The role and sequencing of academic emotions during mathematics problem solving among elementary students

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Abstract

Emotions are ubiquitous in academic settings. However, until recently, the role of emotions during learning has been overlooked in educational research. For decades, research calls have been made to examine the role of emotions in learning and to integrate theories of emotion into educational interventions. In this dissertation, I first conduct a literature review that examines relevant theoretical frameworks and methodologies. Limitations from previous research are identified and recommendations for advancing the field are offered. These recommendations include: (1) assessing the antecedents and consequences of emotions during learning, (2) identifying patterns of emotional state transitions, and, (3) determining how theories and methods from cognitive and emotional domains can be integrated into practice. Following this review, two empirical manuscripts are presented that address these issues and aim to extend the literature. The first empirical manuscript reports on two studies that explore the role and dynamics of emotions during mathematics problem solving among elementary students. Results demonstrated that emotions predicted cognitive and metacognitive learning strategies; patterns of emotional state transitions were observed; and confusion and frustration occurred most frequently during problem solving. The second empirical manuscript reports on the efficacy of a cognitive-emotional intervention I designed to help elementary students resolve confusion during mathematics problem solving through promoting self-regulated learning strategies. Results revealed that students who received the intervention had better achievement scores, used more learning strategies, and expressed less frustration and more positive emotions than students in the control condition. Theoretical and methodological contributions, educational implications, and future directions are discussed in each manuscript. I conclude the dissertation with a final discussion of the overall contributions of this research and future directions.

Résumé

Les émotions sont omniprésentes dans les milieux académiques. Cependant, jusqu'à récemment, le rôle des émotions au cours de l'apprentissage a été négligé dans la recherche en éducation. Pendant des décennies, des appels à la recherche ont été lancés pour examiner le rôle des émotions dans l'apprentissage et pour intégrer les théories de l'émotion aux interventions éducatives. Dans cette thèse, je mène d'abord une analyse de la littérature qui examine les structures théoriques et méthodologiques pertinentes. Des restrictions de recherches précédentes sont identifiées et des recommandations progressives sont proposées : (1) l'évaluation des antécédents et des conséquences des émotions au cours de l'apprentissage, (2) l'identification des transitions des états émotionnels et (3) la manière dont les théories et les méthodes des domaines cognitifs et émotionnels peuvent être intégrées à la pratique. Suite à cette analyse, deux manuscrits empiriques sont présentés et abordent ces questions et visent à approfondir la littérature. Le premier présente deux études explorant le rôle et la dynamique des émotions lors de la résolution de problèmes de mathématiques chez les élèves du primaire. Les résultats révélés que les émotions prédisaient des stratégies d'apprentissage cognitives et métacognitives ; des modèles de transitions d'état émotionnel ont été observés ; et confusion et frustration se sont produites le plus souvent. Le deuxième manuscrit présente l'efficacité d'une intervention que j'ai conçue pour aider les élèves du primaire à résoudre leur confusion au cours de la résolution de problèmes de mathématiques en promouvant des stratégies d'apprentissage. Les élèves qui ont reçu l'intervention avaient obtenu de meilleurs résultats, utilisaient plus de stratégies d'apprentissage et exprimaient moins de frustration et plus d'émotions positives que les élèves de la condition de contrôle. Les contributions théoriques et méthodologiques, les implications pédagogiques et les orientations futures sont discutées dans chaque manuscrit. Je termine par une dernière discussion sur les contributions globales de cette recherche et les orientations futures.

Dedication

I dedicate this dissertation to my parents. I am incredibly grateful for your unwavering support, encouragement, and endless love.

Acknowledgments

This acknowledgment section is presented at the beginning of this dissertation; however, it is the final piece I have written, which has afforded me the opportunity to reflect on my overall experience as a doctoral student. Such reflection has left me feeling emotional. Most saliently, I feel an immense sense of pride in all the work I have accomplished as well as in my perseverance, resilience, and dedication that has ultimately led to the completion of my dissertation. Most exceptionally though, I feel tremendously grateful to all those who have supported me throughout this process and who have contributed to my personal, academic, and professional growth and achievement.

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Preface and Contribution of Authors

I am the primary author on each manuscript and am responsible for their content. I wrote Chapters 1, 2, 3, and 4 independently and Dr. Krista R. Muis provided feedback. The first manuscript presented in this thesis (Chapter 2) was co-authored with Dr. Muis who provided input on various aspects of the research and will be described in detail below. I wrote the second empirical manuscript presented in this dissertation (Chapter 3) independently and Dr. Muis provided feedback. A modified version of this manuscript will be submitted to a peer-reviewed journal for publication, co-authored with Dr. Muis who provided feedback. The contributions made by myself, my co-authors, and colleagues are detailed below for both manuscripts. The conclusions drawn from these chapters are considered original and distinct contributions to knowledge.

Chapter 2

Citation

Di Leo, I., & Muis, K. R., Singh, C. A., & Psaradellis, C. (2019). Curiosity… Confusion? Frustration! The role and sequencing of academic emotions during complex problem solving. *Contemporary Educational Psychology, 58*, 121-137.

Contributions

The research design is based on Muis, Psaradellis, Lajoie, Di Leo, and Chevrier (2015). I was responsible for the conceptualization of research questions, developing the emotions coding scheme, coding the transcriptions, scoring the mathematics problem, conducting the data analysis, and writing the manuscript in its entirety. Dr. Muis provided feedback on full drafts. The third and fourth authors assisted with data collection, transcribing participants' audio recordings, scoring the mathematics problem, and achieving an acceptable inter-rater reliability.

Chapter 3

Contributions

I designed the intervention with guidance from Dr. Tina Montreuil and Dr. Krista R. Muis. I was responsible for the research design and conceptualization of research questions, transcribing the audio recordings, coding the transcripts, scoring the mathematics problems, conducting the data analysis, and writing the manuscript in its entirety. Dr. Muis provided feedback on full drafts. Cara Singh, Marianne Chevrier, Brendan Munzar, and Kelsey Losenno assisted with data collection. Cara Singh assisted with establishing an inter-rater reliability for the coding of transcripts and the mathematics problem scores.

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Chapter 1

Introduction

Introduction

Emotions are prominent in academic settings; students continuously experience them before, during, and after various academic tasks. Until recently, research on emotions in academic settings focused primarily on test anxiety (Zeidner, 1998), particularly with regard to mathematics learning and problem solving. Today, researchers agree that emotions play a critical role in students' learning, motivation, and academic achievement (Pekrun & Stephens, 2012). So, what exactly is an emotion? An emotion is a construct that falls under the umbrella term of affect, which broadly consists of moods, feelings, beliefs, attitudes, and emotions. Affect is commonly thought of as subjective experiential states that have either positive (pleasant) or negative (unpleasant) valence (Efklides, 2017; Forgas, 1994). Specifically, emotions are multi-componential and include "... sets of coordinated psychological processes including affective, cognitive, physiological, motivational, and expressive components" (Pekrun & Stephens, 2012, p. 4). Moreover, they are activated in response to an event that relates to one's goals or concerns (Pekrun, 2006). Feelings and moods have been considered as resulting from emotions (Forgas, 1994; Frijda, 1986).

However, Pekrun (2006) argued that emotions and moods should not be categorically distinct, but rather part of one multi-dimensional space of emotions that include dimensions of intensity (i.e., mild to intense), duration (i.e., momentary/brief to long-lasting), and object focus (i.e., no focus to clear object focus). Furthermore, emotions typically are organized into different categories along dimensions of valence (positive or negative) and activation (activating or deactivating arousal) (e.g., Feldman Barrett & Russell, 1998; Shuman & Scherer, 2014). Emotions can be further classified by whether they are positive activating (e.g., curiosity, hope, enjoyment, pride), positive deactivating (e.g., relief), negative activating (e.g., anxiety, confusion, frustration, anger, shame), or negative deactivating (e.g., boredom, hopelessness, sadness) (Linnenbrink, 2007; Pekrun, 2006). Emotions do not occur spontaneously; they are activated by an event, and subsequently can influence other processes such as motivation, cognition, and self-regulated learning. Indeed, emotions predict the cognitive and metacognitive processes used during learning and problem solving through perceptions of control (both action control and outcome control) and value for the learning task (Efklides, 2017; Pekrun, 2006). Given these relations, researchers acknowledge that emotions play an important role in self-regulated learning.

Self-Regulated Learning

Self-regulated learning occurs during a learning task and is goal-directed. It includes cognitive, metacognitive, motivational, and affective processes (Muis, Singh, & Chevrier, 2018; Pintrich, 2000; Zimmerman, 1990). Learners who are highly self-regulated have an awareness of the strategies that are involved in regulatory processes to attain optimal academic outcomes and are aware of when and how to implement these strategies to achieve their academic goals (Zimmerman, 1990). Following this, self-regulated learning is viewed as a self-directive process that involves a dynamic feedback loop (Butler & Winne, 1995; Carver & Scheier, 1981; Hattie & Timperley, 2007; Muis, 2007; Zimmerman, 1989, 2000). It functions in a cyclical way wherein students set goals and plans, and then receive feedback regarding the effectiveness of their learning methods or strategies via their own monitoring and evaluation of their progress or from another individual like a teacher. If goals are not being achieved, students then respond to this feedback in various ways including resetting goals and plans, shifting their perceptions of control and task value, and replacing a particular learning strategy with another (Muis, 2007; Zimmerman, 1989). Applying self-regulated learning assumes that a student takes responsibility for their learning and plays an active role through cognitive, metacognitive, behavioural, affective, and motivational processes (Zimmerman, 1986; 2001).

Boekaerts (1999) further delineated three areas that are regulated during learning: cognition, metacognition, and motivation/affect. Cognition relates to the cognitive strategies that are applied and implemented during a learning task, metacognition relates to the metacognitive strategies that control and regulate cognition, and finally, motivation/affect relates to a student's motivational beliefs (e.g., self-efficacy, beliefs, interests) and the emotional reactions to the task. Metacognitive processes are required for the regulation over one's learning (Brown, 1978; Brown & DeLoache, 1978; Flavell, 1992; Kluwe, 1987) and include planning and setting goals, organizing, self-monitoring, and self-evaluating. Metacognition also facilitates students' ability to be aware, knowledgeable, and deliberate of their learning methods and strategies (Corno, 1986, 1989; Ghatala, 1986; Pressley, Borkowski, & Schneider, 1987).

Numerous models have been developed to delineate how students engage in self-regulated learning. For example, Muis' (2007) model of self-regulated learning includes four phases of learning or problem solving, namely, task definition, planning and goal setting, enactment, and evaluation, and five areas for regulation including cognition, motivation, affect, behaviour, and context. In the first phase, students begin by defining the task, which is influenced by the five areas for regulation. Learning strategies that might be employed during the task definition phase include prior knowledge activation and identifying important information. For the second phase, learners may set goals and plans to establish what they will do to solve the problem, including selecting the appropriate learning strategies. The third phase, enactment, begins once learners implement the selected strategies to carry out the task. In the context of mathematics problem solving, the enactment phase may include hypothesizing, summarizing, help seeking, calculating/measuring, or re-reading (Muis, Psaradellis, Lajoie, Di Leo, & Chevrier, 2015). In the last phase, individuals may evaluate the successes or failures of each phase, and/or perceptions about themselves or the context. Critical to this phase is metacognitive monitoring and evaluation. Strategies implemented during this phase might include self-questioning, monitoring, judgments of learning, self-correcting, and evaluating (Muis et al., 2015). Muis (2007) further proposed that metacognitive processes can occur within all phases of self-regulated learning and can be ongoing throughout the learning and problem-solving process. The skills required for each phase, including metacognitive monitoring, are critical for successful mathematics problem solving (Bedard & Chi, 1992; Fuchs et al., 2006; Jacobse & Harskamp, 2012; Schoenfeld, 1994).

Mathematics Problem Solving

Understanding the role of emotions as well as cognitive processes is important when examining them in relation to problem solving. Mathematics problem solving is complex. Effectively solving mathematics problems involves various skills such as the ability to understand number sense, apply basic mathematics facts and mathematical reasoning, implement accurate and fluent calculations, activate relevant prior knowledge (Davidson & Sternberg, 1998; Montague, Warger, & Morgan, 2000), and engage in reading comprehension to understand the problem and its parameters (Fuentes, 1998; Vilenius-Tuohimaa, Aunola, & Nurmi, 2008). Moreover, because of the complexity of solving a mathematics problem, a student is required to engage in higher-order learning and reasoning, strategic approach, and decision making (Maccini & Ruhl, 2001). To engage in complex problem solving, a student must coordinate efforts from memory (Fuchs & Fuchs, 2002) and implement the appropriate operation and carry it out correctly (Huinker, 1989; Montague & Applegate, 1993), accurately read and comprehend the word problem, integrate the problem information, and develop a solution path (Montague et al., 2000). Thus, mathematics problem solving requires a student to acquire and implement a set of metacognitive abilities such as self-monitoring, evaluation, and self-awareness. As such, effective self-regulated learning is critical for successful mathematics problem solving.

More specifically, engagement in self-regulated learning is necessary to work through multiple steps of a mathematics problem, efficiently integrate the information presented, develop and plan a solution path, execute the solution (Montague et al., 2000), monitor and evaluate work (Cawley & Miller, 1986; Engelmann, Carnine, & Steely, 1991; Parmar, Cawley & Miller, 1994; Wilson & Sindelar, 1991), and recruit from their executive functions to organize, sustain and shift attention, inhibit distractions, utilize working memory, and maintain an appropriate level of motivation (Cragg & Gilmore, 2014). As such, self-regulated learning is central to mathematics problem solving and achievement (Jacobse & Harskamp, 2012; Schoenfeld, 1982). Indeed, early research on academic performance and achievement placed a heavy focus on cognitive processes, metacognition (e.g., Gaskins, 1994), and the use of learning strategies (e.g., Griffin, Case, & Siegler, 1994; Pressley, 1995). Therefore, cognitive processes have been a dominant area of empirical focus within educational research for decades (Winne, 2005) with little focus on the role that emotions play in learning and achievement (Pekrun, 2006).

Despite the prominence of emotions during problem solving, research on this topic was initially overlooked and understudied (Commission on Standards for School Mathematics, 1989; DeBellis & Goldin, 2006; Mandler, 1989; McLeod, 1992; National Council of Teachers of Mathematics, 2000; Norman, 1980; Rosiek, 2003). In fact, a cognitive theorist, George Mandler (1989) stated, “Affect is the least investigated aspect of human problem solving, yet it is probably the aspect most often mentioned as deserving further investigation.” (p. 3). During the

1980's and early 1990's, many researchers in the field of teaching and learning perceived emotions as fundamental to achievement and stressed the importance of empirically examining emotional issues in mathematics learning and problem solving (Dai & Sternberg, 2004; DeBellis & Goldin, 2006; McLeod, 1992; Silver, 1985). Ford (1992), another cognitive psychologist, whose research focused on motivation and emotions, articulated, ‘‘emotions are not simply motivational ‘‘add-ons’’ or ‘‘afterthoughts’’—… but that in fact may be every bit as influential as cognitive processes in terms of enduring motivational patterns’’ (p. 147).

In contrast to these beliefs and perspectives, some researchers did not consider affect or emotions to be part of students' experiences during mathematics. Specifically, findings from Goodlad's (1983) study conducted in over 1,000 classrooms led him to the conclusion that "affect - either positive or negative - was virtually absent. What we observed could only be described as neutral, or perhaps 'flat'" (p.467). Certainly, educational psychology has come a long way from this belief. However, this is a reminder that there once existed a great divide in research between cognition and emotion. Possible reasons for their absence in past empirical research may be due to the perception of emotion and cognition as opposing constructs and to the methodological limitations in measuring emotions.

Historically, emotion and cognition have been considered as separate and opposing constructs that compete for control over an individual's attention and action (Lazarus, 1991a, 1991b). Specifically, in cognitive psychology, emotion and cognition were considered as independent of one another, especially in the domain of mathematics learning (Goldin, 2014). Initial understanding was that emotions and cognitive processes were believed to be distinct, occur separately, and without influencing one another (Goldin, 2014). This train of thought was further compounded by the fact that mathematics problem solving was also considered to be cognitive and logical rather than emotional, and therefore cognitive and emotional processes were not seen as mutual occurrences (McLeod, 1992).

Additionally, the absence of cognitive-emotional theoretical frameworks within cognitive science and research on problem solving (Kulm, 1980; McLeod, 1988) contributed to difficulties in assessing academic emotions during learning tasks. The complexity and lack of shared language, definitions, and terminology of emotions in academic contexts created methodological challenges to study this construct (DeBellis & Goldin, 2006; Goldin, 2014; Gross & Thompson, 2007; McLeod, 1992). Furthermore, emotions are often rapidly changing, and can also be experienced in conscious, unconscious, or preconscious states (Damasio, 1994). Thus, students may be aware or equally unaware of their emotional states as they occur, making it especially difficult for researchers to accurately assess student emotions (DeBellis & Goldin, 2006). Today, methodological advances have been made due to an increase in the use of interdisciplinary methods to effectively study and detect emotions in learning contexts including physiological (e.g., galvanic skin response, heart rate), behavioural (e.g., body posture, facial expression), and online trace methodologies (e.g., think- and emote-aloud protocols, eye-tracking, facial expression) and with concurrent offline methodologies (e.g., self-report measures) to capture experiential activity that occurs during learning (see Harley, 2015).

Connections between Emotions and Cognitive Processes during Learning

The increase in cross-sectional research spurred the broadening of theoretical perspectives and frameworks, which ultimately led to the understanding that learning and problem solving also involves the experience of emotions. More recently, researchers in educational and cognitive psychology have made greater efforts to identify the relationship between emotions, cognitive processes, and problem solving (e.g., D'Mello & Graesser, 2012;

Pekrun, 2000, 2006). Today's integrative view recognizes the mutual contributions of emotions and cognitive processes in learning and achievement (Cole, Martin, Dennis, 2004; Damasio, 2004; Pekrun, 2006) and acknowledges that this integrative view is critical in the design of instruction and intervention (Calkins & Bell, 2010). As a result, there are multiple theoretical frameworks that conceptualize the role of emotions in learning and problem solving (see Hannula, Evans, Philippou, & Zan, 2004).

One prominent theoretical framework is Pekrun's (2006; Pekrun & Perry, 2014) control-value theory of achievement emotions. In this integrative framework, Pekrun (2006) proposed that perceptions of value and control serve as antecedents to the emotions that students experience in achievement situations (related to the task/activity and to retrospective and prospective outcomes). Perceptions of value refer to the importance that students place on the achievement-related task and outcome (e.g., the student's perceived importance of their success). Control refers to students' perception of controllability they have over the achievement-related task and outcome (e.g., belief that one has control over their studying and that their persistent studying leads to success) (Pekrun, 2006; Pekrun & Perry, 2014).

According to Pekrun (2006), perceptions of control and value interact to predict the kinds of achievement emotions students experience during learning. For instance, if a student perceives that learning mathematics is highly controllable and highly valuable, they are likely to experience positive emotions such as enjoyment or curiosity while engaging in mathematics-related tasks. Alternatively, if a student has perceptions of low control and low value on a cognitively demanding task, they might experience negative emotions such as boredom. If a student has perceptions of low control and high value, they might experience negative emotions such as anxiety, confusion, anger, hopelessness, or frustration.

Emotions subsequently predict the cognitive learning strategies (e.g., summarizing) and metacognitive learning strategies (e.g., monitoring, evaluation) that students use during a task (Pekrun, Frenzel, Goetz, & Perry, 2007). Strategies that are implemented can then hinder or facilitate learning outcomes (Baker, D'Mello, Rodrigo, & Graesser, 2010; D'Mello & Graesser, 2011; Pekrun, Goetz, Daniels, Stupinsky, & Perry, 2010). Although there are exceptions to the rule, theoretically, positive emotions, like enjoyment and curiosity, can facilitate learning through the use of flexible learning strategies like critical thinking, elaboration, self-questioning, or monitoring of one's progress (Muis et al., 2015; Pekrun, Elliot, & Maier, 2009). In contrast, negative emotions like boredom and frustration can hinder learning through a reduction in use of all strategies or an increase in more rigid processing strategies like maintenance rehearsal or re-reading (Muis et al., 2015; Op't Eynde, De Corte, & Verschaffel, 2007; Pekrun, Goetz, Titz, & Perry, 2002).

Empirical evidence supports these hypothesized relations (Muis et al., 2015; Pekrun & Stephens, 2012). Specifically, curiosity has been shown to positively predict cognitive and metacognitive learning strategies, whereas boredom negatively predicted cognitive and metacognitive learning strategies (Acee & Weinstein, 2010; Muis et al., 2015; Pekrun et al., 2010, 2011). Surprise is related to greater cognitive and metacognitive processes (D'Mello & Graesser, 2011, 2012; Foster & Keane, 2015) whereas anxiety and frustration have been related to shallow processing strategies (Pekrun et al., 2011). However, though not typically the case, anxiety and frustration have been shown to relate to deeper processing strategies when both extrinsic motivation and the avoidance of failure are high (see Pekrun & Stephens, 2012). Therefore, as Pekrun (2006) and D'Mello and Graesser (2011, 2012) argued, to understand how emotions predict cognitive and metacognitive learning strategies, it is important to take into consideration students' perceptions of control and value as these variables might interact to predict the types of emotions students experience that then can predict the cognitive and metacognitive learning strategies they implement.

