DH 366
- 61, Mondays, 6-7:50pm, DH 353
- 70, Mondays, 6-7:50pm, EH 3125
- 55, Mondays, 6-7:50pm, DH 350
- 52, Tuesdays, 10-11:50am, EH 2127
- 56, Tuesdays, 5:30-7:20pm, EH 2130
- 58, Tuesdays, 5:30-7:20pm, DH353
- 63, Tuesdays, 5:30-7:20pm, EH 3125
- 53, Wednesdays, 6-7:50pm, DH 355
- 59, Wednesdays, 6-7:50pm, DH 353
- 66, Wednesdays, 6-7:50pm, DH 367
- 71, Wednesdays, 6-7:50, EH 3125

- 60 Wednesdays, 6-7:50pm, EH 3125
- 60, Thursdays, 5:30-7:20pm, DH 366
- 67, Thursdays, 5:30-7:20pm, DH 368
- 72, Thursdays, 5:30-7:20pm, EH 3125
- 68, Thursdays, 7:30-9:20pm, DH 366
- 73, Thursdays, 7:30-9:20pm, EH 3125
- 54, Thursdays, 10-11:50am, DH 350
- 62, Fridays, 5:30-7:20pm, DH 366
- 64, Fridays, 2:30-4:20pm, DH 353
- 74, Fridays, 2:30-4:20pm, DH 350
- 69, Fridays, 4:30-6:20pm, DH 353

9. The Metacognitive Awareness Inventory (MAI) was constructed by Schraw and Dennison (1994) to assess metacognitive knowledge and metacognitive regulation. Please answer the following to the best of your ability:

1. I ask myself periodically if I am meeting my goals.*

1	2	3	4	5
never	rarely	sometimes	often	always

*[All other questions utilized the same scale, which is not repeated here.]

2. I consider several alternatives to a problem before I answer.
3. I try to use strategies that have worked in the past.
4. I pace myself while learning in order to have enough time.
5. I understand my intellectual strengths and weaknesses.
6. I think about what I really need to learn before I begin a task.
7. I know how well I did once I finish a test.
8. I set specific goals before I begin a task.
9. I slow down when I encounter important information.
10. I know what kind of information is most important to learn.
11. I ask myself if I have considered all options when solving a problem.
12. I am good at organizing information.
13. I consciously focus my attention on important information.
14. I have a specific purpose for each strategy I use.
15. I learn best when I know something about the topic.
16. I know what the teacher expects me to learn.
17. I am good at remembering information.
18. I use different learning strategies depending on the situation.
19. I ask myself if there was an easier way to do things after I finish a task.
20. I have control over how well I learn.
21. I periodically review to help me understand important relationships.
22. I ask myself questions about the material before I begin.
23. I think of several ways to solve a problem and choose the best one.
24. I summarize what I've learned after I finish.

25. I ask others for help when I don't understand something.
26. I can motivate myself to learn when I need to.
27. I am aware of what strategies I use when I study.
28. I find myself analyzing the usefulness of strategies while I study.
29. I use my intellectual strengths to compensate for my weaknesses.
30. I focus on the meaning and significance of new information.
31. I create my own examples to make information more meaningful.
32. I am a good judge of how well I understand something.
33. I find myself using helpful learning strategies automatically.
34. I find myself pausing regularly to check my comprehension.
35. I know when each strategy I use will be most effective.
36. I ask myself how well I accomplished my goals once I'm finished.
37. I draw pictures or diagrams to help me understand while learning.
38. I ask myself if I have considered all options after I solve a problem.
39. I try to translate new information into my own words.
40. I change strategies when I fail to understand.
41. I use the organizational structure of the text to help me learn.
42. I read instructions carefully before I begin a task.
43. I ask myself if what I'm reading is related to what I already know.
44. I re-evaluate my assumptions when I get confused.
45. I organize my time to best accomplish my goals.
46. I learn more when I am interested in the topic.
47. I try to break studying down into smaller steps.
48. I focus on overall meaning rather than specifics.
49. I ask myself questions about how well I am doing while I am learning something new.
50. I ask myself if I learned as much as I could have once I finish a task.
51. I stop and go back over new information that is not clear.
52. I stop and reread when I get confused.

APPENDIX B – STRUCTURED INTERVIEW QUESTIONS

An outgoing, one-hour, semi-structured, one-on-one interview was conducted. The following questions were used during such interviews with the participants. Additional related questions were asked for the purposes of seeking clarification and understanding from the participants.

The following was read prior to commencing the interview:

> “Earlier you provided consent to participate in the study **Investigating the Transfer of Metacognition to Another Domain from Mathematics** [Show signed consent form]. Before commencing this interview, we are seeking re-affirmation that you consent to the process of being interviewed, and to confirm your understanding of the invitation to participate in completing a survey. As mentioned in the consent form, I am committed to your confidentiality. You will be allowed to leave at any time from the interview; however the information already collected may be used unless indicated otherwise. You may/may not respond to questions on a voluntary basis. Please take time to review the consent form you signed previously. [Pause]. Do you have any additional questions? [Await questions or assent to proceed]. To confirm, do you still wish to participate in this interview?”