Additionally, researchers are beginning to pay greater attention to the temporal and sequential nature of emotions as emotional processes are considered to be fluid rather than occurring in isolation and unrelated to other emotions (D'Mello & Graesser, 2012). This increase in attention on emotional dynamics has propelled researchers to investigate how emotions evolve and transition from one emotion to another (D'Mello & Graesser, 2012). However, this research has been conducted with university students or adult populations and, to our knowledge, no research on the dynamics of emotions has been conducted with younger students. To date, it is unknown whether elementary students' emotions during academic tasks transition in the same way as adult learners' emotions given that the executive functioning skills involved in emotion regulation and cognitive control develop and are refined as individuals age (Thompson, 1991; 1994). Moreover, adult students have had many more years of exposure to academic tasks and experience solving complex problems than younger elementary students. As such, adult students may have developed and honed strategies to overcome impasses and challenges that inevitably arise during problem solving.

Young students' self-regulatory processes–their ability to regulate their emotions and effectively implement, monitor, and evaluate their strategy use–are still developing. That is, young students' ability to manage certain emotions as they arise during learning tasks may differ from adult learners, which may result in emotional state transitions and trajectories that are specific to young students. Furthermore, younger learners might have more difficulty controlling and managing their negative emotions, thus leading to the continued experience of the same emotion or the transition to other negative emotions, which ultimately affect their learning outcomes. As such, it is imperative to explore the sequencing of emotions and cognitive and metacognitive learning strategies among children, particularly as they engage in tasks that can trigger intense emotions, like during complex mathematics problem solving (Muis et al., 2015).

D'Mello and Graesser (2012) proposed a model of affect dynamics to delineate when emotions arise during the enactment phase of learning. They argued that emotions are triggered by states of uncertainty that occur when an individual is confronted with obstacles to goals, impasses, contradictions, anomalous events, dissonance, incongruities, unexpected feedback, and novelty. These emotions are considered epistemic emotions (Muis et al., 2018; Pekrun & Stephens, 2012) given their focus on the cognitive qualities of information and processing of that information, and include emotions like surprise, curiosity, and confusion (Pekrun & Stephens, 2012). Muis et al. (2018) further proposed that when these emotions arise under conditions of uncertainty or cognitive disequilibrium, they predict the types of cognitive and metacognitive learning strategies that individuals use during learning. Specifically, under conditions of cognitive incongruity, surprise, curiosity, and confusion should lead to higher rates of cognitive and metacognitive strategies to resolve the incongruity and result in deeper learning. In contrast, other emotions such as anxiety, frustration and boredom may lead to a reduction in effortful strategies due to the cognitive resources being consumed by the negative activating emotions (see Pekrun et al., 2011; Pekrun & Stephens, 2012). When cognitive resources are consumed by negative emotions, this typically results in the use of cognitive and metacognitive learning strategies that require fewer cognitive resources, like memorization (Pekrun & Stephens, 2012).

Given the frequency with which cognitive incongruities are expected to occur during complex learning (D'Mello & Grasser, 2012), it stands to reason that younger students will also experience a high rate of cognitive incongruity during complex mathematics problem solving, which suggests that younger students are likely to experience a high rate of epistemic emotions. Moreover, emotional states that students experience may be more intense when the student is solving the problem for a longer period of time and especially if the student is an inexperienced problem solver (McLeod, 1988; Thompson, 1991; 1994). As such, many young students may have difficulty with complex mathematics problems as they grapple with their emotions during problem solving, which may predict struggles with implementing regulatory strategies that are critical to problem solving (Mayer & Hegarty, 1996; Zimmerman, 1990). Fortunately, interventions have been designed to help younger students develop the skills necessary to successfully engage in mathematics problem solving.

Intervention Research

To date, many mathematics interventions have been designed to promote self-regulated learning specifically for students with learning disabilities (Geary, 1994; Kroesbergen & Van Luit, 2003; Lerner, 2000). Cognitive strategy instruction is drawn from theories of metacognition and self-regulated learning (Montague & Dietz, 2009). Its purpose is to teach students multiple cognitive and metacognitive strategies to promote independent and self-regulated learning and improve performance in a specific domain, such as mathematics problem solving (MacArthur, 2012; Montague, 2008). According to Swanson (1999), strategy instruction can be characterized by systematic and direct explanations of a task; verbal modeling of the steps and processes of the cognitive routine by the instructor; systematic prompts of when to use the procedures, processes, or strategies; and cognitive modeling by the instructor through thinking aloud during problem solving to model task completion.

Cognitive control and the conscious reflection of one's cognitive processes are taught within cognitive strategy instruction. Metacognitive knowledge, i.e., being conscious of the tools one has, and when and how to implement them, is a large component of cognitive strategy instruction, and this can be extended to include emotional states through emotional awareness. Despite positive outcomes of various interventions, none have taken into consideration how emotions may play a role in the process. Indeed, interventions that focus on emotions have also minimized the role of self-regulated learning. As such, it may benefit students most to design an intervention that incorporates both emotions and self-regulated learning. Since emotions can occur subconsciously, it would be beneficial to teach students emotional awareness by having them stop and take a step back from the task and reflect on their emotional state, especially when they feel confused or have reached an impasse, tune in, and pay attention to the emotions they are experiencing. Students could then be taught to select the appropriate learning strategy and implement it to carry out the academic task. Emotional awareness can be developed by teaching students about the various emotions that can arise specifically during learning and problem solving, about the influence of those emotions on their learning, and how to identify and be aware of their emotional states. Explicitly and overtly teaching students about emotional states during problem solving tasks that draw from techniques of cognitive strategy instruction may result in the best learning outcomes for students.

Bridging the Gap from Theory to Practice

There is value to studying emotions and cognitive processes separately, to improve the understanding of how they develop, what their function is, and what their influence and implications are on learning and problem solving. It is also imperative to further establish the integrative view that acknowledges the dynamically linked relationship between emotions and cognitive processes and how they mutually influence each other during learning and problem solving. Moreover, this theoretical integration needs to extend into practice through educational interventions and instructional design. Schutz and Pekrun (2007) recommended the need for the development of interventions targeting emotions in educational contexts. As researchers move forward with integrating emotions into cognitive strategy instruction interventions, the use of evidence-based interventions can facilitate its implementation into classrooms thus bridging the gap between theory and practice. With methodological advances, integrative theoretical frameworks leading to a greater understanding of the link between emotions and cognition, now is the time to bridge the gap between theory and practice. This can be accomplished through providing teachers with evidence-based, structured and systematic programs and interventions that can be implemented into the curriculum and educational practice. Interventions should be designed with teachers in mind so that they can feasibly and effectively deliver such interventions. Accordingly, the purpose of this dissertation research is to address these gaps in the literature. Specifically, the goals of this research is to examine relations between emotions, cognitive and metacognitive learning strategies, and learning outcomes during complex mathematics problem solving with a sample of elementary school students. The final goal is to evaluate an intervention designed to help elementary students resolve confusion during mathematics problem solving through promoting emotional awareness and self-regulated learning strategies.

The Current Dissertation

In recent decades, there has been significant progress in the field of educational psychology regarding emotions in academic contexts. However, there remain unanswered questions with regard to emotions, especially pertaining to elementary students. Some of these questions include: What are the antecedents and consequences of emotions during complex mathematics problem solving among elementary students? Do patterns of emotional dynamics exist among elementary students and, if so, are the patterns similar to those found among adult learners? Is a cognitive-emotional strategy instruction effective for elementary students' mathematics problem solving abilities in terms of improving learning processes and learning outcomes?

The empirical manuscripts I present in this dissertation directly address these research questions. To develop an intervention that targets confusion, it is first necessary to better understand precisely when confusion arises and what subsequently occurs when young students experience confusion. Therefore, the following research questions were addressed in the first study (Chapter 2): (1) Do students' perceptions of task value and control interact to predict the emotions they experience during complex mathematics problem solving? (2) Do emotions predict planning, cognitive and metacognitive learning strategies during complex mathematics problem solving? (3) Do emotions mediate relations between task value and control and achievement? (4) Do cognitive and metacognitive learning strategies mediate relations between emotions and mathematics problem-solving achievement? (5) Are cognitive and metacognitive learning strategies predictors of mathematics problem-solving achievement?

The following research questions were addressed in the second research study (Chapter 2): (1) Which emotions do elementary students verbally express during complex mathematics problem solving and to what frequency? (2) Which emotion-to-emotion transitions exist during complex mathematics problem solving among elementary students? (3) Which emotion-to-learning strategy transitions exist during complex mathematics problem solving among elementary students? (4) Of the various transitions that occur, which ones have a probability that is higher than expected by chance?

Finally, the following research questions were addressed in the third research study (Chapter 3): (1) Do students who participate in an emotion-cognitive strategy instruction intervention (i.e., intervention condition) perform better on a mathematics problem solving task compared to students who receive no explicit training (i.e., control condition)? (2) Will students in the intervention condition use more cognitive and metacognitive strategies during mathematics problem solving compared to students in the control condition? (3) Will students in the intervention condition experience more positive emotions and fewer negative emotions compared to students in the control condition?

In addressing these research questions, this dissertation reveals relations between emotions and learning processes across the four phases of self-regulated learning (i.e., task definition, planning and goal setting, enactment, and evaluation), and the patterns of emotional dynamics during learning tasks. Moreover, I propose and evaluate an integrative emotion-cognition intervention within mathematics problem solving for elementary students. This work has implications for the design and implementation of classroom-based interventions and instructional practice.

Overview of the Chapters

Chapter 2 presents two empirical studies that examine how emotions relate to cognitive and metacognitive learning strategies and learning outcomes, and explores the patterns of state transitions that occur during complex mathematics problem solving in a classroom setting with elementary students. A think-aloud protocol was employed in both studies to capture students' emotions and cognitive processes as they occurred in real time.

Chapter 3 presents an empirical study that builds from findings from the two studies in Chapter 2. I developed an intervention for fifth-grade students using cognitive strategy instruction and modeling techniques to provide students with a repertoire of strategies that can be implemented to overcome confusion when it occurs during mathematics problem solving, which was delivered within a traditional classroom setting with students of varying ability. A think-emote-aloud protocol was employed to gather rich data on students' emotions and cognitive processes as they solved the mathematics problem.

Chapter 4 closes with the final discussion and overall conclusions of the empirical research presented in this dissertation. It includes contributions to the advancement of knowledge, limitations of the presented research, and future directions.

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Chapter 2: Manuscript 1

Curiosity… Confusion? Frustration! The role and sequencing of emotions during mathematics problem solving

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Abstract

The objectives of this research were to explore the role and transitions of emotions during complex mathematics problem solving over two studies. In Study 1, we examined the antecedents and consequences of emotions during learning with a sample of 138 students from grades 5 and 6. In Study 2, emotional state transitions were explored with a different sample of 79 students from grade 5. For Study 1, students self-reported their task value and perceptions of control for mathematics problem solving, solved the problem, and then self-reported their emotions and the cognitive and metacognitive learning strategies they used to solve the problem. Results from path analyses revealed that task value and control predicted students' emotions during problem solving, and that emotions predicted cognitive and metacognitive learning strategies, which subsequently predicted achievement. For Study 2, emotions and cognitive and metacognitive learning strategies were captured via a think-aloud protocol to explore their sequencing. Results demonstrated that the most frequently occurring emotions during problem solving included frustration (24.34%) and confusion (22.63%). Emotion-to-emotion transition analyses revealed that students' frustration transitioned to negative emotions. Confusion primarily transitioned to negative emotions (i.e., frustration, boredom, anxiety) but transitioned to positive emotions when confusion was resolved. We conclude with theoretical implications and delineate interventions that should be developed to teach students skills to overcome frustration and confusion to improve learning outcomes.

Keywords: achievement emotions; emotional state transitions; self-regulated learning; mathematics problem solving.

1. Introduction

Emotions are ubiquitous in academic settings; students experience emotions continuously throughout the day, and during various tasks and contexts. In the field of educational psychology, researchers have typically placed greater emphasis on the cognitive processes of learning and problem solving than on the emotional processes that also occur (Baker, D'Mello, Rodrigo, & Graesser, 2010; Calvo & D'Mello, 2011). However, a shift in focus has recently occurred towards investigating the role of emotions during learning as learning is increasingly recognized as an emotionally charged experience (e.g., Baker et al., 2010; Calvo & D'Mello, 2011; D'Mello & Graesser, 2012; Muis, Chevrier, & Singh, 2018). For example, anxiety might be experienced when students feel unprepared for an important presentation or exam, surprise when the answer to a mathematics problem is unexpected, curiosity about why an answer was incorrect, confusion when there is an aspect of a problem that is not understood, or frustration if the confusion cannot be resolved. The recent surge of interest in understanding the role of emotions in learning processes and learning outcomes has led to empirical evidence that demonstrates that emotions are fundamental and influential in students' learning, motivation, self-regulated learning, and academic achievement (Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011; Pekrun & Linnenbrink-Garcia, 2014; Pekrun & Stephens, 2012).

For instance, emotions predict the types of cognitive (e.g., self-questioning, summarizing) and metacognitive (e.g., monitoring, evaluation) learning strategies students select during a task (Pekrun, Frenzel, Goetz, & Perry, 2007), which can hinder or facilitate learning (Baker et al., 2010; D'Mello & Graesser, 2011; Pekrun, Goetz, Daniels, Stupinsky, & Perry, 2010). Positive emotions, like enjoyment and curiosity, can facilitate learning (Muis, Psaradellis, Lajoie, Di Leo, & Chevrier, 2015; Pekrun, Elliot, & Maier, 2009) whereas negative emotions, like boredom and frustration, can hinder learning (Pekrun et al., 2011). These relations are said to occur through self-regulatory processes including motivation and cognitive and metacognitive learning strategies (Muis et al., 2015; Op't Eynde, De Corte, & Verschaffel, 2007; Pekrun, Goetz, Titz, & Perry, 2002).

Additionally, researchers are beginning to pay greater attention to the temporal and sequential nature of emotions, as emotional processes are considered to be fluid rather than occurring in isolation and unrelated to other emotions (D'Mello & Graesser, 2012). This increase in attention on emotional dynamics has propelled researchers to investigate how emotions evolve and transition from one emotion to another and from one emotion to a learning strategy during learning and problem solving (Harley, 2015). However, this research has been conducted with university students or adult populations and, to our knowledge, no research on the dynamics of emotions has been conducted with younger students. To date, it is unknown whether elementary students' emotions during academic tasks transition in the same way as adult learners' emotions given that the executive functioning skills involved in emotion regulation and cognitive control develop and are refined as individuals age (Thompson, 1991; 1994).

Younger students' self-regulatory processes–their ability to regulate their emotions and effectively implement, monitor, and evaluate their strategy use–are still developing. That is, young students' ability to manage certain emotions as they arise during learning tasks may differ from adult learners, which may result in emotional state transitions and trajectories that are specific to young students. Furthermore, younger learners might have more difficulty controlling and managing their negative emotions, thus leading to the continued experience of the same emotion or the transition to other negative emotions, which ultimately affects their learning outcomes. As such, it is imperative to explore the sequencing of emotions and cognitive and metacognitive learning strategies among children, particularly as they engage in tasks that can trigger intense emotions, like during complex mathematics problem solving (Muis et al., 2015).

As previous research has shown, complex mathematics problem solving presents an emotionally laden and strategically challenging activity for younger students as they often struggle with it emotionally and strategically (Muis et al., 2015). To understand the sequential nature of emotions and cognitive and metacognitive learning strategies with younger students is therefore of critical importance; better understanding of relations can be used to inform interventions designed to foster improved learning outcomes. In particular, as Muis et al. (2015) found, confusion is problematic for this population given that they may not have the required skills to resolve confusion. They posited that younger students might lack the awareness of what to do in a state of confusion. That is, they might not have yet acquired the appropriate strategies or might not know which strategies to implement while in a state of confusion. In comparison, adults have had many years of education and thus experience in engaging in complex problem solving and, over the years, might have learned how to effectively resolve confusion by implementing appropriate cognitive and metacognitive learning strategies. Therefore, young students might benefit from the explicit instruction of how to reason and problem solve and apply appropriate learning strategies (Kuhn, 2009; MacArthur, 2012).

To develop interventions that target this issue, it is first necessary to better understand precisely when confusion arises and what subsequently occurs when young students experience confusion. Therefore, to address this gap in the literature we conducted two studies to first examine how emotions relate to cognitive and metacognitive learning strategies and learning outcomes and second, to explore the patterns of state transitions that occur during complex mathematics problem solving in a classroom setting with elementary students. Prior to delineating our specific research questions and hypotheses, we first define emotions and then present a prominent theoretical framework to situate this research. Relevant empirical work is then reviewed.

1.1 Academic emotions

Emotions are multifaceted as they include cognitive, affective, physiological, motivational, and expressive components (Scherer, 2000). To illustrate, when students experience anxiety about a mathematics exam, they might worry about their performance (cognitive), experience nervousness (affective), have a stomach ache (physiological), want to avoid the situation (motivational), and have a worried facial expression (expressive) (Pekrun & Stephens, 2012). Moreover, emotions can be categorized by their valence and activation. These two dimensions group emotional states in terms of the degree of positive or negative valence (e.g., pleasant or unpleasant) and in terms of activating or deactivating arousal (e.g., Feldman Barrett, & Russell, 1998; Shuman & Scherer, 2014). As such, emotions can be placed into four broad categories: 1) positive activating (e.g., curiosity, hope, enjoyment, pride), 2) positive deactivating (e.g., relief), 3) negative activating (e.g., anxiety, confusion, frustration, anger, shame), and 4) negative deactivating (e.g., boredom, hopelessness, sadness) (Linnenbrink, 2007; Pekrun, 2006). Surprise, which is elicited in response to unexpected events during a learning task, is a neutral activating emotion as it can have positive or negative arousal depending on the context (Muis et al., 2018; Mauss & Robinson, 2009).

Researchers have also conceptualized emotions in terms of their object focus, which determines whether an emotion relates to an academic task at hand or to an extenuating circumstance (Pekrun, 2006; Pekrun & Linnenbrink-Garcia, 2014). Two categories of emotions that fall under the broader umbrella of academic emotions include *achievement* emotions and *epistemic* emotions (Pekrun & Stephens, 2010). *Achievement* emotions are emotions related to learning activities such as problem solving and test-taking (e.g., anxiety, frustration, hope) or related to learning outcomes such as success or failure (e.g., pride, shame, relief). *Epistemic* emotions arise specifically from appraisals about whether incoming information conflicts or is consistent with prior knowledge, existing beliefs, or recently processed information (D'Mello & Graesser, 2012; Muis et al., 2018). Typical examples of epistemic emotions include surprise, which can occur when a student encounters unexpected information, curiosity with regard to wanting to learn more about something, or confusion when a student encounters cognitive incongruity or an impasse (D'Mello & Graesser, 2012). These emotions are therefore triggered by cognitive incongruity and novelty.

1.2 Control-Value Theory of Achievement Emotions

Given the function that emotions play in educational contexts, numerous theoretical frameworks have been developed to delineate their antecedents and consequences. One prominent theoretical framework is Pekrun's (2006; Pekrun & Perry, 2014) control-value theory of achievement emotions. In this integrative framework, Pekrun (2006) proposed that perceptions of value and control serve as antecedents to the emotions that students experience in achievement situations (related to the task/activity and to retrospective and prospective outcomes). Perceptions of value refer to the importance that students place on the achievement-related task and outcome (e.g., the student's perceived importance of their success). Control refers to students' perception of controllability they have over the achievement-related task and outcome (e.g., belief that one has control over their studying and that their persistent studying leads to success) (Pekrun, 2006; Pekrun & Perry, 2014).

According to Pekrun (2006), perceptions of control and value interact to predict the kinds of achievement emotions students experience during learning. For instance, if a student perceives that learning mathematics is highly controllable and highly valuable, they are likely to experience positive emotions such as enjoyment or curiosity while engaging in mathematics-related tasks. Alternatively, if a student has perceptions of low control and low value on a cognitively demanding task, they might experience negative emotions such as boredom. If a student has perceptions of low control and high value, they might experience negative emotions such as anxiety, confusion, anger, hopelessness, or frustration.

1.3 Epistemic Emotions

Recently, educational psychologists have begun to explore the role that epistemic emotions play in learning processes and learning outcomes (see Muis et al., 2018). D'Mello and Graesser (2012) proposed a model of affect dynamics to delineate when such emotions arise during the enactment phase of learning. They argued that these epistemic emotions are triggered by states of uncertainty that occur when an individual is confronted with obstacles to goals, impasses, contradictions, anomalous events, dissonance, incongruities, unexpected feedback, and novelty. Muis et al. (2018) further proposed that when these emotions do arise, they predict the types of cognitive and metacognitive learning strategies that individuals use during learning. Specifically, under conditions of cognitive incongruity, surprise, curiosity, and confusion should lead to higher rates of cognitive and metacognitive strategies to resolve the incongruity and result in deeper learning. In contrast, other emotions such as anxiety, frustration and boredom may lead to a reduction in effortful strategies due to the cognitive resources being consumed by the negative activating emotions (see Pekrun et al., 2011; Pekrun & Stephens, 2012). When cognitive resources are consumed by negative emotions, this typically results in the use of cognitive and metacognitive learning strategies that require fewer cognitive resources, like memorization (Pekrun & Stephens, 2012).

Empirical evidence supports these hypothesized relations (Muis et al, 2015; Pekrun & Stephens, 2012). Specifically, curiosity has been shown to positively predict cognitive and metacognitive learning strategies, whereas boredom negatively predicted cognitive and metacognitive learning strategies (Acee & Weinstein, 2010; Muis et al., 2015; Pekrun et al., 2010, 2011). Surprise is related to greater cognitive and metacognitive processes (D'Mello & Graesser, 2011, 2012; Foster & Keane, 2015) whereas anxiety and frustration have been related to shallow processing strategies (Pekrun et al., 2011). However, though not typically the case, anxiety and frustration have been shown to relate to deeper processing strategies when both extrinsic motivation and the avoidance of failure is high (see Pekrun & Stephens, 2012). Therefore, as Pekrun (2006) and D'Mello and Graesser (2011, 2012) argued, to understand how emotions predict cognitive and metacognitive learning strategies, it is important to take into consideration students' perceptions of control and value as these variables might interact to predict the types of emotions students experience that then can predict the cognitive and metacognitive learning strategies they implement.