The following was read only upon receiving verbal confirmation:

> “Please answer the following to the best of your ability. Additional related questions may be asked for the purposes of seeking clarification and understanding.”

Metacognitive Strategic Knowledge

1. What problem-solving strategies did you learn during the laboratory sessions of *Differential Calculus*?

2. What learning strategies did you learn during the laboratory sessions of *Differential Calculus*?

- For example, Sarah was learning to play the piano, and she recognized that practicing every day helped her learn the pieces.
- [Additional example]: In learning a new song, she recognized that she could break the song down into pieces to make her learning easier.

3. What other strategies did you learn during the laboratory sessions of *Differential Calculus*?

- For example, Sam was stressed before tests. Sam learned a deep breathing exercise to calm down before conducting a test.

4. What are your feelings and thoughts regarding the strategies you learned?

- [Follow-up]: What value do these strategies have for you?

Metacognitive Personal Knowledge

5. Describe your comfort level with the strategies you learned.

Metacognitive Experiences

6. On a scale from one to five, five being you learned a great deal, how much did you learn about your thinking processes during the laboratory sessions of *Differential Calculus*? Describe your experiences to support your answer.
7. What did you learn about your thinking processes [i.e., how you think] during your laboratory sessions of *Differential Calculus*? Describe what you learned about your thinking processes.
8. What did you feel during the learning of these thinking processes? Describe your experiences to support your answer.

Metacognitive Planning

9. What did you learn about planning your thinking during the laboratory sessions of *Differential Calculus*? Describe your experiences to support your answer.

Metacognitive Monitoring

10. What did you learn about your awareness of your thinking during the laboratory sessions of *Differential Calculus?*

- [For Example]: A presenter was speaking and used the word "um" often without realizing it. An audience member pointed this out to the speaker. The speaker was now aware of the use of the word 'um' during thinking.
- [Alternately] During the laboratory sessions of *Differential Calculus*, you had thoughts, and at times may have also been aware of those thoughts. What did you learn about your awareness of your thoughts from the labs?

Metacognitive Information Managing

11. What did you learn about your information management processes during the laboratory sessions of *Differential Calculus*? Describe your experiences to support your answer.

Metacognitive Debugging

12. What did you learn about how you find alternate approaches to thinking during the laboratory sessions of *Differential Calculus*?

- [Follow-up]: What did you learn about how you found that strategy?

Transfer of Metacognition

[Example of *thinking strategies*]: Joe found he was wasting water when doing the dishes. He now has new ways to make more efficient use of water. [Additional example]: One of the way he makes better use of water is he plans the order of doing the dishes.

13. What impact did learning the thinking strategies/processes during the laboratory sessions in *Differential Calculus* have on your other courses? Describe your experiences to support your answer.
14. What impact did learning the thinking strategies/processes during the laboratory sessions in *Differential Calculus* have on your understanding of your learning processes? Describe your experiences to support your answer.
15. What impact did learning the thinking strategies/processes during the laboratory sessions in *Differential Calculus* have in other areas of your life? Provide an example.
16. What have you learned from your study in *Differential Calculus* that was useful to you? Describe any thinking strategies and processes you applied from your learning during the laboratory sessions in *Differential Calculus* to other courses.

- [Follow-up]: Where did you apply these thinking strategies/processes?
- [Follow-up]: Having had time to reflect, where else in your life could you see yourself using these thinking strategies/processes?
- [Follow-up]: Describe what benefits you foresee as a result of using these thinking strategies/processes in that area of your life.

17. [Participants were provided the following content (in the same format shown below). The first paragraph was read to the participant. A one-minute warning was provided at the fourteenth (14th) minute.]

In this next question, you will be presented with a hypothetical task for you to complete. You will be given 15 minutes to formulate your answer. There is no correct answer to this task. A paper, pencil, and the ability to use www.wikipedia.org on a tablet will be provided. During and at the conclusion of the task, describe how you developed your answer.

Please read the following task instructions out loud:

"You are asked to conduct a research project. You are tasked to lead a team of three total researchers on a two-week investigation of the biological evolution of the dragon's blood tree (*Dracaena cinnabari*), giant succulent tree (Dorstenia gigas), Socotra starling (*Onychognathus frater*), and the Socotran chameleon (*Chameleo monachus*). These are plant and animal species endemic to the island of Socotra, which is located between the Guardafui Channel and the Arabian sea. Socotra is currently contested for sovereignty between the Yemen and Somalian governments. **Describe *orally* the key steps you would take in preparing for the research project. You are encouraged to think aloud, or document your thinking during the exercise.** Your answer should include considerations to:

- awareness of both governments
- sensitivity to the indigeneous communities
- survival (that is, food and shelter) on the island for a period of two weeks
- minimizing negative impact of the research on the ecosystem *and*
- effectively assessing the habits of at least two of the organisms"

18. Please share any other impacts this learning journey has had on you.

- [Follow-up]: Please share any other impacts this interview has had on you.

VITA AUCTORIS

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