To date, the majority of research in educational psychology that has examined relations between emotions and learning processes and learning outcomes has been primarily conducted with adult populations. Those that have been conducted with elementary students in the mathematics context have focused on the antecedents of emotions (Frenzel, Pekrun, & Goetz, 2007a, 2007b), or growth in mathematics achievement over time as a function of motivation, cognitive strategies, and intelligence (Murayama, Pekrun, Lichtenfeld, & vom Hole, 2013). To our knowledge, only one study has examined the antecedents and consequences of epistemic emotions during complex learning with elementary students (Muis et al., 2015). Muis et al. (2015) investigated whether fifth-grade students' perceptions of task value and control served as antecedents to the epistemic emotions experienced while solving a complex mathematics problem. Findings demonstrated that students who reported higher levels of control reported less confusion and anxiety. In addition, high levels of positive task value were related to more curiosity and enjoyment, and less confusion, frustration, boredom, and anxiety. Path analyses further revealed that epistemic emotions predicted cognitive and metacognitive learning strategies. Specifically, curiosity positively predicted metacognitive learning strategies, whereas surprise negatively predicted metacognitive learning strategies, boredom negatively predicted deep processing cognitive and metacognitive learning strategies, and anxiety positively predicted shallow cognitive and metacognitive learning strategies. Moreover, frustration positively predicted shallow cognitive learning strategies. Finally, confusion negatively predicted shallow and deep cognitive learning strategies.

Of particular concern, the results pertaining to confusion were inconsistent with previous research conducted with adult populations (Craig, Graesser, Sullins, & Gholson, 2004; D'Mello & Graesser, 2011; D'Mello, Lehman, Pekrun, & Graesser, 2014; Graesser, Chipman, King, McDaniel, & D'Mello, 2007). Contrary to the findings that Muis et al. (2015) observed among elementary students, research with adults demonstrated that confusion can facilitate learning when the confusion can be appropriately regulated and resolved through cognitive and metacognitive learning strategies (Craig, et al., 2004; D'Mello & Graesser, 2011; Graesser et al., 2007; Pekrun & Stephens, 2012).

To understand how confusion can be beneficial for learning, D'Mello and Graesser (2012) developed a model to delineate the dynamic nature of epistemic emotions during complex learning. Specifically, they predicted that a learner who is in the state of engagement/flow (i.e., a cognitive-affective state of positive valence and moderate level of arousal whereby a learner experiences a high state of engagement in the learning task) will experience confusion when faced with cognitive incongruities, contradictions, or an impasse. Once the cognitive incongruity has been resolved by engaging in cognitive and metacognitive learning strategies, the learner will then return to a state of engagement/flow. However, if the learner is unable to resolve confusion, this will transition into frustration. With persistent failure in overcoming the impasse, the learner's frustration will eventually transition to boredom, at which point the learner will likely disengage from the task.

Results from D'Mello and Graesser's (2012) study with university students supported their hypotheses. These findings confirm that confusion can be productive when resolved, which then leads to deeper learning of the material. When learners' confusion is resolved through implementing cognitive and metacognitive learning strategies, their emotional state transitions to engagement/flow. However, contrary to productive confusion, hopeless confusion can occur when the impasse cannot be overcome, which then leads to frustration and boredom. These results warrant further investigation into the sequencing of emotions and cognitive and metacognitive learning strategies to better understand their dynamic relationship in younger students.

In terms of emotional state transitions, important observations have been made for surprise. When surprise is experienced, it does not persist for long periods of time compared to other emotions (Baker, Rodrigo, & Xolocotzin, 2007), indicating that surprise is temporary and may transition to another emotion quickly. Additionally, the intensity of surprise that students' experience predicts subsequent cognitive and metacognitive learning strategies, whereby greater perceptions of surprise predict greater cognitive effort to explain the surprising event (Foster & Keane, 2015). In contrast, low perceptions of surprise result in no change in course of action (Muis et al., 2018). Moreover, surprise may transition to curiosity or confusion, depending on perceptions of the level of effort required to account for the surprise (Silvia, 2010).

Taken together, research suggests that multiple emotions dynamically transition into other emotions or cognitive and metacognitive learning strategies. To better understand the role of emotions during complex learning, it is critical to fully explore the sequencing of emotions and cognitive and metacognitive learning strategies as they dynamically occur in real time. Although previous research has examined emotional state transitions with older adult students, it is not clear whether similar patterns would arise with younger elementary students. Results from such work may help to inform the development of interventions designed to foster better learning processes and learning outcomes.

The current research fills these gaps in the literature. Across two studies, we examined relations between epistemic emotions, cognitive and metacognitive learning strategies and achievement outcomes during complex mathematics problem solving with samples of elementary students. In the first study, we replicated Muis et al.'s (2015) study by exploring whether task value and control interact to predict the epistemic and activity emotions that students experience while solving a complex mathematics problem, and whether emotions subsequently predicted the cognitive and metacognitive learning strategies students reported using during problem solving. We were particularly interested in whether relations between confusion and learning strategies could be replicated with a new sample of elementary students. We also examined whether cognitive and metacognitive learning strategies mediated relations between emotions and mathematics problem solving achievement. To broaden generalizability, students were sampled from grades 5 and 6 and a different but equally complex problem was used.

For the second study, we investigated the dynamic sequencing of emotions and learning strategies during complex mathematics problem solving with a sample of students from grade 5. Students were given a complex mathematics problem and, to capture their emotions and cognitive and metacognitive learning strategies as they occurred in real time, students were asked to think out loud as they solved the problem. Study 2 extends previous literature by evaluating whether D'Mello and Graesser's (2012) model of affect dynamics applies to elementary students as they solved a complex problem in an authentic classroom context.

2. Study 1

The aim of Study 1 was to assess the antecedents and consequences of emotions among elementary students during complex mathematics problem solving. The following research questions were addressed: (1) Do students' perceptions of task value and control interact to predict the emotions they experience during complex mathematics problem solving? (2) Do emotions predict planning, cognitive and metacognitive learning strategies during complex mathematics problem solving? (3) Do emotions mediate relations between task value x control and achievement? (4) Do cognitive and metacognitive learning strategies mediate relations between emotions and mathematics problem-solving achievement? (5) Are cognitive and metacognitive learning strategies predictors of mathematics problem-solving achievement?

Following Pekrun's control value theory of achievement emotions (Pekrun, 2006; Pekrun & Perry, 2014) and results from Muis et al.'s (2015) study, we hypothesized the following: (1) task value and control will interact to predict students' emotions. Specifically, perceptions of high value and high control will predict greater levels of self-reported enjoyment and curiosity, and lower levels of self-reported confusion, anxiety, frustration, and boredom. Perceptions of high value but low control will predict higher levels of anxiety and frustration, and perceptions of low value and low control will predict boredom. (2) Self-reported emotions will predict the cognitive and metacognitive learning strategies that students reported using during problem solving. Specifically, following Muis et al.'s (2015) study, we focused on three macro-level (see Greene & Azevedo, 2009) learning strategies including planning (e.g., planning and goal setting), cognitive learning strategies (e.g., hypothesizing, re-reading, highlighting/labelling, coordinating informational sources, summarizing), and metacognitive learning strategies (e.g., self-correcting, monitoring understanding). We hypothesized that surprise will positively predict cognitive and metacognitive learning strategies; enjoyment and curiosity will positively predict planning, and cognitive and metacognitive learning strategies; frustration and anxiety will positively predict cognitive learning strategies and negatively predict metacognitive learning strategies; confusion will positively predict metacognitive learning strategies and negatively predict cognitive learning strategies; and that boredom will negatively predict planning, cognitive learning strategies and metacognitive learning strategies. (3) Emotions will mediate relations between task value x control and planning and cognitive and metacognitive learning strategies. (4) Planning, cognitive and metacognitive learning strategies will mediate the relationship between emotions and mathematics achievement. Finally, we hypothesized that (5) cognitive and metacognitive learning strategies will predict mathematics achievement. Figure 1 illustrates the hypothesized model.

3. Methodology

3.1 Participants

One hundred thirty-eight elementary students from grade 5 (*n* = 110, 54 female) and grade 6 (*n* = 28, 15 female) participated. Students were sampled from seven classrooms across three elementary schools from two school boards. Students' socio-economic status ranged from low to middle-high for each of the schools, and students' mathematics achievement ranged from low (i.e., standardized provincial exam grade of 20%) to high (i.e., standardized provincial exam grade of 100%), with an average standardized provincial grade of 69.87% (*SD* = 19.38). The mean age of the sample was 11 years (*SD* = 0.69).

3.2 Materials

3.2.1 Demographics. Demographic information was collected from the parental consent form including student's date of birth, sex, and primary and secondary languages.

3.2.2 Prior Knowledge. To assess students' prior knowledge, their standardized achievement score on their most recent compulsory provincial exam was obtained one week prior to the beginning of the research study. The standardized exam included multiple-choice questions that assessed students' knowledge of mathematics content learned over the school year, several application problems that took students approximately 40-60 minutes to solve, and one situational problem, which took students several hours to complete over several days. Given that teachers provided us with students' exam score, we were not able to calculate reliability.

3.2.3 Academic Control Scale. To measure perceived control for learning mathematics and for mathematics problem solving, participants completed the Academic Control Scale (Perry, Hladkyi, Pekrun, & Pelletier, 2001), which was previously modified and validated for use with elementary students (see Muis et al., 2015). The original version of this scale (Perry et al., 2001) has eight items and was developed for undergraduate/adult populations. The modified version of this scale also has eight items but some words were changed to be more appropriate for elementary students. Item scales also included specific reference to mathematics. For example, item 2 of the original scale is “The more effort I put into my courses, the better I do in them”, which was modified to “The more effort I put into learning math, the better I do.” Participants completed this scale one week prior to beginning the mathematics problem and rated how much they agreed to each item on a Likert scale ranging from “Strongly disagree” (a rating of 1) to “Strongly agree” (a rating of 5). Higher values represent higher perceptions of control. Cronbach’s alpha reliability estimate was .71.

3.2.4 Task Value. The Task Value Measure (Muis et al., 2015; Eccles, Wigfield, Harold, & Blumenfeld, 1993; Pekrun & Meier, 2011) was administered one week prior to students solving the problem to measure their perceptions of value for mathematics problem solving. This scale assesses three dimension of task value: intrinsic interest value (e.g., “In general, I find learning about math very interesting”), importance (e.g., “Learning more about math is very important”), and utility value (e.g., “In general, learning about math is useful”). Participants rated seven items on a 5-point Likert-scale ranging from “Not at all true of me” (a rating of 1) to “Very true of me” (a rating of 5). Similar to Muis et al. (2015), confirmatory factor analyses revealed that a one-factor solution fit better than a three-factor solution (RMSEA = .06, CFI = .96 for a one-factor solution; RMSEA = .10, CFI = .90 for a three-factor solution). Cronbach’s alpha reliability estimate was .84.

3.2.5 Epistemic and activity emotions. The Epistemically-Related Emotions Scales (EES; Pekrun, Vogl, Muis, & Sinatra [2017], adapted for elementary students [Muis et al., 2015]) measured students’ epistemic and activity emotions experienced during mathematics problem solving. It was adapted for elementary students by simplifying the words used for some of the emotion adjectives. This single-adjective self-report questionnaire has 21 items that assesses three epistemic emotions (three items for each emotion) and four activity emotions (three items for each emotion) including surprise (i.e., “shocked,” “amazed”), curiosity (i.e., “curious,” “interested”), enjoyment (i.e., “joyful,” “excited”), confusion (i.e., “confused,” “puzzled”), frustration (i.e., “frustrated,” “irritated”), anxiety (i.e., “anxious,” “nervous”) and boredom (i.e., “bored,” “dull”). Each item is made up of a single word describing a single emotion (e.g., confusion). Students completed the scale after each day of problem solving and were instructed to rate how strongly they felt each emotion during the mathematics problem solving session, on a 5-point Likert-scale ranging from “Not at All” to “Very Strong.” The average scores of items belonging to each emotion subscale were calculated for each day of data collection. Given that there were no differences in emotions across days, one average was calculated for each emotion across all days and Cronbach’s alpha reliability estimates were calculated across all days. Reliabilities were as follows: surprise, $\alpha = .78$; curiosity, $\alpha = .78$; enjoyment, $\alpha = .81$; confusion, $\alpha = .88$; anxiety, $\alpha = .87$; frustration, $\alpha = .77$; and boredom, $\alpha = .87$.

3.2.6 Learning strategies. The Learning Strategies Scale for Mathematics (LSSM; based on work from Muis et al., 2015) measured self-reported learning strategies that students engaged in while solving the mathematics problem. This 13-item scale assesses cognitive learning strategies (five items: Re-reading, Highlighting/Labelling, Calculating, Coordinating informational resources, and Help-seeking.; e.g., help-seeking: “When I got stuck or didn’t know what to do next, I asked someone for help”), metacognitive learning strategies (five items: Monitoring, Judgment of learning, Self-correcting, Control, and Evaluation; e.g., monitoring: “I checked my calculations to make sure they were correct”), and planning and goal setting (three items, Making/restating a plan, Setting/restating a goal; e.g., making a plan: “I planned how to solve the math problem before I began solving it"). Students were given this instrument after each day of problem solving and were instructed to report the strategies they used while solving the problem. Students rated the frequency using a 5-point Likert-scale ranging from "Not at all" to "A lot." No differences across days were found on frequency of self-reported strategies and, as such, were averaged across the three days of problem solving. Cronbach's alpha reliability estimates were calculated across all days: 78 for planning and goal setting, .86 for cognitive strategies, and .81 for metacognitive strategies.

To further assess the validity of the factor structure, we conducted a confirmatory factor analysis to assess the fit of a one-factor model (i.e., all items loading onto one factor), a two-factor model (i.e., all cognitive and metacognitive items loading onto one factor), and a three-factor model (i.e., one factor for cognitive strategies, one for metacognitive strategies, and one for planning and goal setting). Results from the CFA revealed that the three-factor model was the best fit: $^2 = 106.96$, $df = 61$, $p = .0003$. CFI = .94 and RMSEA = .07, which is interpreted as a good fit (Tabachnick & Fidell, 2013). The other two models resulted in a poor fit (Model 1: $^2 = 161.42$, $df = 65$, $p < .001$. CFI = .79 and RMSEA = .10; Model 2: $^2 = 108.05$, $df = 63$, $p < .001$. CFI = .87 and RMSEA = .10.

3.2.7 Situational mathematics problem. The situational problem was drawn from the compulsory Quebec Exam in Mathematics, *The Amazing Race (*Ministère de l'Education, du Loisir et du Sport, 2008). The objective of this exam is for students to solve a situational problem that meets the following criteria: 1) the procedure that is required to solve the situational problem is not obvious as it involves choosing previously acquired mathematical concepts and processes and applying them in a new way to solve the problem; 2) the situation focuses on obstacles to overcome, which requires various learning strategies; and 3) the instructions do not suggest a procedure to be followed or concepts and processes to use (Ministère de l'Education, du Loisir et du Sport, 2008). To successfully complete this problem, students had to plan an air-travel itinerary with the following guidelines and limitations; 1) Start and return the trip in Ottawa, Canada; 2) Select at least five cities as destinations on a map of the world; 3) The total distance travelled for the overall trip must be between 35,000 km and 50,000 km; 4) The total cost of the trip (including cost of flights and meals) cannot exceed $10,000; and 5) The pilot cannot fly more than 8 consecutive hours. Students were required to measure distances between cities on their map with a ruler, convert centimeters to kilometers, determine the furthest distance the pilot could fly based on the speed with which the plane travels, calculate the cost of each flight based on distance, the cost of meals per city visited, and then calculate the total cost and total distance of the trip.

3.3 Procedure

Parental consent, student assent and demographic information were collected prior to the mathematics problem session. Participants individually completed the Task Value and Academic Control questionnaires one week prior to solving the mathematics problem. All instructions and items of each self-report questionnaire were read out loud to the students in a group setting, and students were monitored as they filled in their responses. The primary investigator then provided instructions to the participants including the importance of working alone but that students could ask for help from any one of the researchers at any time. Students were spread out within the classrooms to ensure they could not see each other's work. Following this, all students worked individually on the mathematics problem in their classroom during regular class time. Students engaged in problem solving sessions between one to three hours per day over the course of five consecutive school days (75% of students completed the problem within three days[1]). The EES and the LSSM scales were administered immediately following each mathematics problem solving session until the mathematics problem was solved. The primary investigator explained to students how to respond to each item on the questionnaires and provided definitions of the various emotions that students might have experienced. To ensure that students understood the qualifying words on the emotions scale, students were asked to verbally give examples of the various emotions on the scale, and each item on the questionnaire was read out loud while the students rated their emotions and responded to all questionnaires individually. Once all students completed the problem, each student received a $15 iTunes gift card for participating.

3.4 Scoring of Mathematics Achievement

The total score on the complex mathematics problem was used as the overall measure of mathematics achievement. A grading rubric was developed to score each student's achievement on the mathematics problem. Participants earned points for successfully completing elements and partial points were given if elements were partially missing or if calculations were partially incorrect. Zero points were given if an element was completely missing or if calculations were completely incorrect. The total number of possible points to attain was 33. The problem was categorized into three main sections with multiple elements and specific values allotted to each section. The major sections were the following: (1) Cost of Flights, which included measuring the distance in centimeters, calculating the distance from centimeters to kilometers, and calculating the cost of the flight (total 17 points); (2) Final Itinerary, which included cost of meals for the day and total cost of meals and flight per destination (total 11 points); (3) Followed

[1] Given that there were no differences in emotions or learning strategies over time, or when comparing three to five days for those who took longer than three days, we used only the first three days of self-reported data to maximize the sample size

rules and guidelines (total 5 points). The first and fourth author together coded 10 of the mathematics problems to establish consistency in use of the rubric. Agreement was 98% and inconsistencies were discussed and agreed upon for a new agreement of 100%. The two coders then coded 10 additional mathematics problems independently to establish inter-rater agreement. Agreement was 100%. The first and fourth authors then each scored 54 mathematics problems.

4. Results

4.1 Preliminary Analyses

Skewness and kurtosis values were examined for normality for all variables. All variables were within the acceptable range for skewness and kurtosis (using Tabachnick & Fidell, 2013 criteria of $<|3|$). Collinearity diagnostics were conducted to ensure no multicollinearity issues. To ensure level of specificity was equivalent across all variables and over time, students' self-reported emotions and learning strategies were used and averaged across the three days of mathematics problem solving. Means and standard deviations of all emotions and learning strategies averaged across the three days are presented in Table 1, and the zero-order correlations are presented in Table 2.

Differences across schools on each of the variables were also examined and intraclass correlation coefficients (ICC) were calculated to examine whether nested analyses were necessary. No differences were found on any of the variables (all $p > .05$) and all ICCs ranged between .06 and .23, with all but two ICCs being less than .10. Given no differences between schools on the variables of interest and low ICCs, the three schools were combined into one overall sample.

4.2 Moderated Mediation Path Analysis

To test the hypothesized moderated mediation model presented in Figure 1, Hayes and Preacher's (2014) PROCESS macro, a path analytic modeling add-on for SPSS that employs bootstrap sampling[2] was used. This is the recommended method to analyze complex models with smaller sample sizes as it retains power while controlling for Type 1 errors (see Preacher & Hayes, 2008). Moreover, given that a x b distributions typically are not normal, bootstrap sampling was the most appropriate approach given that it has no underlying distributional assumptions (Hayes, 2013). For the analyses, prior knowledge was included as a covariate. Figure 2 displays the final moderated mediation path model. To reduce complexity in the figure, prior knowledge is linked only to achievement, but was a covariate for all variables.

For the first research question, "Do students' perceptions of task value and control interact to predict the emotions they experience during complex mathematics problem solving?", results revealed a significant total effects model F (1, 132) = 7.71, $p < .05$. For the direct effects of task value on emotions, results revealed that task value positively predicted curiosity ($\beta = .35$, p < .001) and enjoyment ($\beta = .22$, $p = .01$), and negatively predicted boredom ($\beta = -.29$, p < .001). For the direct effects of control on emotions, results revealed that control negatively predicted surprise ($\beta = -.18$, p =.03), confusion ($\beta = -.18$, p < .04), frustration ($\beta = -.18$, p = .04), anxiety ($\beta = -.18$, p = .04), and boredom ($\beta = -.30$, p < .001). Finally, the interaction between task value and control negatively predicted confusion ($\beta = -.32$, $p = .009$), frustration ($\beta = -.58$, $p = .002$), anxiety ($\beta = -.50$, $p = .007$), and boredom ($\beta = -.39$, $p = .03$).

For the second research question, "Do emotions predict planning, cognitive and metacognitive learning strategies during complex mathematics problem solving?", results revealed that curiosity positively predicted planning ($\beta =.31$, $p = .006$), cognitive ($\beta =.40$, $p =$

[2] This add-on is not a model-fitting program and, as such, fit indices cannot be reported.

.001), and metacognitive ($\beta = .56$, $p < .001$) learning strategies; confusion negatively predicted planning ($\beta = -.24$, $p < .001$) and cognitive learning strategies ($\beta = -.24$, $p < .001$) and positively predicted metacognitive learning strategies ($\beta = .27$, $p = .04$); frustration negatively predicted planning ($\beta = -.26$, $p < .001$) and cognitive learning strategies ($\beta = -.25$, $p < .001$); and boredom negative predicted planning ($\beta = -.20$, $p = .01$), cognitive learning strategies ($\beta = -.27$, $p < .001$) and metacognitive learning strategies ($\beta = -.28$, $p < .001$).

For the third research question, "Do emotions mediate relations between control and value and planning, cognitive and metacognitive learning strategies?", results demonstrated that curiosity mediated relations between value and planning (*indirect effect* = .10, *SE* = .05, *Bootstrap CI* = .03 to .18) and cognitive learning strategies (*indirect effect* = .15, *SE* = .06, *Bootstrap CI* = .06 to .26). Boredom also mediated relations between value and planning (*indirect effect* = .06, *SE* = .03, *Bootstrap CI* = .01 to .12) and metacognitive learning strategies (*indirect effect* = .07, *SE* = .05, *Bootstrap CI* = .01 to .16). Results further revealed that confusion mediated relations between control and planning (*indirect effect* = .04, *SE* = .03, *Bootstrap CI* = .01 to .11) as did boredom (*indirect effect* = .06, *SE* = .04, *Bootstrap CI* = .01 to .12), and that boredom mediated relations between control and metacognitive learning strategies (*indirect effect* = .9, *SE* = .05, *Bootstrap CI* = .02 to .18). Finally, for the interaction between task value and control, results revealed that boredom mediated relations between task value x control and planning (*indirect effect* = .04, *SE* = .03, *Bootstrap CI* = .01 to .09) and metacognitive learning strategies (*indirect effect* = .15, *SE* = .03, *Bootstrap CI* = .01 to .11). No other mediations were found.

For the fourth research question, "Do cognitive and metacognitive learning strategies mediate relations between emotions and achievement?", results revealed a significant total effects model, $F = 20.48$, $df = 132$, $p < .01$. First, for direct effects of emotions on achievement, only curiosity (β =.18, $p = .03$), confusion (β = -.17, $p = .03$), and boredom (β = -.19, $p = .03$) were significant predictors. Second, cognitive learning strategies mediated the relationship between confusion and mathematics achievement (*indirect effect* = -.04, *SE* = .03, *Bootstrap CI* = -.001 to -.09) and between curiosity and mathematics achievement (*indirect effect = .04*, *SE* = .01, *Bootstrap CI* = .03 to .09). Furthermore, the relationship between boredom and mathematics achievement was mediated by cognitive learning strategies (*indirect effect = -.05*, *SE* = .02, *Bootstrap CI* = -.11 to -.01) and by metacognitive learning strategies (*indirect effect = -.05*, *SE* = .04, *Bootstrap CI* = -.08 to -.001) but not for frustration (effects *ns*). Finally, for the last research question, "Are cognitive and metacognitive learning strategies predictors of mathematics problem-solving achievement?", our hypotheses were supported. Planning was not a predictor of mathematics achievement (ns). However, cognitive and metacognitive learning strategies each positively predicted mathematics achievement (β = .56 and β = .58, respectively).

4.3 Brief Discussion of Study 1

Overall, findings from Study 1 are in line with the majority of our hypotheses (i.e., 25 of 33 predictors) that positive task value and control interact to predict the emotions that learners experience during complex mathematics problem solving. Moreover, these emotions mediated relations between positive task value, control and the interaction between positive task value x control and planning, cognitive and metacognitive learning strategies. Additionally, cognitive and metacognitive learning strategies mediated relations between emotions and achievement. Furthermore, our results are generally consistent with Muis et al.'s (2015) findings. Interestingly, although Muis et al.'s (2015) work did not find support for the interaction of the antecedents in predicting emotions, our results provide evidence for the interactive nature of control and value in Pekrun's (2006) control-value theory of achievement emotions. We briefly discuss the theoretical significance of each of the relations found.

4.3.1 Antecedents. Positive task value and control were important antecedents to students' epistemic and activity emotions. More specifically, higher levels of positive task value positively predicted enjoyment and curiosity, and negatively predicted boredom. Higher levels of academic control negatively predicted surprise, confusion, frustration, anxiety, and boredom. Finally, the interaction of task value and academic control negatively predicted confusion, frustration, anxiety, and boredom, and did not positively predict any emotions. Taken together, results from the current study provide strong support for Pekrun's (2006) control-value theory of achievement emotions whereby appraisals of task value and control interact to predict the type of emotions students experience during a learning task. This demonstrates the importance of students' perceptions of the control they have regarding completing a learning task and whether that task is meaningful to them. Greater perceived control and positive task value predict more positive academic emotions and fewer negative academic emotions (Pekrun, 2006).

4.3.2 Mediations. Pekrun's (2006) framework also implies that the links between emotions and their motivational antecedents and cognitive and metacognitive consequences are mediated. This was supported in the current study whereby boredom and curiosity mediated relations between value and planning; confusion mediated relations between control and planning, cognitive and metacognitive learning strategies; frustration mediated relations between control and planning and cognitive learning strategies, and boredom mediated relations between control and planning, cognitive and metacognitive learning strategies. Finally, confusion and boredom each mediated relations between the interaction of task value and control and planning, cognitive and metacognitive learning strategies, and frustration mediated relations between the interaction of task value and control and planning, and cognitive learning strategies. Additionally, results from our study demonstrate that boredom mediated relations between cognitive and metacognitive learning strategies and mathematics achievement, and that cognitive learning strategies also mediated relations between both confusion and mathematics achievement and curiosity and mathematics achievement. In Muis et al.'s (2015) study, mediated relations between emotions, learning strategies, and achievement were also found for confusion and curiosity, but not for boredom. Differences in patterns of relations may be due to the different type of problem chosen, or differences in populations given that the current study sampled from grade 5 and grade 6. As such, more work is necessary to fully chart relations between emotions, their antecedents and consequences.

4.3.3 Consequences. Our second research question focused on whether emotions predicted planning, cognitive and metacognitive learning strategies during complex problem solving. Consistent with Muis et al.'s (2015), results revealed that emotions significantly predicted planning, and cognitive and metacognitive learning strategies. Specifically, curiosity positively predicted planning, cognitive and metacognitive learning strategies; confusion negatively predicted planning and cognitive learning strategies but positively predicted metacognitive strategies; frustration negatively predicted planning and cognitive learning strategies; and boredom negatively predicted planning, cognitive and metacognitive learning strategies.

Theoretically, confusion should predict higher levels of metacognitive learning strategies to resolve the confusion. Our results supported this prediction. However, confusion was also partly problematic for learning, as it predicted a decrease in planning and cognitive learning strategies. As such, although confusion can be beneficial for adults during learning if properly resolved (D'Mello et al., 2014), our research suggests that confusion may have mixed benefits for elementary students. It may be the case that the cognitive load is too high for students when attempting to resolve confusion via metacognitive learning strategies and, as such, they reduce planning and cognitive learning strategies to compensate.

Overall, these results demonstrate that emotions predict the planning, cognitive and metacognitive learning strategies elementary students implement during problem solving. Specifically, consistent with previous research (Azevedo & Chauncey Strain, 2011; Murayama et al., 2013; Pekrun et al., 2010, 2011), positive emotions, specifically curiosity, predicted greater use of cognitive and metacognitive strategies, whereas negative emotions, specifically frustration and boredom, predicted a decrease in all processing strategies. Also consistent with previous research (Muis et al., 2015; D'Mello et al., 2014), cognitive and metacognitive learning strategies were positive predictors of achievement.

4.4 Bridge to Study 2

During complex problem-solving tasks when there are numerous opportunities for a student to encounter an impasse, negative emotions such as confusion and frustration caused by incongruities are expected and can be experienced at a high frequency. As such, the educational implications to intervene are great. As a student, knowing which learning strategies to engage in to overcome an impasse is important to move on with the task and persevere. Moreover, exploring the dynamics of emotions during problem solving among young students can provided in-depth understanding of the consequences of emotions as they transition from one to another and from one emotion to a subsequent learning strategy.

Ample research evidence suggests that levels of motivation and perceived control to complete a task predict positive or negative emotions experienced during a task. There is also evidence that emotions predict learning strategies and achievement (see Pekrun & Stephens, 2012). However, less is known regarding the trajectory of emotions as they evolve into a subsequent emotion and transition to a learning strategy, and whether the patterns among elementary students are similar to those found with adults during complex problem solving. It is crucial to understand how emotions transition to other emotions or to learning strategies to gain insight on the cognitive, metacognitive and affective processes that occur during a problem-solving task. If dynamic affective patterns exist whereby negative emotions further transition to subsequent negative emotions or lead to a reduction of learning strategies altogether, it would be beneficial to use this information to develop interventions targeting such negative emotions to optimize student success. Thus, our second study addresses whether there are patterns of emotional state transitions that occur during complex mathematics problem solving among elementary students.

5. Study 2

We used a think-aloud protocol to examine how emotions transition to other emotions or learning strategies. Given that emotions and cognitive processes are fluid, the aim of this study was to explore the sequencing of emotions as they occur dynamically during mathematics problem solving among elementary students. To date, empirical work exploring relations between emotions, learning strategies, and achievement has relied primarily on self-report instruments or have assessed these relations with high school or university student populations. Given that elementary students might not possess the same skills as adults, it is critical to determine the sequencing of emotions and learning strategies as they occur in real time in a classroom setting.

More importantly, our conceptualization of the role of emotions during learning is that emotions are not static; they transition to other emotions, which further predict learning strategies and learning outcomes. As D'Mello et al. (2014) found with adults, confusion can be beneficial for learning if regulated and resolved. However, in Muis et al.'s (2015) and the present study, confusion was a negative predictor of planning and cognitive learning strategies, but it is unclear whether confusion led to a reduction in strategy use, or if it transitioned to another emotion that led to this reduction. Moreover, it is unclear whether elementary students benefited from confusion if they were able to resolve it via metacognitive learning strategies as we found in Study 1. To fully understand the role that epistemic and activity emotions play in complex learning and problem solving with elementary students, it is critical to measure these emotions and learning strategies as they dynamically occur. Assessing moment-to-moment states of student emotions has significant value for understanding emotional processes in educational contexts. Study 2 addresses this gap in the literature.

Accordingly, the following research questions were addressed: (1) Which emotions do elementary students verbally express during complex mathematics problem solving and to what frequency? (2) Which emotion-to-emotion transitions exist during complex mathematics problem solving among elementary students? (3) Which emotion-to-learning strategy transitions exist during complex mathematics problem solving among elementary students? (4) Of the various transitions that occur, which ones have a probability that is higher than expected by chance?

6. Methodology

6.1 Participants

Seventy-nine students from the fifth grade (*n* = 34 females) from two rural schools across four classrooms participated[3]. All students were from the same school board. There were 41 students (*n* = 20 females) who participated from one school, and 38 students (*n* = 14 females) who participated from the second school. The mean age of the sample was 11 years (*SD* = 0.31). Participant assent and parent consent was received from 95% of all students from both schools who were invited to participate. Only those who received permission participated.

6.2 Materials

All Study 2 materials were the same as Study 1 with the exception of the mathematics problem administered and the addition of a think-aloud protocol.

6.2.1 Emotions and self-regulatory processes. To capture students' emotions and self-regulatory processes as they read and solved the complex mathematics problem, a Type 1 think-aloud protocol was used, i.e., thinking out loud while completing a task (see Ericsson and Simon [1998]). Students wore Apple Ear Pods connected to digital recording devices to capture their voices. Students were instructed to say out loud whatever came to their mind and were trained to think aloud prior to the problem-solving session.

6.2.2 Situational mathematics problem. The situational problem was drawn from the 2009 compulsory Quebec Exam in Mathematics, *Start Your Engines!* (Ministère de L'Education, du Loisir et du Sport, 2009). Students were required to read the problem, then solve the problem and show all their steps and decisions made. To successfully complete this problem, students were required to: create a seven-sided polygon for the racetrack design that ranges in length between 4.5km and 5km; include at least one acute angle, one obtuse angle, and one angle greater than 180 degrees; create spectator areas with 15 squares per section to seat 120,000

[3] Data were drawn from Muis et al.'s (2015) study. In the original study, emotions were not coded in the think-alouds and sequencing of emotions and learning strategies was not assessed.

spectators; draw a starting line frieze pattern that is one-third white, reflected twice, and calculate the cost of the paint for the starting line given indications of the price per unit.

6.3 Procedure

The procedure for this study was identical to the procedure of Study 1 except for the added think-aloud protocol. Parental consent and student assent were obtained to participate in the study as well as to be audio-recorded during mathematics problem solving. Demographic information and baseline data regarding task value and academic control for mathematics was collected in the identical manner as in Study 1. Students were first trained to think out loud one day prior to being given the mathematics problem. The second author trained students using a script to make sure all students received identical training. Thinking out loud was described as *"say everything that you are thinking and doing out loud."* Students then listened to an audio file that first modeled what not to do during a think-aloud, and then modeled how to appropriately think out loud that included spontaneous thoughts and the steps taken to solve a math problem. Finally, students practiced thinking out loud for approximately 15 minutes while solving the following short mathematics problem, "Kim can walk three kilometers in one hour. How far can she walk in two and a half hours?"

The following day during regular class time, students were given the complex mathematics problem to solve. Students were instructed to treat the problem as if it were an exam, that they must work individually and not interact with each other, and were not allowed to copy each other's work during problem solving. Given that there were 20-25 students per classroom, barriers were placed between students to reduce the noise level and to prevent cheating. Moreover, the decibel level in the room was loud enough that students could not clearly hear one another. Students then worked on the problem over three to four consecutive days for approximately 1.5 to 2 hours each day (the majority of students completed the problem in 3.5 hours). To verify that all students were thinking out loud while problem solving, five trained research assistants and the second author prompted students to continue to think out loud if they were silent for more than five seconds. Once students complete the problem and submitted their work to the research team, they each received a $15 iTunes gift card for participating.

6.4 Coding and Scoring of Think-Aloud Protocols

Student think-alouds ranged from 90 minutes to 4.5 hours and were transcribed verbatim, which resulted in 1086 single-spaced pages of text (29,078 lines). The transcriptions were segmented and coded first for micro-level planning, cognitive and metacognitive learning strategies (i.e., specific types of strategies that fall under these broader macro-level categories [Greene & Azevedo, 2009]; see Table 3) and later coded for academic emotions. Specifically, 19 learning strategies were coded: prior knowledge activation, identifying important information, making/restating a plan, setting/restating a goal, hypothesizing, summarizing, help-seeking, coordinating informational sources, highlighting/coloring/drawing, calculating/measuring, re-reading, making inferences, self-questioning, monitoring, judgment of learning, self-correcting, evaluation, control, and task difficulty. Some examples of strategies included the following: Making a plan, "So now, I'm going to draw it on paper and see if it is between 4.5 and 5km"; and Monitoring, "I'm not sure there is a reflex angle in my drawing. Let me check."

The emotions coding scheme (see Table 4) was developed using the control-value theory of achievement emotions (Pekrun, 2006; Pekrun et al., 2007; Pekrun et al., 2011) and using D'Mello and Graesser (2011, 2012) definitions of emotions. To code each segment for emotions, we considered the context in which the emotion was expressed including the sentence uttered before and after the emotion. Overall, 13 emotions were identified (i.e., surprise, curiosity, enjoyment, pride, hope, relief, confusion, frustration, boredom, anxiety, hopelessness, shame, and anger). The following are some examples: surprise, “Woah! That is a lot more than I thought”; curiosity, “…for math, I’m really, really curious”; confusion, “I am getting mixed up”; frustration, “Ugh, this is so annoying!!”; pride, “I did it! Yes! I rock!” Based on the codes developed by the first and second author, the first author coded two transcripts to further refine the coding scheme. The first and second authors worked together to modify and establish the coding scheme. The first author and a trained graduate student (the third author) then worked together to code and recode 10% of the transcripts until an acceptable level of inter-rater reliability was achieved. At the end of this process, inter-rater agreement was 81%. The first and third authors then coded five more transcripts to ensure consistent inter-rater reliability and established inter-rater agreement at 91%. Disagreements were resolved through discussion. As such, 16% of the transcripts were coded to establish inter-rater reliability (at 25% of the length of the transcriptions). The first author then coded the remaining transcriptions.

7. Results

To explore the dynamic relationship that exists between emotions and learning strategies during mathematics problem solving, we analyzed emotion-to-emotion transitions and emotion-to-learning strategy transitions using two-way Chi-square analyses. Chi square analyses examine relations among categorical variables and whether observed frequencies are significantly different than the expected frequencies within a distribution. This type of analysis allowed us to investigate whether a certain emotion could be expected to follow another emotion (e.g., confusion then frustration) more often than statistically expected and whether this pattern of emotion-to-emotion transition could be expected to occur more often than statistically expected. If the observed frequencies are different than the expected frequencies, the value of χ^2 is large and the null hypothesis is rejected (Tabachnick & Fidell, 2013). In the case of the current study, certain expected emotion-to-emotion transitions were observed to occur frequently, such as confusion to frustration and frustration to confusion. As such, the Chi square test was used to assess how likely an observed emotion-to-emotion transition or an emotion-to-learning strategy transition was due to chance.

7.1 Expressed emotions and learning strategies

To address the first research question that was concerned with which emotions were experienced during mathematics problem solving, we examined the think-aloud protocols for emotions that were verbally expressed. Overall, there were 760 instances of expressed emotions and 15,544 learning strategies throughout the sample. Across 760 instances of expressed emotions, the most frequently expressed emotions included frustration (n = 185, 24.34%) and confusion (n = 172, 22.63%). The next most frequently expressed emotions were pride (n = 77, 10.13%), surprise (n = 74, 9.73%), and enjoyment (n = 73, 9.60%) (see Table 5 for the overall frequency of each emotion). Across 15,544 instances of learning strategies, the most frequently expressed learning strategies included planning (n = 3154, 20.29%), highlighting, labelling, colouring, drawing (HLCD) (n = 2188, 14.08%), monitoring (n = 2126, 13.68%), calculating (n = 1924, 12.38%), and evaluating (n = 1039, 6.68%) (see Table 6 for the overall frequency of each self-regulatory learning strategy).

7.2 Emotion-to-emotion and emotion-to-learning strategy transitions

To address the second research question, which concerned how emotions transitioned from one emotion to another emotion or to a learning strategy, we analyzed the transitions between emotional states using Chi-square tests. The Chi-square tests allowed us to determine which emotions and learning strategies were most likely to occur following an experienced emotion. The frequency of emotions expressed in the overall sample was first determined. Following this, the frequency of two-state emotional transitions, that is, the number of times an emotion at time t is followed by another emotion or by a learning strategy at time $t + 1$, was also assessed. With these frequencies, multiple 2 x 2 contingency tables were created to test for statistical differences between the observed frequency of a state immediately following an emotion with the expected frequency of that follow-up state, considering its frequency in the overall sample. Of note, we compared the frequency of expected transitions to the probability of occurrence by chance and not to the frequency of non-occurrence of these transitions. Due to the number of analyses that were made, Type I errors were controlled for by setting alpha to .01. Only statistically significant findings are presented below. The emotional state transitions are presented first by emotion-to-emotion transitions then emotion-to-learning strategy transitions by each emotion in the order of more frequently expressed emotion within the sample (see Table 7 for the frequency of all emotion-to-emotion transitions).

7.2.1 Surprise. The emotions that followed surprise more often than statistically expected were: confusion ($\chi^2(1) = 40.67$, $p < .001$), curiosity ($\chi^2(1) = 23.43$, $p < .001$), and frustration ($\chi^2(1) = 15.69$, $p < .001$). Examples of these sequences include: “Wait, I’m not sure this is 10cm. Woah! It is! [surprise], so I wonder if I could do it like this… [curiosity];” “3 plus 9, 14, 17, 19, 21, woah! What?! [surprise]. I’m completely confused [confusion].” No learning strategies followed surprise significantly more often than statistically expected.

7.2.2 Enjoyment. The emotions that followed enjoyment more often than statistically expected were: pride ($\chi^2(1) = 47.21$, $p < .001$) and relief ($\chi^2(1) = 12.52$, $p < .001$). Monitoring was the only learning strategy that followed enjoyment more often than statistically expected (χ^2 (1) = 4.36, $p = .03$). Examples of these sequences included: “Yes! Oh, I am happy [enjoyment]! Yes! I got it! I rock! [pride]" and, "Acute means cute and little. That's what my teacher says (laughing). I like this. [enjoyment]. Okay. 1200 meters, 1,2,3,4,5,6,7. 1,2,3,4,5,6,7. Thank God! Oh my gosh, that was close [relief]."

7.2.3 Pride. The emotions that followed pride more often than statistically expected were: enjoyment ($\chi^2(1) = 71.51$, $p < .001$) and relief ($\chi^2(1) = 12.19$, $p < .001$). The learning strategies that followed pride more often than statistically expected were: planning ($\chi^2(1) = 8.97$, $p = .002$) and evaluating ($\chi^2(1) = 4.54$, $p =.03$). Examples of these sequences included the following: "Yes! Okay so I'm finally done! I'm a genius [pride]. I'm happy [enjoyment];" "So I'm finished! Oh yeah! I did it! [pride]. So, I'm gonna check to see what I have to mark [planning]."

7.2.4 Hope. Of all the emotions and learning strategies, only evaluation followed hope more often than statistically expected ($\chi^2(1) = 13.36$, $p < .001$). An example of this sequence includes: "Hopefully I'm gonna get a good mark [hope]. Okay, so I'm done my first rectangle [evaluation]." No learning strategies followed hope more often than statistically expected.

7.2.5 Relief. Pride was the only emotion that followed relief more often than statistically expected ($\chi^2(1) = 126.47$, $p < .001$). An example of this sequence includes the following: "Thank God, I finished everything [relief]. Yes! I did it! [pride]." No learning strategies followed relief more often than statistically expected.

7.2.6 Curiosity. The emotions that followed curiosity more often than statistically expected were: anxiety ($\chi^2(1) = 6.11$, $p = .01$) and hope ($\chi^2(1) = 3.28$, $p = .06$). Examples of these sequences include: "I wonder if it's even [curiosity]. I hope so because it does take a while to do [hope]." No learning strategies followed curiosity significantly more often than statistically expected.

7.2.7 Confusion. Emotion-to-emotion transition analyses revealed that the emotions that followed confusion more often than statistically expected were: frustration ($\chi^2(1) = 44.35$, $p < .001$), boredom ($\chi^2(1) = 22.71$, $p < .001$), curiosity ($\chi^2(1) = 12.72$, $p < .001$), and anxiety ($\chi^2(1) = 12.16$, $p < .001$). Examples of these sequences included: "So confusing. [confusion]. I can't even think of a pattern. I wonder if I could like… 1, 2, 3, 4, 5 [curiosity]." "This doesn't make any sense. What? [confusion]. Ugh. Oh my God, I want to cry [frustration]." The learning strategies that followed confusion more often than statistically expected were: help-seeking for information ($\chi^2(1) = 158.35$, $p <.001$), identifying important information ($\chi^2(1) = 20.36$, $p <.001$), monitoring ($\chi^2(1) = 6.08$, $p = .01$), and planning ($\chi^2(1) = 3.75$, $p = .05$). An example of these sequences includes: "My brain hurts, I don't know what to do. I'm stuck in my head [confusion]. Uh I have a question, what do I write here? [Help-seeking for information]."

7.2.8 Anxiety. The emotions that followed anxiety more often than statistically expected were: frustration ($\chi^2(1) = 25.81$, $p < .001$), shame ($\chi^2(1) = 16.74$, $p < .001$), and hopelessness ($\chi^2(1) = 7.89$, $p = .005$). An example includes: "Oh my gosh I'm gonna get such a bad mark [anxiety]. I feel so, so bad, I'm sure I'm gonna fail [hopelessness]." No learning strategies followed anxiety more often than statistically expected.

7.2.9 Frustration. Emotion-to-emotion transition analyses revealed that the emotions that followed frustration more often than statistically expected were: anger ($\chi^2(1) = 75.54$, $p < .0001$), hopelessness ($\chi^2(1) = 10.67$, $p = .001$), and confusion ($\chi^2(1) = 3.25$, $p = .07$). Examples of these sequences included: "Ugh, this is taking forever! [frustration]. Like I said before, I'm confused [confusion]", and "This is so annoying [frustration]… I feel like giving up! [hopelessness]." Emotion-to-learning strategy transition analyses revealed that control ($\chi^2(1) = 42.61$, $p < .001$), help-seeking for information ($\chi^2(1) = 19.01$, $p < .001$), and planning ($\chi^2(1) =$

9.12, $p = .003$) each followed frustration more often than statistically expected. An example includes “I’m frustrated and I really don’t want to get yelled at. [frustration]. [Student to helper:] What do I do? Do I do the race track? [help-seeking for information].”

7.2.10 Boredom. No emotions or learning strategies followed boredom significantly more often than statistically expected.

7.2.11 Hopelessness. The emotions that followed hopelessness more often than statistically expected were: boredom ($\chi^2(1) = 14.73$, $p < .001$) and frustration ($\chi^2(1) = 12.43$, $p < .001$). Examples of these sequences included “I feel like giving up so bad [hopelessness]… So bored. Ugh... My God! [boredom].” No learning strategies followed hopelessness more often than statistically expected.

7.2.12 Shame. Hopelessness followed shame more often than statistically expected ($\chi^2(1) = 47.90$, $p < .001$), and control followed shame more often than statistically expected ($\chi^2(1) = 18.03$, $p < .001$).

7.2.13 Anger. No emotions or learning strategies followed anger more often than statistically expected.

7.3 Discussion of Study 2

The purpose of Study 2 was to explore the sequential dynamics of emotions. Specifically, we investigated transitions of emotions to subsequent emotions and to learning strategies and identified whether patterns of transitions existed. With regard to the first research question, the list of emotions that were expressed is impressive and consistent with previous work (see Pekrun, 2006). A second notable finding was that the emotions that were expressed most frequently throughout the mathematics problem-solving task was frustration (24.34%) and confusion (22.63%), which is also consistent with previous research (D’Mello & Graesser, 2012). This suggests that during mathematics problem solving, negative emotions that are considered to be detrimental to learning outcomes are the emotions that occurred the most frequently among our sample of young students.

The next most frequently expressed emotions were pride (10.13%), surprise (9.73%), and enjoyment (9.60%). Although we were pleased to find that boredom was expressed only 2.5% of the time, curiosity, a positive activating emotion that drives deeper engagement in problem solving, was also expressed very infrequently and accounted for 2.3% of all emotions expressed. While this finding was not so surprising, it is concerning that the high frequency of confusion during complex problem solving (when the likeliness of experiencing cognitive incongruities is high) is not matched with a comparable high frequency of curiosity needed to resolve the incongruity.

With regard to the second research question, patterns of emotional state transitions were observed exhibiting that emotions do evolve into secondary emotions. The majority of our results related to emotion-to-emotion transitions provide support for D'Mello and Graesser's (2012) model of affect dynamics with adults. Importantly, the patterns of results that they found with adult learners were replicated with younger students. Specifically, consistent with the patterns they found with adults, we found that frustration transitioned to hopelessness as well as to confusion; and confusion transitioned to frustration, boredom, and curiosity.

Furthermore, we find it particularly noteworthy that following surprise, elementary students experienced curiosity or confusion more often than other emotions. These results provide support for Muis et al.'s (2018) theoretical model and Silvia's (2010) empirical work with regard to the nature of surprise. As Silvia (2010) proposed, once surprise is experienced, one of two emotions is likely to occur next–curiosity following an appraisal that the surprising event can be readily resolved, or confusion following an appraisal that the surprising event may be particularly difficult to resolve. Although Silvia's studies were conducted with adults, it may be the case that younger students make similar kinds of appraisals when cognitive incongruity triggers surprise. Moreover, results from our study revealed that it may even be the case that learners can experience both curiosity and confusion following surprise if a learning strategy implemented to resolve the discrepancy fails (as noted in the example provided above). What was unexpected to us, however, was that surprise also transitioned to frustration. To interpret this, we argue that during mathematics problem solving, when surprise is experienced repeatedly due to incongruities (which was the case in our sample as it was the fourth most frequently experienced emotion) and those incongruities are difficult to resolve, students' surprise may turn into frustration.

Additionally, in contrast to D'Mello and Graesser's (2012) model where frustration transitioned to boredom, frustration in our sample did not transition to boredom significantly more than expected. It is possible that boredom is an emotion that when experienced, might not be always explicitly vocalized and therefore may not be objectively captured by researchers. This could explain why boredom only accounted for a small percentage of all emotions expressed among our sample and perhaps why we did not observe frustration transitioning to boredom. However, we also captured students' self-reports of the emotions they experienced during problem solving, and the average for boredom was considered low ($M = 1.95$, $SD = .84$). As such, it may also be the case that students did not experience much boredom during complex problem solving, perhaps because the mathematics problem selected was at an optimal level of challenge for most students and did not illicit the boredom that occurs when students feel under- or over-challenged (Pekrun & Stephens, 2012).

Another interesting finding that pertained to boredom was that it represented a momentary disengagement in problem solving as no emotions or learning strategies immediately followed this emotion. This adds to the evidence that boredom is a deactivating emotion (Fisher, 1993; see also Goetz & Frenzel, 2006). While the long-term consequences of boredom in academic settings have led to dropout (Bearden, Spencer, & Moracco, 1989; Tidwell, 1988) and truancy (Sommer, 1985), the immediate consequences of boredom are also negative as it affects students' perseverance towards completing the task at hand (see Pekrun, et al., 2010). Our finding provides evidence that boredom, even in children, leads to a standstill during problem solving. Thus, boredom remains a concern in achievement settings and warrants more empirical investigation.

Another unexpected finding was that curiosity transitioned to anxiety. Curiosity is a positive emotion, which has been observed to predict other positive emotions and lead to deeper learning strategy use. However, it is possible that with elementary students, curiosity might in fact behave similarly to confusion if the student does not know what steps to take next once this emotion arises. When this occurs, it is likely that anxiety might subsequently arise, especially if the student perceived the task as being meaningful. Alternatively, it may be the case that curiosity quickly turned to confusion if followed by surprise. As Silvia (2010) explained, curiosity follows surprise when the amount of effort to resolve the incongruity is deemed not too high or if one perceives their ability as sufficient. However, confusion follows surprise when the amount of effort to resolve the incongruity is deemed to be high or beyond one's ability. Perhaps students in our sample experienced curiosity following surprise, which then quickly transition to confusion and then anxiety. Given that we did not explicitly ask students to emote out loud (see

D'Mello & Graesser, 2012), some emotions and emotional state transitions such as this one may have been missed.

Interestingly, the emotions that followed anxiety were frustration, shame, and hopelessness. Depending on the levels of anxiety, it may be another emotion that is either productive or detrimental to learning. However, in our sample, students' anxiety only transitioned to negative emotions, suggesting that young students may not know how to interpret or cope with the anxiety they experience during problem solving.

Finally, with regard to our last research question, patterns of emotion-to-learning strategy transitions were observed that were in line with, but also counter to previous research (Muis et al., 2015) and findings from Study 1. Consistent with previous research, results from sequential analyses revealed that enjoyment positively predicts use of metacognitive strategies. That is, after experiencing enjoyment, students more often engaged in monitoring of their progress than any other strategy. However, in contrast to previous research, both confusion and frustration resulted in students asking for help, monitoring or controlling their progress or understanding, and making plans to continue to solve the problem. This is counter to Muis et al.'s (2015) previous work and results from Study 1 wherein confusion and frustration were negative predictors of planning and cognitive learning strategies, but consistent with Study 1 with regard to confusion positively predicting metacognitive learning strategies.

To explain this, it may very well be the case that negative relations between these emotions (i.e., confusion to frustration) and learning strategies reflect a reduction in those above-mentioned strategies. Despite a reduction in strategy use, the likelihood of a strategy occurring following an emotion does not necessarily predict its frequency of occurrence; rather, likelihoods predict the probability of something occurring. It may be the case that total frequencies of strategy use dropped following these emotions, but that those strategies that did occur were captured by the sequential analyses. Clearly, more research is necessary to fully chart the sequential dynamics of emotions as they occur during complex problem solving. We discuss the general findings next.

8. General Discussion

The findings of these two studies improve understanding of relations between emotions, learning strategies, and learning outcomes among elementary students. Pekrun's (2006) control value theory of achievement emotions and D'Mello and Graesser's (2012) model of cognitive-affective dynamics served as the theoretical foundations that led to the development of the current studies' conceptualizations and hypotheses. The overall purpose of these studies was to explore the role and sequencing of emotions during mathematics problem solving among elementary students. The aim of Study 1 was to examine the antecedents and consequences of emotions that elementary students experience during complex problem solving and to replicate Muis et al.'s (2015) results. The aim for Study 2 was to explore the dynamics of emotions in real time as they transition from one emotion to another emotion and from one emotion to a learning strategy during mathematics problem solving.

Results from Study 1 provide support for Pekrun's (2006) control value theory of achievement emotions and successfully replicated those of Muis et al.'s (2015) study. These findings further emphasize the importance of students' task value and their perceptions of control as they predict students' emotions and cognitive and metacognitive learning strategies used during learning. As such, educators must creatively find ways to help their students pull meaning from learning tasks to increase students' perceptions of task value. Furthermore, the majority of results from Study 2 were consistent with D'Mello and Graesser's (2012) model, which suggests that this model applies to elementary students as well. Notably, as confusion can be “productive” or “hopeless” for adult students, it appears that confusion plays the same role for elementary students.

8.1 Implications

To our knowledge, Study 2 is the first to examine the dynamics of emotions and their transitions to other emotions and to learning strategies among elementary students during complex mathematics problem solving within a classroom setting. Study 2 examined students’ emotions as they occurred in real time and extends D’Mello and Graesser’s (2012) work to explore whether similar patterns of transitions occurred with young students. Our study extends this model by also identifying the learning strategies that immediately follow an emotion.

It does not appear that emotions among young students are experienced differently than adults during complex problem solving, but the function or effect of certain emotions may be different for young versus adult students. Emotions triggered by cognitive incongruities such as confusion, surprise, and curiosity, that have been observed to propel adult learners to engage in deeper learning strategies might be overwhelming for young students who have yet to learn the skills to resolve such cognitive incongruities. The findings from Study 1 provide evidence that confusion for young students is both negative and unproductive with regard to predicting decreases in planning and cognitive learning strategies, yet at the same time it predicts an increase in metacognitive learning strategies. However, in Study 2, confusion mostly transitioned to other negative emotions. Furthermore, surprise appeared to be experienced as a more negative emotion as well, findings that contradict the adult literature that demonstrate both positive and negative effects of surprise.

During complex problem solving, it is expected that students will experience cognitive incongruity that triggers surprise or confusion and will require the appropriate skills to implement suitable learning strategies to resolve the incongruity. Therefore, young students need to learn not only about the role of emotions in learning, but also need to be explicitly taught specific learning strategies to resolve confusion and when to implement them. Moreover, young students also need to be taught how to regulate their emotions during problem solving to lessen their negative effects. These types of interventions will hopefully aid young students in learning how to persevere and minimize the risk of falling into the confusion-to-frustration/boredom/anxiety patterns that then lead to lower achievement outcomes. As such, given the high prevalence of confusion during problem solving, efforts need to be made to ensure that students' experiences of confusion are productive (i.e., confusion-to-curiosity-to-deep learning strategy use) rather than unproductive (i.e., confusion-to-frustration-to-boredom/hopelessness and task disengagement).

8.2 Limitations and future work

Although our set of studies add substantively to the literature, there are several limitations that should be addressed in future work. First, for Study 1, self-report measures were used to measure students' learning strategies and emotions experienced while they solved a mathematics problem. Although self-reports serve as a valuable method and are the most widely-used tools (Muis & Singh, 2018), it is important to also recognize their limitations. Even though the self-report scales were administered immediately after the task, students in this study might not have accurately reported their learning strategies or emotions. Moreover, it is possible that the drawbacks related to self-reports of metacognitive processes might be more pronounced in children. However, it is important to note that typically-developing young children have begun to develop metacognitive and regulatory processes (Perry, 1998; Whitebread, Coltman, Anderson, Mehta, & Pino Pasternak, 2005; Whitebread, Bingham, Grau, Pasternak, & Sangster, 2007), emotional awareness, the ability to verbalize their emotions, and generate emotion-regulation strategies (Davis, Levine, Lench, & Quas, 2010). Despite this evidence, it is possible that asking students to self-report their emotions and learning strategies might not be the most ideal method. As such, to address this issue, we implemented a think-aloud protocol in Study 2 to gain a more accurate picture of students' cognitive and metacognitive processes and emotions in real-time (rather than retrospectively). Nevertheless, it would be important for future research to triangulate across data sources and cross-validate the findings of other methods. For example, future studies could include think-alouds and self-report instruments coupled with video data of students as they solve the problems. Students could then be interviewed to further probe what they were doing or why they were feeling a particular emotion.

Second, the dynamic of emotions may occur within seconds and subconsciously (Pekrun, 2006), thus making it a challenge to objectively capture. Therefore, for Study 2, not every single emotional state transition experienced by the participants in this sample was captured. First, emotions evolve continuously but may not always be verbalized. In our coding, we included emotional state transitions that occurred immediately, that is within the transcriptions. For example, if frustration was expressed in one segment and boredom was expressed in the next segment, then this was coded as a frustration-to-boredom transition. However, following a verbalization of frustration, if students did not express their boredom despite feeling it, then this was an instance of frustration-to-boredom that was not captured and not coded as the participant did not explicitly state it even if they experienced it. Therefore, not every emotion was expressed and thus, not every transition was captured.

Third, students in this study were instructed to think aloud and “Say everything that is on your mind” but were not explicitly told to also “Say everything you are feeling” such as in an emote-aloud protocol. As such, some emotions experienced might have gone undetected, as students might not have expressed an emotion when experienced. Additionally, individual differences might exist in the level of expressivity of emotions whereby some individuals express many of their emotions frequently while others do not. Therefore, it might be beneficial to use an emote-aloud protocol or an integrated think-emote-aloud protocol whereby students are instructed to say what they are thinking as well as feeling while performing a task. Additional methods or techniques that may be beneficial to implement include physiological indicators (i.e., facial expression) and physical arousal (i.e., galvanic skin response) to study and capture emotions as they are experienced in real time (Azevedo, 2009).

Fourth, we coded sequences of emotions based on real time and what emotion was expressed first. Despite analyzing emotions in a linear manner, it is possible that certain emotions co-occurred simultaneously. An example of potential simultaneously occurring emotions within our data were pride and enjoyment. Although these are distinct emotions, it is possible that these two emotions do not just follow each other in sequence, but can actually co-occur. For instance, when a student feels pride, they are also likely to feel enjoyment, which suggests they are likely to be experienced simultaneously. With our design, we were not able to detect whether these emotions occurred simultaneously or not.

Another limitation is that we did not assess individual differences for emotional state transitions and thus do not have information regarding the immediate antecedent and consequence of specific transitions for each participant. Therefore, in addition to identifying patterns of emotional state transitions, future work might aim to identify the causes and effects of these transitions as they occur in real time at an individual level. Additionally, we did not assess for intensity of emotions. For example, when a student experienced surprise, we did not measure whether this was a high or low level of surprise. This could be important information to obtain as varying intensities of emotions can influence what learning strategies a student will engage in next and what emotion will follow. It is possible that experiencing any emotion intensely is detrimental to learning as it can be overwhelming, regardless of the emotion (whether positive or negative). However, it remains unclear how different levels of intensity of emotions affect the dynamics of emotions during a learning task.

For Study 2, we also made efforts to identify emotional state transitions that occurred during complex problem solving among young students. However, these were only two-state transitions (i.e., emotion-to-emotion and emotion-to-learning strategy). As emotions are complex and continuously evolve, it would be beneficial to identify the dynamics of emotions and cognitive processes that extend beyond two states to obtain a broader picture of how emotions transition and influence cognitive and metacognitive strategy use.

Although previously stated, it must be emphasized that classroom-based interventions are developed to target the negative effects of negative emotions, such as confusion and frustration, that arise during complex problem solving. Confusion is a complex emotion that can have various dynamics, whereby it can be productive if it transitions to curiosity and if the student adopts effortful learning strategies to resolve the confusion. However, it can also be detrimental if the confusion transitions to other negative emotions such as frustration or boredom, which has been observed among elementary-aged students. As such, these younger students need to be explicitly taught the skills and appropriate learning strategies necessary to resolve confusion when it arises to ultimately foster better academic outcomes.

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Table 1.
Means and standard deviations

	Mean	Standard Deviation
Surprise	2.50	.85
Enjoyment	3.05	.78
Curiosity	3.22	.80
Confusion	2.48	.93
Anxiety	2.23	.97
Frustration	1.93	.96
Boredom	1.88	.89
Planning and Goal Setting	3.72	.85
Cognitive Strategies	3.68	.69
Metacognitive Strategies	3.41	.70
Task Value	4.08	.77
Academic Control	3.99	. 58
Achievement	69.24	17.27

Note. Scores are averages based on a Likert scale ranging from 1 to 5. The mean for achievement represents the average score on 100.

Table 2
Zero-order correlations between all variables

	2	3	4	5	6	7	8	9	10	11	12	13
1. Surprise	.50**	.59**	.38**	.41**	.27*	.03	.18	.25*	.32**	.08	-.18*	-.01
2. Enjoyment		.60**	.03	.04	-.10	-.29**	.38**	.24**	.16	.23**	.08	.06
3.Curiosity			.25**	.27**	.10	-.25**	.41**	.39**	.36**	.36**	.10	.13
4. Confusion				.73**	.73**	.48**	-.19*	-.01	.26**	-.09	-.18*	-.10
5. Anxiety					.67**	.35**	-.11	.03	.21*	.00	-.18*	-.06
6. Frustration						.56**	-.15	-.07	.17*	-.03	-.18*	-.18*
7. Boredom							-.40**	-.19*	-.12	-.30**	-.30**	-.19*
8. Planning and Goal Setting								.49**	.37**	.36**	.24**	.13
9. Cognitive Strategies									.48**	0.08	-.05	.12
10. Metacognitive Strategies										.16	-.12	.07
11. Task Value											.46**	.31**
12. Academic Control												.18*
13. Achievement												

**p* = .05
** *p* < .01

Table 3.
Coding scheme for learning strategies in think-aloud protocol

Level (Macro) / Micro	**Definition**	**Examples**
Level 1 – Task Definition	A learner generates a perception about the task, context, and the self in relation to the task. External and internal conditions play a major role.	Prior knowledge activation, beliefs, motivation, and knowledge of strategies are activated during this level.
Prior Knowledge Activation	Searching for or explicitly recalling relevant prior knowledge.	"An acute angle, I know what that is. It's an angle that is less than 90 degrees."
Identifying Important Information	Recognizing the usefulness of information.	"The important information in here is to draw the track" "The important things are one acute angle, one obtuse angle, one angle that measures a hundred and eighty degrees."
Level 2 – Planning and Goal Setting	The learner begins to devise a plan to solve the problem and sets goals.	E.g., Planning to use means-ends analysis, trying trial and error, identifying which part of the problem to solve first, solving it within a specific amount of time.
Making / Restating a Plan	Stating what approach will be taken, what strategy will be used to solve the problem, or what part of the problem will be solved in some sequence. This includes restating plans.	"Okay, the next one I will do is the spectator area." "First, I have to figure out how many are in each row, then I can figure out how many people fit in each row to fit 120,000 people."
Setting / Restating a Goal	A goal is modeled as a multifaceted profile of information, and each standard in the profile is used as a basis to compare the products created when engaged in the activity. This includes restating goals.	"I need to find a reflex angle." "Alright, I have to figure out the perimeter of the track."

Level (Macro) / Micro	**Definition**	**Examples**
Level 3 – Enactment	Enactment occurs when the learner begins to work on the task by applying tactics or strategies chosen for the task.	
Hypothesizing	Making predictions.	"I suppose a square meter is probably one of those squares that are in the picture." "It looks like it could be approximately 1000 squares"
Summarizing	Summarizing what was just read in the problem statement.	"So, it surrounds the track and it has to be able to seat 120,000 people." [after reading the problem] "Ok, so the length of the outside perimeter of my track must measure between 4.5km and 5km."
Help Seeking	Asking for help from a teacher, peer, or other source. Help seeking for information VERSUS help seeking for evaluation.	"Can you put the starting line where the acute angle is, and the obtuse where the right angle is?" "Did I do this right?"
Coordinating Informational Sources	Using other sources of information to help solve the problem.	"I'll just go back to my popplet." [Popplet includes the concept map, and learner is going back to the concept map he created to help solve the problem].

Level (Macro) / Micro	**Definition**	**Examples**
Level 3 – Enactment continued	Enactment occurs when the learner begins to work on the task by applying tactics or strategies chosen for the task.	
Highlighting / Labeling / Drawing / Writing	Highlighting information, labeling information as part of the problem-solving process, or taking notes in reference to the problem. Making a drawing to assist learning or as part of solving the problem.	"Oh, let me just label that thing" "Our seating area must have 120,000 people seated, I'll put that in red." [highlighting]
Calculating / Measuring	Solving equations, measuring, or other similar features.	"Now, to transfer to meters into km, we have to multiply by 1000. So, there are 5kms. How much meters are in 5kms? So 5 times 1000 equals 5000 meters." "I'm going to measure it now, so that's like 1km."
Re-Reading	Re-reading a section of the problem, word for word. Important that it is word for word, otherwise it is summarizing.	[reading] "The starting line must be painted with a frieze pattern. This pattern is a rectangular design. Wait. The starting line must be painted with a frieze pattern. Ok." "Uh, I'll re-read this…"
Making Inferences	Making inferences based on information read or products created from solving the problem. self-explanation). Explaining why something was done. Key word is "because."	"There are no calculations involved, it's just kind of a fact." "So, it can't be symmetrical because it has to be 7-sided."
Goal-directed search		"What are some other important information?"

Level (Macro) / Micro	**Definition**	**Examples**
Level 4 – Monitoring and Evaluation	Various types of reactions and reflections are carried out to evaluate the successes or failures of each level or products created for the task, or perceptions about the self or context. Reaction and reflection also includes judgments and evaluations of performance on a task as well as the attributions for success or failure.	Products created are compared to the standards set via metacognitive monitoring. Monitoring and evaluation can include any facet listed above (e.g., progress, motivation, plans, goals, strategies, products like answers or drawings made).
Self-Questioning	Posing a question.	"How am I supposed to do my acute angle?" "Which one didn't I mark?"
Monitoring	Monitoring something relative to goals.	"Ok so let me double check if I missed anything." "Ok so let's see, so now we have three sections so far. So, three sections." "The answer is 144.90."
Judgment of Learning	Learner is aware that something is unknown, not fully understood, or difficult to do.	"I have no idea how I'm going to figure that out." "This is going to be a hard part. This is going to be very hard to figure out." "I don't know, I just really don't get it."

Level (Macro) / Micro	**Definition**	**Examples**
Level 4 – Monitoring and Evaluation continued	Various types of reactions and reflections are carried out to evaluate the successes or failures of each level or products created for the task, or perceptions about the self or context. Reaction and reflection also includes judgments and evaluations of performance on a task as well as the attributions for success or failure.	Products created are compared to the standards set via metacognitive monitoring. Monitoring and evaluation can include any facet listed above (e.g., progress, motivation, plans, goals, strategies, products like answers or drawings made).
Self-Correcting	Correcting one's mistakes.	"I measured the wrong thing by accident. So, let's just erase this." "It doesn't look even. So, I will do it again and put the line over here." "I'm just going to re-do my counting because I just did something wrong."
Evaluation	Judging whether goals have been met, whether a particular strategy is working, whether the answer is correct, whether the work is neat, etc. Judgment of all facets that fall under monitoring.	"So there, I've done my checkered pattern. That's a good pattern." "My pattern is good because one third of it is white." "Oh, that looks messy."
Control	Changing strategy when monitoring or evaluation results in a determination that goal has not been met.	"So, I need to do it this way because that didn't work." [after judging that polygon was not 7-sided] "I'm just going to erase this. It has to be a 7-sided polygon so let's do a different one."
Task Difficulty	Statements reflecting the difficulty or easiness of a task.	"Why must this be so hard?" "I don't think this will be too hard, but you never know."

Table 4.
Coding scheme for emotions in think-aloud protocols

Code	Description/Definition	Example
Curiosity	Interest, intrigued	"I wonder if I could do like 1, 2, 3, 4, 5" "Wait a minute, I got an idea, let me go check with my calculator" "Because I wonder how to make it into kilometer"
Enjoyment	Excited, enthusiastic, happy	"I think that this is the funnest part" "My track is awesome!!!!" "It's going to be so much fun" "So I'm excited I'm starting it" (counting) "… 12000, 13000, 14000, 15000, yay!"
Surprise	Astonished, amazed	"Woah that's a big number!" "Wow that's a lot of people" "Woah!! This is more difficult than I thought it would be" (gasps) "Oh my god I just did it! Oh my God"
Confusion	Puzzled, mixed up	"…So confusing" "I'm getting mixed up here" "Okay how many?... This doesn't make sense" "I don't know what to do anymore right now" "I'm lost"
Frustration	Irritated, dissatisfied	"Oh my god, I'm kind of getting annoyed" "Ahhh driving me insane" "No, no, no, uh, no, no… Why!? Why!? Why, why torturing me, math, why are you torturing me, math?! Ahhh…"

Boredom	Dull, monotonous	"Ugh this is tiring" "I'm bored of doing this"
Anxiety	Worried, nervous	"Oh boy, I'm in trouble" "Oh man this is gonna be hard, I don't think I'll be able to do my track" "How am I possibly going to find a way to get this done?!" "Nooo! It's 4.2km! what am I gonna do?! Uhhh oh no!!"
Pride	The state of being proud. A feeling of happiness when you do something good or difficult.	"This looks like a pretty good job to me… I feel pretty good" "Okay so I'm really proud of my last, last, last ones" "I did it! Yes! I did it! I rock, I did it!"
Relief	The removal or lightening of something painful or distressing.	"Good, I finally got it. Finally!"
Hope	To want something to happen or be true and think that it could happen or be true.	"I hope this time it will work" "Hopefully I won't make the same mistake"
Hopelessness	Having no hope, no expectation of good or success. Incapable of solution, management, or accomplishment.	"I can't do this" "I feel like giving up"
Anger	To become angry	"I'm getting really angry!" "This is my fourth time! I have to do mine again, this is so hard, I'm so mad!"
Shame	A feeling of guilt, regret, or sadness that you have because you know you have done something wrong	"I like feel so, so bad, so horrible"

Table 5.
Frequency of emotions in think-aloud protocols

Emotions	Frequency	Percentage that the emotion was experienced among all emotions
Frustration	185	24.34%
Confusion	172	22.63%
Pride	77	10.13%
Surprise	74	9.73%
Enjoyment	73	9.60%
Hope	56	7.36%
Anxiety	33	4.34%
Relief	31	4.07%
Boredom	19	2.5%
Curiosity	17	2.23%
Hopelessness	13	1.71%
Shame	6	0.78%
Anger	4	0.52%
Total	760	100%

Table 6.
Frequency of learning strategies in think-aloud protocols

Learning strategy	Frequency	Percentage	Learning strategy	Frequency	Percentage
Planning	3154	20.29	Self-correcting	389	2.50
HLCD	2188	14.08	Self-questioning	348	2.23
Monitoring	2126	13.68	Control	295	1.90
Calculating	1924	12.38	Making inference	267	1.71
Evaluating	1039	6.68	Task-difficulty	260	1.67
Help-seeking:			Prior knowledge		1.44
Information	691	4.44	Activation	224	
		4.14	Help-seeking:		1.16
Summarizing	644		Evaluation	181	
		4.12	Coordinating		0.58
Goals	641		information	91	
Re-reading	559	3.60	Hypothesizing	86	0.55
Judgment of		2.81			
learning	437				
			Total	15,544	100

Table 7.
Frequency of emotion-to-emotion transitions in think-aloud protocols

Emotion-to-emotion transition	Frequency	Emotion-to-emotion transition	Frequency
Frustration		Confusion	
Frustration → Confusion	5	Confusion → Frustration	12
Frustration → Anger	3	Confusion → Confusion	4
Frustration → Frustration	4	Confusion → Anxiety	3
Frustration → Hopelessness	2	Confusion → Boredom	3
Frustration → Shame	2	Confusion → Hopelessness	1
Frustration → Hope	2	Confusion → Surprise	1
Frustration → Anxiety	1	Confusion → Curiosity	1
Frustration → Boredom	1		
Frustration → Curiosity	1		
Pride		Surprise	
Pride → Enjoyment	6	Surprise → Confusion	7
Pride → Relief	2	Surprise → Frustration	5
Pride → Hope	1	Surprise → Curiosity	2
Pride → Curiosity	1	Surprise → Pride	2
		Surprise → Enjoyment	1
		Surprise → Shame	1
Enjoyment		Anxiety	
Enjoyment → Pride	5	Anxiety → Frustration	4
Enjoyment → Relief	2	Anxiety → Hope	2
Enjoyment → Enjoyment	1	Anxiety → Hopelessness	1
Enjoyment → Hope	1	Anxiety → Shame	1
Hopelessness		Relief	
Hopelessness → Frustration	2	Relief → Pride	5
Hopelessness → Confusion	1	Relief → Enjoyment	1
Hopelessness → Boredom	1		
Curiosity		Shame	
Curiosity → Hope	1	Shame → Hopelessness	1
Curiosity → Anxiety	1		
Boredom → no emotions			
Hope → no emotions			
Anger → no emotions			

Note. Boredom, anger, and hope did not transition to any emotions.

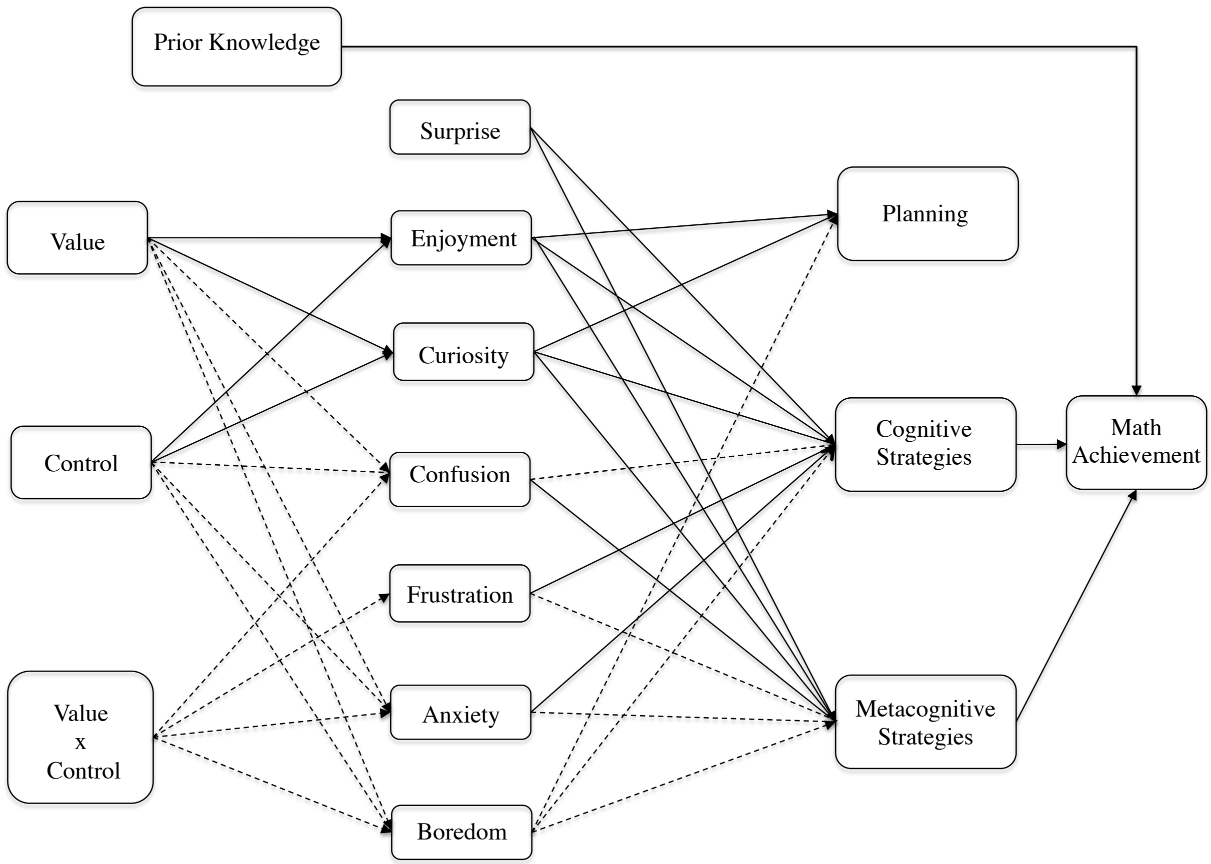

Figure 1. Hypothesized path model. Solid lines indicate positive relationships. Dotted lines indicate negative relationships.

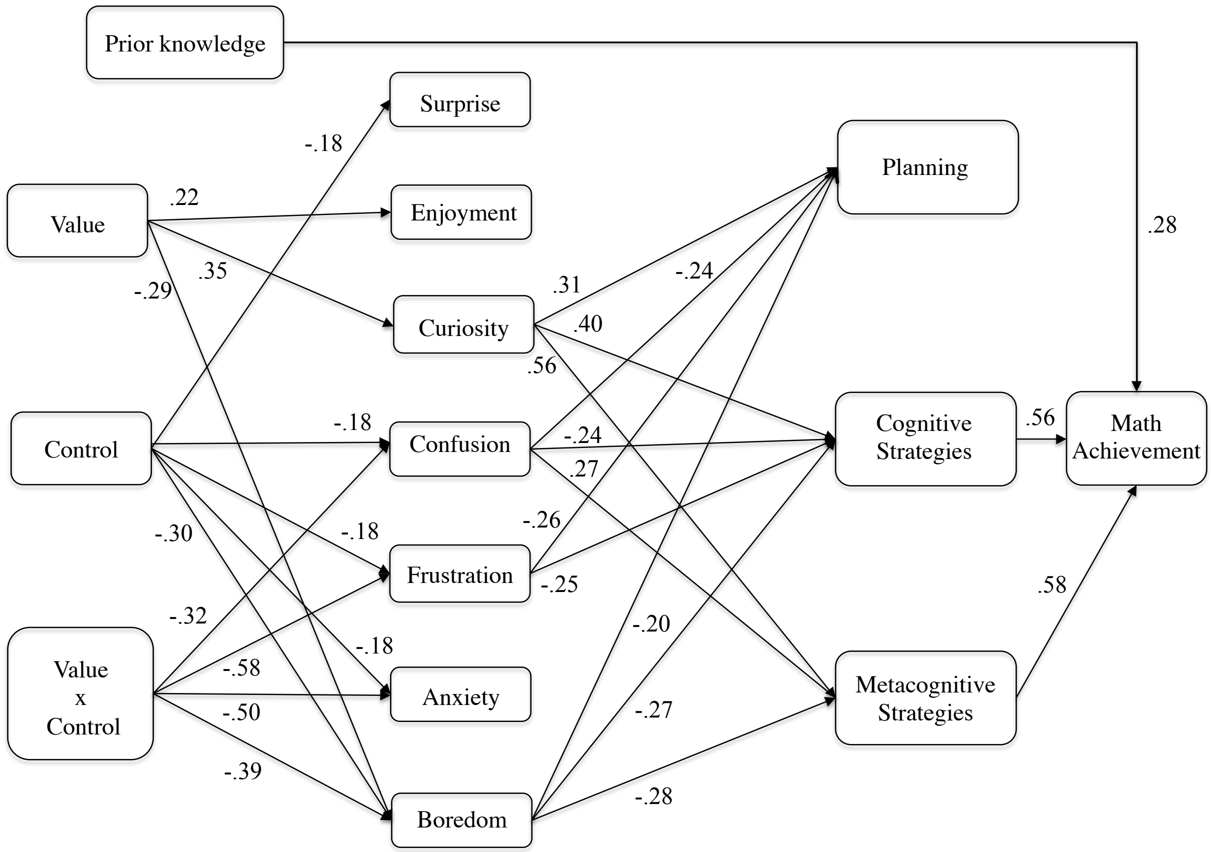

Figure 2. Final path model. Only significant results are illustrated.

Bridging Text

In Chapter 2, two empirical studies were presented. The first was a replication study of Muis et al.'s (2015) work and aimed to examine the antecedents and consequences of academic emotions among elementary students during mathematics problem solving. The second study explored the sequencing of emotions as they transitioned to subsequent emotions and learning strategies. Notably, a think-aloud protocol was implemented in Study 2 to capture students' emotions in real time during complex problem solving. Thus, within the broader context of the dissertation, Study 2 extended the literature by implementing recent methodology that acquires students' in-the-moment cognitive and emotional processes.

Results from Study 1 provided support for Pekrun's (2006) control value theory of achievement emotions and successfully replicated those of Muis et al.'s (2015) study with confusion remaining negative rather than beneficial for elementary students. These findings further emphasize the importance of students' task value and their perceptions of control as they moderate the effects of academic emotions on cognitive and metacognitive strategies. Furthermore, emotions significantly predicted self-regulated learning strategies including planning/goal setting, and cognitive and metacognitive strategies. Specifically, curiosity positively predicted planning, and cognitive and metacognitive learning strategies; confusion and frustration both negatively predicted planning and cognitive learning strategies; and boredom negatively predicted planning, cognitive and metacognitive learning strategies.

Results from Study 2 revealed that elementary students experience negative emotions including confusion and frustration at a particularly high frequency during problem solving compared to other academic emotions. Moreover, confusion and frustration were observed to transition to other negative emotions such as anxiety, boredom, and hopelessness, as well as to shallow learning strategies (i.e., strategies that are not considered cognitive or metacognitive learning strategies). These findings suggested that confusion seems to be particularly detrimental rather than productive for elementary students.

Taken together, results from these studies as well as previous work (e.g., Muis et al., 2015) indicate that elementary students do not seem to engage in the appropriate self-regulated learning strategies to resolve their cognitive incongruity or possess the skills necessary to overcome their confusion. To date, there are no classroom-based interventions designed to target confusion among elementary students during mathematics problem solving. Therefore, the objective of the research study proposed in Chapter 3 was to implement a classroom-based intervention developed to teach fifth-grade students specific self-regulated learning strategies to overcome confusion when it arises during mathematics problem solving. Outcomes of this study will be valuable for students and educators. Students will learn the strategies necessary to overcome their confusion they commonly face during math problem solving. For teachers, the information gathered from this study may help to inform instruction designed to better meet the needs of all students.

Chapter 3: Manuscript 2

Confused, now what? A cognitive-emotional strategy instruction intervention for elementary students during mathematics problem solving

Abstract

Mathematics problem solving is complex and multi-componential. Although it is considered a cognitive task requiring students to engage in self-regulated learning strategies such as monitoring and evaluating, it also evokes various emotions like frustration and confusion. Emotions are influential in mathematics problem solving and can either facilitate or hinder a student's progress. Confusion among elementary students has been observed to lead to frustration and boredom, which subsequently predicts an increase in shallow learning strategies. It is therefore possible that elementary students lack the necessary skills to overcome their confusion as they solve mathematics problems. As such, an intervention was developed to teach fifth-grade students self-regulated learning strategies that can be used when confusion is experienced during math problem solving. The purpose of this study was to evaluate whether students who received the intervention performed better on a complex mathematics problem, engaged in more cognitive and metacognitive learning strategies, and expressed more positive emotions and fewer negative emotions while solving the problem than students in the control condition who did not receive the intervention. A think-emote-aloud protocol was administered to capture self-regulatory processes and emotions as students solved the problem. Results from analysis of covariance revealed that students who received the intervention had significantly greater achievement scores, implemented more cognitive and metacognitive learning strategies, and expressed more positive emotions and fewer negative emotions than students in the control condition. These results extend previous findings of strategy instruction by incorporating consideration of the role of emotions during learning. Suggestions for further exploration in this field are offered.

Introduction

In the education system, mathematics is a primary and significant part of the curriculum. The heavy focus on mathematics begins in the elementary school level and continues through secondary school levels. However, the foundation of mathematical skills is developed during the elementary school years. Accordingly, mathematics problem solving is a skill that is critical for young students to acquire and develop proficiency in as it impacts academic success. Research has revealed that early achievement in mathematics is a predictor of later academic achievement, drop-out rates in secondary school, future career options, and success in the workforce (Balfanz & Boccanfuso, 2007; Balfanz, Herzog, & Mac Iver, 2007; Bryant, Bryant, & Hammill, 2000; Charette & Meng 1998; Duncan et al. 2007; Duncan, 2011; Rivera-Batiz, 1992; Romano et al., 2010). However, many students, including those who are high achieving, may experience difficulty with mathematics problem solving at any given point during their education (Rivera, 1997; Van De Rijt & Van Luit, 1998).

Mathematics problem solving is complex and can be challenging. Effectively solving mathematics problems involves various skills such as the ability to understand number sense, apply basic mathematics facts and mathematical reasoning, implement accurate and fluent calculations, activate relevant prior knowledge (Baroody & Dowker, 2013; Davidson & Sternberg, 1998), and reading comprehension (Adams, 2003; Barton & Heidema, 2002; Fuentes, 1998; Vilenius-Tuohimaa, Aunola, & Nurmi, 2008). Moreover, because of the complexity of solving a mathematics problem, students must also engage in strategic action and the self-regulation of learning (Davidson & Sternberg, 1998; De Corte, Verschaffel, & Op't Eynde, 2000; Pape & Smith, 2002). Self-regulated learning facilitates students’ ability to plan, monitor, and evaluate their work, and recruit from their executive functions to organize, sustain and shift attention, inhibit distractions, utilize working memory, and maintain an appropriate level of motivation (Cragg & Gilmore, 2014). Engagement in self-regulated learning is necessary to work through multiple steps of a mathematics problem, efficiently integrate the information presented, develop and plan a solution path, execute the solution (Montague, Warger, & Morgan, 2000; Wilson, Fernandez, & Hadaway, 1993), and monitor and evaluate work (Cawley & Miller, 1986; Davidson & Sternberg, 1998; Pugalee, 2001). All of these aspects of problem solving must be managed, while at the same time, students might also have to suppress distracting information (inhibition) and apply flexible thinking (shifting attention between different tasks) (Cragg & Gilmore, 2014).

Undoubtedly, mathematics problem solving is a demanding cognitive task, but it also includes affective components. Indeed, as students solve complex mathematics problems, they can experience an array of emotions ranging from positive emotions, such as curiosity, enjoyment, and pride, to negative emotions, such as frustration, anxiety, and boredom (e.g., Di Leo, Muis, Singh, & Psaradellis, 2019; Muis, Psaradellis, Lajoie, Di Leo, & Chevrier, 2015a). Given the complexity of mathematics problem solving, there are numerous opportunities for students to be faced with a challenge, to reach an impasse, and become stuck. An impasse could be attributed to an external event, such as an issue with the learning material, or attributed to an internal event, such as limited prior knowledge (VanLehn, 1988). Experiencing challenges and impasses during problem solving can elicit confusion and frustration among adult students (D'Mello & Graesser, 2012) as well as elementary students (Di Leo et al., 2019). As Di Leo et al. (2019) found, confusion and frustration were the two emotions that were most frequently expressed by fifth-grade students during a mathematics problem-solving task. This is alarming given that negative emotions can have detrimental effects on mathematics achievement (e.g., Muis et al., 2015a).

Di Leo et al. (2019) and Muis et al. (2015a) argued that young students lack, or have difficulty implementing, the necessary skills to resolve impasses or deal with the confusion that is elicited during mathematics problem solving. It is possible that younger students do not engage in the self-regulation of learning required in evaluating the source of their confusion. Järvenoja and Järvelä's research (2005) revealed the importance of students' evaluation of the source of their emotions to manage their emotions and motivation. As such, young students might be less likely to monitor their confusion, adjust their strategies accordingly, and evaluate the success of their strategies to overcome the confusion. It is therefore imperative that interventions are developed to provide elementary students with the specific skills and strategies they require to effectively carry out a mathematics problem when faced with a challenge, an impasse, or high levels of confusion.

Several interventions exist in the literature that have been effective in fostering emotion regulation (e.g., Quoidbach, Mikolajczak, & Gross, 2015; Wyman, Cross, Brown, Yu, Tu, & Eberly, 2010) or self-regulated learning (Muis, Psaradellis, Chevrier, Di Leo, & Lajoie, 2015). However, even though emotions and cognitive processes are interconnected and dynamically linked (Blair, 2002; Cacioppo & Berntson, 1999) and that the integration of emotions and cognitions are important for academic achievement in elementary school (Blair, 2002; Raver, 2002), to our knowledge, there are currently no interventions that take into consideration emotion-cognition relations to improve mathematics problem solving skills among elementary students. As such, the goal of this study was to design and implement an intervention to help elementary students resolve confusion during mathematics problem solving through promoting emotional awareness and self-regulated learning strategies. The intervention included an emphasis on academic emotions and aimed to promote emotional awareness in the context of mathematics problem solving, foster self-regulated learning, and enhance students' repertoire of cognitive and metacognitive learning strategies to increase mathematics problem solving achievement. Moreover, to promote students' evaluation of the source of their confusion, students were taught to question why they are in a state of confusion, identify the source of that confusion, and select an appropriate strategy to address their specific impasse. Specifically, students were explained that confusion is a normal experience and can be expected during mathematics problem solving. Additionally, they were taught to think of confusion as a signal indicating the need to stop, think about the source of confusion, and identify and implement a strategy. Prior to delineating the specific intervention, relevant theoretical and empirical work is reviewed first.

Emotions

Traditionally, research on mathematics learning focused on cognitive processes, with the role of emotions being underrepresented in research as well as in practice (DeBellis & Goldin, 2006; McLeod, 1992; National Council of Teachers of Mathematics, 1989; National Council of Teachers of Mathematics, 2000; Norman, 1980). Many educational researchers in the 1980's and early 1990's called for a greater focus on affective issues as they relate to academic achievement and the cognitive processes involved in problem solving (Silver, 1985). The increase in cross-sectional research spurred the broadening of theoretical perspectives and frameworks, which ultimately led to the understanding that learning and problem solving also involve the experience of emotions. More recently, researchers in educational and cognitive psychology have made greater efforts to identify the relationship between emotions, cognitive processes, and problem solving (e.g., D'Mello & Graesser, 2012; Pekrun, 2000, 2006). Today's integrative view recognizes the mutual contributions of emotions and cognitive processes in learning and achievement and acknowledges that this integrative view is critical in the design of instruction and intervention (Calkins & Bell, 2010). So, what exactly are emotions?

Emotions are multifaceted phenomena that include components relating to cognition, affect, physiology, motivation, and expression (Scherer, 2000). For example, the anxiety that students experience about mathematics problem solving may consist of worrying about not accurately solving the problem (cognitive), feelings of nervousness (affective), increased cardiovascular activation (physiological), impulses to flee the situation (motivational), and anxious facial expression (expressive) (Scherer, 2000). Emotions typically are organized into different categories along two dimensions: valence (positive or negative) and activation (activating or deactivating arousal) (e.g., Feldman Barrett & Russell, 1998; Shuman & Scherer, 2014). Emotions can be further classified by whether they are positive activating (e.g., curiosity, hope, enjoyment, pride), positive deactivating (e.g., relief), negative activating (e.g., anxiety, confusion, frustration, anger, shame), and negative deactivating (e.g., boredom, hopelessness, sadness) (Linnenbrink, 2007; Pekrun, 2006). One additional emotion, surprise, is considered neutral in valence but can elicit positive or negative arousal depending on the context (Mauss & Robinson, 2009).

In addition to categorizing emotions along valence and activation dimensions, they can be characterized as a function of their object focus. For example, in the context of learning, achievement emotions refer to emotions that are related to achievement activities or achievement outcomes. Activity emotions occur during engagement in an activity, whereas outcome emotions occur prior to or after an activity that focus specifically on the outcome, like anxiety for possible future successes or failures and like pride or shame for previous successes or failures. Activity and outcome emotions that occur during achievement situations are therefore part of the broader category of achievement emotions. Another type of emotion that can occur during learning includes epistemic emotions, which are emotions that arise specifically from appraisals about whether incoming information is consistent with prior knowledge, existing beliefs, or recently processed information (Muis, Chevrier, & Singh, 2018). Epistemic emotions such as confusion, surprise, and curiosity are often experienced during mathematics problem solving as they are triggered by cognitive incongruity, novelty, and impasses (D'Mello & Graesser, 2012). For example, surprise is likely to be experienced when a student encounters unexpected information, curiosity when the student experiences something new and has the desire to learn more about something, and confusion when a student encounters cognitive incongruity or an impasse (Graesser & D'Mello, 2012).

Pekrun's Control-Value Theory of Achievement Emotions

Given an increased focus on emotions in learning situations, several theoretical frameworks have been developed to delineate more precisely their role in learning. For example, to delineate the antecedents and consequences of emotions in achievement settings, Pekrun (2006; Pekrun & Perry, 2014) developed the control-value theory of achievement emotions. In this integrative framework, students' perceptions of control and task value are antecedents to the emotions they experience in achievement situations. Together, these perceptions of control and task value interact to predict the kinds of emotions experienced during learning. For example, a student's perceptions that learning mathematics is highly controllable (i.e., the student believes they have control over the achievement activity and outcome) and highly valuable (i.e., the student believes the task is meaningful and holds high value for the achievement activity and outcome) is likely to yield positive emotions such as enjoyment. In contrast, a student's perceptions of low control (i.e., believing that they do not have control over the achievement activity) and low task value (i.e., the student does not value the achievement task and outcome) are likely to yield negative emotions such as boredom. Moreover, a student's belief of low control and high task value is likely to yield negative emotions such as anxiety, frustration, or hopelessness.

Empirical support for Pekrun's (2006) control-value theory of achievement emotions has been observed among elementary students. For example, Muis et al. (2015a) investigated the antecedents and consequences of emotions among fifth-grade students as they solved a complex mathematics problem. Students who reported greater perceptions of control reported less confusion and anxiety, and students who reported greater task value reported more curiosity and enjoyment, and less confusion, frustration, boredom, and anxiety. Emotions then predicted the cognitive and metacognitive learning strategies students used to solve the problem. Positive emotions, like curiosity, positively predicted metacognitive learning strategies, and negative emotions, such as boredom and confusion, negatively predicted cognitive and metacognitive learning strategies. Results also revealed that students' emotions mediated relations between control and task value and learning strategies. These results highlight the predictive nature of emotions in learning contexts. Recent research has also shown that emotions are dynamic as they can fluctuate and oscillate from one emotion to another during complex learning and problem solving (Di Leo et al., 2019; D'Mello & Graesser, 2012).

Dynamics of Emotions

D'Mello and Graesser (2012) developed a model to explain the dynamic nature of emotional states that occur during complex learning. They proposed that a learner who is in the state of engagement/flow (i.e., a cognitive-affective state of positive valence and moderate level of arousal that elicits a high state of engagement in the learning task) will experience confusion when confronted with cognitive incongruities, contradictions, anomalies, or impasses. The learner will then implement cognitive and metacognitive learning strategies to overcome the incongruity. If the cognitive incongruity (confusion) has been resolved, the learner will return to a state of engagement/flow. However, if the learner has failed to resolve the incongruity, they might feel stuck and their confusion will transition to frustration, at which point the learner may oscillate between confusion and frustration. With persistent failure in resolving the incongruity, the learner's frustration will eventually transition to boredom. Their model illustrates that confusion can be productive when it is resolved and the learner transitions to engagement/flow. However, confusion can be unproductive when the learner has difficulty resolving the incongruity and will oscillate between confusion and frustration and then transition from frustration to boredom, which subsequently leads to disengagement from the task.

D'Mello and Graesser's (2012) model has been empirically supported among adult students (Craig, Graesser, Sullins, & Gholson, 2004; D'Mello & Graesser, 2012; D'Mello, Lehman, Pekrun, & Graesser, 2014; Graesser, Chipman, King, McDaniel, & D'Mello, 2007) and more recently with elementary students in the fifth grade (Di Leo et al., 2019; Muis et al., 2015a). In Muis et al.'s (2015a) study, elementary students' confusion during mathematics problem solving negatively predicted the use of cognitive and metacognitive strategies and reduced the use of learning strategies altogether. It appeared that confusion, among this sample of elementary students, was unproductive rather than productive. Muis et al. (2015a) proposed that young students perhaps do not have sufficient skills to self-regulate learning to overcome the confusion that is evoked during an impasse as they solve a complex mathematics problem. Also consistent with D'Mello and Graesser's (2012) model, Di Leo et al. (2019) found that fifth grade students' confusion during mathematics problem solving functioned in both productive and unproductive ways. Although confusion positively predicted metacognitive learning strategies, it also negatively predicted planning and cognitive learning strategies.

Di Leo et al. (2019) also investigated the dynamics of emotions through emotional-state transitions. Using a think-aloud protocol, students' thoughts and emotions were captured as they solved a complex mathematics problem. Concordant with D'Mello and Graesser's (2012) model, patterns of emotional-state transitions were observed. Confusion transitioned to negative emotions, including frustration and boredom, but also transitioned to curiosity. Frustration transitioned to hopelessness and confusion. Additionally, patterns were observed between emotions and learning strategies. In particular, confusion transitioned to cognitive and metacognitive learning strategies including help-seeking, planning, identifying important information, and monitoring. This evidence suggests that confusion can be both productive and unproductive for elementary students.

Moreover, analyses from Di Leo et al.'s (2019) study revealed that the most frequently expressed emotions that these fifth-grade students experienced during mathematics problem solving were negative emotions including confusion and frustration. This implies that the overall experience of solving mathematics problems might be unpleasant for elementary students, which may constrain the learning strategies they implement and thus their overall performance. Sufficient evidence reveals that experiencing confusion can be particularly detrimental for young students (Muis et al., 2015a). Although confusion is commonly experienced for all students, young students may more frequently fall into a pattern of emotional-state transitions of confusion to frustration and thus remain in a negative emotional state. Persistent or unresolved confusion can lead to greater opportunities to experience boredom, use fewer self-regulated learning strategies, and eventually disengage from the task.

Given that young students might not implement the appropriate learning strategies to resolve the cognitive incongruity or confusion, their persistent state of confusion can negatively impact their performance and subsequently elicit various negative emotions that further hamper their mathematics performance (Muis et al., 2015a). It is likely that young students need to be explicitly taught a set of strategies they can apply to overcome confusion when it arises in mathematics problem solving. This underlines the importance, particularly for young students, to acquire a foundation of self-regulatory skills to have awareness of their cognitive processes, as well as emotional states, and to appropriately implement self-regulated learning strategies during mathematics problem solving. As such, it is critical to develop an intervention for elementary students that facilitates self-regulated learning while also taking into account the role that emotions play in facilitating or constraining self-regulated learning (Muis et al., 2018).

Self-Regulated Learning

Self-regulated learning is central to mathematics problem solving (Jacobse & Harskamp, 2012; Schoenfeld, 1982) and positively predicts academic achievement and learning motivation (Zimmerman, 2001; Zimmerman & Bandura, 1994). As such, it has been a dominant subject within educational research for decades (Winne, 2005). Self-regulated learning refers to the complex, interactive, and self-directive processes involved in regulating, planning, directing and evaluating one's behaviour, cognitions, and emotions for the purpose of goal attainment in a learning context (Schunk & Zimmerman, 1997). Applying self-regulated learning assumes that a student takes responsibility for their learning and plays an active role through metacognitive, behavioural, and motivational processes (Zimmerman, 1986; 1990; 2001; Zimmerman &

Martinez-Pons, 1990). A self-regulated learner will thus engage in self-regulated learning strategies such as planning, goal setting, monitoring, and evaluating throughout the learning process (Corno, 1986; 1989; Pressley, Borkowski, & Schneider 1987).

Boekaerts (1999) further delineated three areas that are regulated during learning: cognition, metacognition, and motivation/affect. Cognition relates to the cognitive strategies that are applied and implemented during a learning task, metacognition relates to the metacognitive strategies that control and regulate cognition, and finally, motivation/affect relates to a student's motivational beliefs (e.g., self-efficacy, beliefs, interests) and the emotional reactions to the task. Metacognitive processes are required for the regulation over one's learning (Brown, 1978; Brown & DeLoache, 1978; Flavell, 1992; Kluwe, 1987) and facilitate students' ability to be aware, knowledgeable, and deliberate of their learning methods and strategies (Zimmerman, 1990).

Self-regulated learning is viewed as a self-directive process that involves a dynamic feedback loop (Butler & Winne, 1995; Carver & Scheier, 1981; Hattie & Timperley, 2007; Muis, 2007; Zimmerman, 1989, 2000). It functions in a cyclical way wherein students set goals and plans and then receive feedback regarding the effectiveness of their learning methods or strategies via their own monitoring and evaluation of their progress or from another individual like a teacher. Students then respond to this feedback in various ways including resetting goals and plans, shifting their perceptions of control and task value, and replacing a particular learning strategy with another (Muis, 2007; Zimmerman, 1989).

Several models have been developed to delineate how students engage in self-regulated learning. For example, Muis' (2007) model of self-regulated learning includes four phases of learning or problem solving, namely, task definition, planning and goal setting, enactment, and evaluation, and five areas for regulation including cognition, motivation, affect, behaviour, and context. In the first phase, students begin by defining the task, which is influenced by the five areas for regulation. Learning strategies that might be employed during the task definition phase include prior knowledge activation and identifying important information. For the second phase, learners may set goals and plans to establish what they will do to solve the problem, including selecting the appropriate learning strategies. The third phase, enactment, begins once learners implement the selected strategies to carry out the task. In the context of mathematics problem solving, the enactment phase may include hypothesizing, summarizing, help seeking, calculating/measuring, or re-reading (Muis et al., 2015a). In the last phase, individuals may evaluate the successes or failures of each phase, products created for the task, and/or perceptions about the self or context. Critical to this phase is metacognitive monitoring and evaluation. Strategies implemented during this phase might include self-questioning, monitoring, judgments of learning, self-correcting, and evaluating (Muis et al., 2015a). Muis (2007) further proposed that metacognitive processes can occur within all phases of self-regulated learning and can be ongoing throughout the learning and problem solving process. As noted previously, the skills required for each phase, including metacognitive monitoring, are critical for successful mathematics problem solving (Fuchs et al., 2006; Schoenfeld, 1994; Jacobse & Harskamp, 2012). With empirically supported models of self-regulated learning that provide insight into how it functions, it is also important to understand how it develops and how to promote self-regulated learning.

Development of Self-Regulated Learning

Much research has investigated how self-regulated learning develops and ways to best promote it among students of various ages and educational needs. Metacognitive development, independent strategy use, and self-regulated learning develops in young children (e.g, Biemiller, Shany, Inglis, & Meichenbaum, 1998; Bronson, 2000; Perry et al., 2004; Perry, 2013; Perry & Rahim, 2011; Perry, Thauberger, & Hutchinson, 2010; Perry, VandeKamp, Mercer, Nordby, 2002; Schunk & Zimmerman, 1994; Waters & Andreassen, 1983; Whitebread, 1999) and continues to progress as students age and become more aware of their own thinking and the strategies they use during their learning (e.g., Cultice, Somerville, & Wellman, 1983; Flavell, Miller, & Miller, 1993; Paris & Winograd, 1999; Schneider & Sodian, 1997; Schunk & Zimmerman, 1994). From childhood to adolescence and adulthood, students increase their strategy repertoire (Alexander, Carr, & Schwanenflugel, 1995), gain more competency and automaticity in their strategy use, implement more cognitive and metacognitive strategies, and are better able to self-regulate their learning (e.g., Flavell et al., 1993; Schneider & Sodian, 1997). Although the processes required for self-regulated learning develop early, theorists have argued that students only begin to use these self-regulation skills between the ages of 11 and 12 years (Veenman & Spaans, 2005). Historically, cognitive theorists assumed that young students lack the capability and cognitive sophistication to engage in self-regulating their learning during complex tasks (Pressley, Forrest-Pressley, Elliott-Faust, & Miller, 1985; Winne, 1997; Zimmerman, 1990) Although elementary students have demonstrated the capability of self-regulating their learning (Perry, 1998), they often have difficulty implementing cognitive and metacognitive learning strategies (Butler & Winne, 1995; Di Leo et al., 2019; Muis et al., 2015a; Paris & Newman, 1990; Zimmerman, 1990; Zimmerman & Martinez-Pons, 1990).

Students who have neurodevelopmental disorders (e.g., intellectual disability, specific learning disorder, attention-deficit/hyperactivity disorder) may demonstrate difficulty not only with the acquisition of strategies for solving mathematics problems but also with their identification and application (Mercer, 1997; River, 1997). Despite these findings, metacognitive skilfulness is not entirely dependent on intellectual ability but develops in conjunction with it (Veenman & Spaans, 2005). As such, self-regulated learning strategies can be acquired by and taught to elementary students (Dignath, Buettner, & Langfedlt, 2008; Hattie, Biggs, & Purdie, 1996), including those with cognitive deficits and difficulties with learning (Kroesbergen & Van Luit, 2003).

Dignath and Büttner (2008) conducted a meta-analysis that examined intervention studies aimed at enhancing self-regulated learning among elementary and secondary students. Main research questions included whether elementary and secondary students benefit from intervention programs to foster self-regulated learning, whether certain training characteristics make intervention programs more effective, and whether training characteristics function similarly for elementary and secondary students. Results revealed that effect sizes were higher for interventions that trained elementary students in metacognitive strategies compared to interventions for secondary students. This finding supports developmental theories of self-regulated learning in that younger students are still developing their metacognitive skills (Kuhn, 2009; Zimmerman, 2002) and thus appear to benefit from explicit instruction of metacognitive strategies to expand their strategy repertoire (Dignath & Büttner, 2008). Furthermore, effect sizes were greater for interventions that included metacognitive reflection. However, metacognitive strategies (e.g., monitoring and evaluating) did not ameliorate learning outcomes alone; additional factors helped to support effective self-regulated learning including receiving feedback about strategy selection and use (Zimmerman, 2002), as well as information about the strategies and why they are beneficial (Schraw, 1998).

Promoting Self-Regulatory Skills

Given the developmental trajectory of self-regulated learning skills, it is important to consider when and how to facilitate the development and acquisition of these skills among young learners and how to incorporate and deliver training into the classroom (Weinstein, Husman, & Dierking, 2000). Specifically, self-regulated learning might need to be explicitly taught to younger students. Metacognitive and cognitive strategy instructions have been shown to be effective in fostering cognitive processes and self-regulated learning and achievement (e.g., MacArthur, 2012). This type of strategy instruction draws on theories of cognition, of metacognition, and of self-regulated learning. As cognitive strategy instruction relates to how to solve a problem, metacognitive strategy instruction relates to knowing how to solve a problem and can include self-questioning and self-regulation procedures (Kameenui & Griffin, 1989; Montague, 1992). Much research has focused on cognitive strategy instruction designed for elementary students who exhibit difficulty across multiple academic domains including mathematics, particularly students with learning difficulties or those with special educational needs (Geary, 1994; Kroesbergen & Van Luit, 2003). Overall, teaching students how to self-regulate their learning and to master complex strategies can be accomplished through cognitive strategy instruction (MacArthur, 2012). Substantial evidence points to the effectiveness of cognitive strategy instruction to facilitate complex tasks (Rosenshine, 1997), to promote the monitoring of their thinking and progress as they engage in problem solving (Cardelle-Elawar, 1990; Cardelle-Elawar, 1995; Hohn & Frey, 2002; Jitendra et al., 2010; Kramarski & Mevarech, 2003; Mevarech & Kramarski, 2003; Verschaffel, De Corte, Lasure, Van Vaerenbergh, Bogaerts, & Ratinckx, 1999), and to promote mathematics automaticity and problem-solving skills (Carnine, 1997; Case, Harris, Graham, 1992; Fleischner & Manheimer, 1997; Hutchinson, 1993;

Kroesbergen & Van Luit, 2003; Maccini & Hughes, 2000; Montague, 2008; Montague, Enders, & Dietz, 2011).

In cognitive strategy instruction, the explicit teaching, modeling, scaffolding, and coaching of the components and steps of the strategy are considered to be effective in promoting students' achievement (Collins, Brown, & Newman, 1988; Rosenshine, 1997; Schunk & Zimmerman, 1997). Rosenshine (1997) identified two important components of strategy instruction: concrete prompts (e.g., checklists, cue cards) and instructional scaffolds (e.g., model using the strategy, think aloud, begin with simplified material, anticipate difficult areas in the material, provide correction strategies, increase student's responsibility).

To examine cognitive strategy instruction in the context of mathematics problem solving, Cassel and Reid (1996) conducted a study among four students in the third and fourth grades. Half of the students were identified as having a learning disability and the other half were identified as having a mild intellectual disability (IQ between 71 and 80). Their intervention included the main components of cognitive strategy instruction, i.e., concrete prompts and instructional scaffolding. They further provided an explanation to the students of the importance of strategy instruction and how learning a strategy and self-regulation can help students in solving mathematics word problems. The importance of self-speech and self-instruction while solving the problem was also emphasized.

The students were taught strategy steps and were given a prompt card/checklist. The strategy steps were the following: (a) read the problem out loud; (b) find and highlight the questions, then write the label; (c) ask what are the parts of the problem then circle the numbers needed; (d) set up the problem by writing and labeling the numbers; (e) re-read the problem and tie down the sign (decide if you use addition or subtraction); (f) discover the sign (recheck the operation); (g) read the number problem; (h) answer the number problem; and (i) write the answer and check by asking if the answer makes sense. Next, the instructor modeled the use of the strategy with the following self-instructions: (a) problem definition, “What is it I have to do?”; (b) planning, “How can I solve this problem?”; (c) strategy use, “My list of strategies will help me organize my problem solving and remember all the things I need to do in order to successfully complete a word problem.”; (d) self-monitor, “To help me remember what I have done, I can check off the steps of the strategy as they are completed”; (e) self-evaluation, “How am I doing? Does what I am doing make sense? Did I complete all the steps?”; and (f) self-reinforcement, “Great, I’m half-way through the strategy. Oops, I made a mistake, but that’s okay because I can correct it.”

Students then practiced the strategy steps that were taught and modeled by the instructor and then students independently solved a mathematics word problem. After the initial mathematics problem, students were reminded to use the strategy and self-instructions (i.e., prompt card) whenever they worked on mathematics word problems in the classroom (for maintenance checks for 6 and 8 weeks post-strategy instruction). Overall, Cassel and Reid’s (1996) intervention increased mathematics problem solving performance. Furthermore, all students mastered the strategy, which took students between 165-190 minutes to learn and apply the strategies. Students’ performance at 6 and 8 weeks was stable, suggesting maintenance of the strategy use. These results provide empirical support that cognitive strategy instruction is appropriate and effective in increasing mathematics problem solving among elementary students.

Taken together, cognitive strategy instruction has been successful in promoting self-regulated learning to support mathematics achievement for young students with various learning profiles (e.g., Case, et al., 1992; Cassel & Reid, 1996; Mastropieri, Scruggs, & Shiah, 1991; Mercer & Miller, 1992; Montague & Bos, 1986). However, such training programs have focused solely on strategies that emphasize cognitive, metacognitive, and motivational processes without consideration of the role of emotions in learning and problem solving. Given that the emotions experienced during learning and problem solving can facilitate or constrain self-regulated learning and learning outcomes (Di Leo et al., 2019; Muis et al., 2015a; Pekrun, 2006), there is a critical need to incorporate emotional components into training programs that aim to improve mathematics problem solving through strategy instruction. Furthermore, given that self-regulated learning also involves affective states, it would be highly relevant and important to also train students to monitor their emotional states and engage in strategies to either diminish the experience of negative emotions or to increase positive emotions. A broadening of instruction to teach students the importance and relevance of emotional awareness and to monitor one's emotions as they relate to problem solving may have enhanced benefits for students' learning and achievement. Many calls have been made by educational researchers since the 1980's to investigate the relationships between emotions and problem solving (Silver, 1985) and to include emotions into theoretical frameworks of cognitive processes as they relate to mathematics problem solving. Although these concerns have been considered theoretically, what is still lacking is the application of incorporating emotions into forms of cognitive strategy instruction training for young students. As emotions are crucial to problem solving, they should be included in training aimed at promoting elementary students' self-regulated learning skills. In addition to regulating cognitive processes, it is important for students to be aware of their emotions and to engage in ongoing monitoring and regulating of their emotions and actions (i.e., learning strategies) to most effectively carry out the problem and maintain efficient goal-oriented behaviour (Boekaerts, 1996; Boekaerts, Pintrich, & Zeidner, 2000; McCann & Garcia, 1999; Schunk & Zimmerman, 1994; Winne & Hadwin, 1998).

The Current Study

There are numerous interventions that promote self-regulated learning among elementary students but, to date, there are no interventions that overtly incorporate emotions into cognitive strategy instruction training. Research has revealed that confusion and frustration are the two most frequently occurring emotions among young students in the fifth grade (Di Leo et al., 2019), which results in a decrease in cognitive and metacognitive strategies to resolve that confusion. It is possible that young students might not have the skills readily available to overcome their confusion when it occurs and might be unaware of which learning strategies are required to facilitate the task. Much evidence reveals the efficacy of cognitive strategy instruction for students, including those with special educational needs. Therefore, cognitive strategy instruction can be considered as appropriate for classroom settings with students with various learning profiles and educational needs. Many students, including high-achieving students, benefit from greater support and explicit instruction to acquire such self-regulatory skills (Kuhn, 2009). Thus, it is important to deliver interventions not only to students with special educational needs but to all students with varying cognitive and academic profiles. The intervention in the current study was developed to be delivered within a classroom consisting of students with learning difficulties or other special educational needs as well as neuro-typical or high-achieving students.

By explicitly teaching students learning strategies to apply during states of confusion or ideally at the onset of confusion, there is possibly greater likelihood that the experience of confusion might be productive (i.e., confusion to curiosity and confusion to cognitive and metacognitive learning strategies) rather than unproductive (i.e., confusion to frustration to boredom/hopelessness and task disengagement), which then impacts achievement. Moreover, when students experience confusion, their perceptions of control subsequently decrease (Munzar & Muis, under review), which may be a contributing factor to the reduction of learning strategies. To help students conceptualize their state of confusion, if and when it occurs, students can be told that confusion is not only commonly experienced by everyone, but confusion can be expected during complex problem-solving tasks. This message helps to normalize the state of confusion and may enhance their perceptions of control over the task and perhaps also over their emotional state of confusion. As such, interventions that focus on the role that emotions play should include a normalization of the experience of confusion coupled with a focus on an increase in perceptions of control during learning.

Therefore, the objective of this research study was to develop an intervention for fifth-grade students within an inclusive classroom setting using cognitive strategy instruction and modeling techniques to provide students with a repertoire of strategies that can be implemented to overcome confusion when it occurs during mathematics problem solving. The goals of the intervention were the following: (1) to promote emotional awareness as it relates to problem solving through describing and explaining various academic emotions; (2) to describe the emotional state of confusion, when it can arise in the context of mathematics problem solving, normalize the experience of confusion, describe it as an alarm that should trigger the student to reflect on the cause of confusion and identify a strategy to implement to help resolve the confusion; (3) to teach students the cognitive and metacognitive learning strategies to regulate their strategy use specifically when they experience confusion as they solve a mathematics problem; and (4) to teach how and when to implement learning strategies.

To this end, the following research questions were addressed regarding the emotional-cognitive strategy instruction intervention that incorporates both self-regulated learning and emotions: (1) Do students who participate in an emotion-cognitive strategy instruction intervention (i.e., intervention condition) perform better on a mathematics problem solving task compared to students who receive no explicit training (i.e., control condition)? (2) Will students in the intervention condition use more cognitive and metacognitive strategies during mathematics problem solving compared to students in the control condition? (3) Will students in the intervention condition experience more positive emotions and fewer negative emotions compared to students in the control condition? It was hypothesized that while solving a mathematics problem, students in the intervention condition compared to students in the control condition would (1) score higher on the mathematics problem; (2) engage in more cognitive and metacognitive learning strategies; and, (3) experience more overall positive emotions and fewer negative emotions, with the exception of confusion. Specifically, it was hypothesized that students in the intervention condition would experience more enjoyment, pride, and hope and less frustration, boredom, anxiety, and hopelessness given that they were taught skills to resolve confusion when it occurred. We did not expect differences in the amount of confusion experienced, as our intervention did not target a reduction in confusion but rather what to do when confusion occurred. Finally, given that task value, perceptions of control, and emotions regulation predict strategy use and mathematics achievement, these variables were also measured to assess any prior differences between groups and for inclusion as possible covariates (see Di Leo et al., 2019; Muis et al., 2015a).

Methodology

Participants

Sixty-seven students in the fifth grade (*n* = 28 females) across three classrooms at an urban school participated. The homeroom teachers who also taught mathematics were female instructors. The mean age of the sample was 10.84 years (*SD* = 0.31). A total of 11 students were on an individualized education plan (IEP); seven students had an adapted curriculum and no specific diagnosis, three students had an adapted curriculum and a diagnosis of a learning disorder, and one student had an adapted curriculum and a diagnosis of autism spectrum disorder. Participant assent and parental consent was received from 93% of students who were invited to participate. Only students who received parental consent and provided assent participated.

Materials

Prior Knowledge. To assess students' prior knowledge, their standardized achievement scores on their most recent compulsory provincial exam were obtained. The standardized exam included several application problems that took students approximately 40-60 minutes to solve, which assessed their knowledge of mathematics content learned over the school year. Given that teachers provided us with students' exam score, we were not able to calculate reliability.

Academic Control Scale. To measure perceived control for learning mathematics and for mathematics problem solving, participants completed the Academic Control Scale (Perry, Hladkyi, Pekrun, & Pelletier, 2001), which was previously modified and validated for use with elementary students (see Muis et al., 2015a). All participants completed this eight-item scale one week prior to commencing the study. Students rated how much they agreed to each of the eight items on a Likert-scale ranging from "Strongly Disagree" to "Strongly Agree." Sample items include, "The more effort I put into learning math, the better I do" and "I have a lot of control over my grades in math." Higher scores represent higher perceptions of control. Cronbach's alpha reliability estimate was .80.

Task Value. The Task Value Measure (Muis et al., 2015a; Eccles, Wigfield, Harold, & Blumenfeld, 1993; Pekrun & Meier, 2011) was used to measure students' perceptions of value for mathematics problem solving. All participants completed this scale one week prior to commencing the study. This scale assesses three dimensions of task value: intrinsic interest value (e.g., "In general, I find learning about math very interesting"), importance (e.g., "Learning more about math is very important"), and utility value (e.g., "In general, learning about math is useful"). Participants rated seven items on a 5-point Likert-scale ranging from "Not at all True of me" to "Very True of me." Cronbach's alpha reliability estimate was .83.

Emotion Regulation. The Emotion Regulation Questionnaire for Children and Adolescents (ERQ-CA; Gullone & Taffe, 2012) was used to measure students' emotion regulation strategies of cognitive reappraisal and expressive suppression. This questionnaire was modified for children and adolescents from the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003) for adults. The ERQ-CA includes 10 items that assess the emotion regulation strategies of cognitive reappraisal (six items, e.g., "I control my feelings about things by changing the way I think about them") and expressive suppression (four items, e.g., "When I'm feeling bad [e.g., sad, angry, or worried], I'm careful not to show it"). Items are rated on a 5-point Likert-scale ranging from "Strongly Disagree" to "Strongly Agree." It has good internal consistency and construct validity across age and sex (Gullone & Taffe, 2012). Cronbach's alpha reliability estimates were calculated: .84 for cognitive reappraisal and .58 for expressive suppression.

Emotions and self-regulatory processes. To capture students' emotions and self-regulatory processes as they occurred during problem solving, a think-aloud protocol (Type 1 protocol, see Ericsson and Simon [1998]) was combined with an emote-aloud protocol (Craig, D'Mello, Witherspoon, & Graesser, 2008; D'Mello, Craig, Sullins, & Graesser, 2006). This type of protocol provides a more accurate measure of students' self-regulatory processes (see Winne, Jamieson-Noel, & Muis, 2002) and emotions (Craig et al., 2008) as they spontaneously occur in real time. To train all students how to think and emote aloud prior to commencing the study, the researcher modeled how to think and emote aloud while completing a short mathematics problem. Students were instructed to say everything they were thinking and feeling as they experienced it while solving the mathematics problem. Students then had an opportunity to practice thinking and emoting aloud with a short mathematics problem unrelated to the one they were given for the experimental session. During the experimental session, each student's think-emote aloud was audio recorded using Apple Ear Pods with a microphone connected to a digital recording device.

Coding of Emotions and Self-Regulatory Processes

The think-emote-aloud audio recordings were transcribed verbatim, then segmented and coded for emotions and self-regulatory processes. Think-emote-aloud protocols ranged from 9 to 40 minutes. Muis et al.'s (2015a) coding scheme specific to mathematics problem solving was used to code for self-regulatory processes (see Table 8). Nineteen learning strategies were coded: prior knowledge activation, identifying important information, making/restating a plan, setting/restating a goal, hypothesizing, summarizing, help-seeking, coordinating informational sources, highlighting/colouring/drawing, calculating/measuring, re-reading, making inferences, self-questioning, monitoring, judgment of learning, self-correcting, evaluation, control, and task difficulty. These learning strategies were separated into three different categories. Following Muis et al.'s (2015a) study, we focused on three macro-level (see Greene & Azevedo, 2009) learning strategies including planning (e.g., planning and goal setting), cognitive learning strategies (e.g., hypothesizing, re-reading, highlighting/labelling, coordinating informational sources, summarizing), and metacognitive learning strategies (e.g., self-correcting, self-questioning, monitoring progress, evaluating).

To code for emotions, Di Leo et al.'s (2019) coding scheme for emotions specific to mathematics problem solving was used (see Table 9). This coding scheme was developed using the control-value theory of achievement emotions (Pekrun, 2006; Pekrun, Frenzel, Goetz, & Perry, 2007; Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011) as well as Craig et al.'s (2008) and D'Mello and Graesser's (2011) definitions of emotions. Overall, 13 emotions were included: surprise, curiosity, enjoyment, pride, hope, relief, confusion, frustration, boredom, anxiety, hopelessness, shame, and anger. Based on these two coding schemes, the primary investigator and one trained graduate student coded 10% of the transcripts until an acceptable level of inter-rater reliability was reached. Inter-rater agreement was established at 91%. Disagreements were resolved through discussion. The primary investigator coded the remaining transcriptions independently.

Mathematics Problem Solving Achievement. Students were given a complex mathematics problem called *The Garden Plot*. This problem was appropriate for fifth-grade students and was selected from the regular curriculum by the primary investigator and the students' homeroom teacher who was also their mathematics teacher. The standardized provincial grading scheme was used to calculate students' achievement on the problem. The objective of *The Garden Plot* was to have students develop the solution to an application problem by selecting numerous previously acquired mathematical concepts and processes and applying them in a new way. Moreover, the instructions to this problem did not suggest a procedure to follow nor the specific mathematical concepts and processes to use to solve the problem. This mathematics problem consisted of three components including analysis (worth 30%), application (worth 50%), and justification (worth 20%). For the analysis component, students were required to identify the information that was provided in the problem statement in terms of essential information to solve the problem and what information they had to use to solve it. For the application component, students were required to use calculations and apply mathematical concepts and processes to solve the problem. Finally, for the justification component, students had to adequately justify their work and calculations and provide a concluding statement. To establish inter-rater agreement, the primary investigator and one trained graduate student graded 10% of the problems. Inter-rater agreement was established at 98% and disagreements were resolved through discussion. The primary investigator graded the remaining problems.

Intervention. The overall objective of this intervention was to provide fifth-grade students with strategies to resolve their confusion that they experienced during mathematics problem solving. Specifically, through explicit instruction, the intervention was designed to: (1) normalize the experience of confusion during mathematics problem solving, (2) teach students about academic emotions (e.g., curiosity, enjoyment, confusion, frustration, boredom), (3) teach students to be mindful and bring awareness to their emotional state as they solve a mathematics problem, and (4) equip students with the learning strategies (e.g., re-reading, self-questioning, monitoring, evaluating) they can use to overcome confusion during mathematics problem solving.

The intervention titled "*I'm confused, now what?*" is a classroom-based training program designed for fifth-grade students. The three-hour intervention was comprised of two 90-minute lessons. This intervention incorporated instructional procedures as well as interactive activities including group brainstorming, think-pair-share (i.e., think about what was just learned, pair up with a peer, and verbally share with each other what they understand and learned), modelling of the learning strategies during mathematics problem solving by the primary investigator, and opportunities for students to practice the strategies while solving short and simple mathematics problems. The primary investigator delivered the training to the students in the intervention condition as a group, through PowerPoint slides. Content covered in the intervention included discussing what a problem is and the types of problems students can come across during mathematics problem solving; identifying different types of academic emotions, what each emotion can feel like physiologically, and when specific emotions can be experienced during mathematics problem solving (e.g., surprise when you get an unexpected answer to your calculation, anxious when you are worried you will not have enough time to complete the problem, confused when the problem does not make sense and you feel stuck, frustrated when you cannot seem to get the right answer to your calculation); and, identifying the learning strategies that can be helpful to overcome problems that can arise during mathematics problem solving (e.g., re-reading the problem and highlighting or identifying important information when you do not understand what you need to do, re-calculating when you are not sure if you got the correct answer, evaluating and looking over your work to make sure you did not forget anything, asking for help when nothing seems to be working).

Once the lessons on emotions and learning strategies were completed, the primary investigator modeled solving a mathematics problem while thinking and emoting aloud and implementing specific strategies after having expressed certain emotions and difficulties (e.g., "I do not understand what the problem is asking me to do. I am feeling a little bit confused right now and kind of worried I will not be able to solve this. I am noticing my emotions. What are some strategies I can use to help me? Let me look at my worksheet. Right now, I am feeling confused. I can choose certain strategies to help me out. I have control. Okay, I can re-read the problem, I can highlight the important information, and I can ask my teacher for help. Let me start with re-reading." After the primary investigator solved a problem while modelling the strategies, students then practiced implementing the strategies they learned while solving a simple mathematics problem (20 minutes).

Materials used in the Intervention. The primary investigator created a worksheet that was handed out to each student to help them follow a series of steps to take when they felt confused or stuck while solving the problem (see Appendix A). Students were given this worksheet during the first training session and used it during the practice sessions as well as during the study when solving the mathematics problem. Students were told that they could refer to it if needed and that it was not mandatory for them to use. If needed, this worksheet served as a visual prompt for students to help guide them through their confusion. The worksheet included allotted space for students to write their emotions, the issue they were having, and a list of strategies they could use to overcome their issue. The worksheet included six steps to take when confronted with confusion or a sense of being stuck. The six steps were as follows: 1) Stop and take a deep breath; 2) Think "How do I feel right now?" and "What is my problem?"; 3) Say "I have control, I have strategies to help me figure it out"; 4) List up to three strategies that can be used to overcome this problem; 5) Use one of those strategies; and 6) Evaluate whether it worked. If it did work, move on but if it did not work, go back to Step 1.

In addition to the worksheet, there were also two handouts that students could refer to while completing the mathematics problem (see Appendix A). The first handout included an entire list of emotions that can be experienced during mathematics problem solving, and the second handout included an entire list of the learning strategies that could be implemented during mathematics problem solving. Both the comprehensive lists of emotions and learning strategies were discussed during the brainstorming sessions during the lessons on emotions and learning strategies, respectively.

Procedure

Parental consent and student assent were collected prior to the intervention and mathematics problem solving sessions. Participants were randomly assigned to one of two conditions: the intervention condition (n = 34; n = 18 females) or the control condition (n = 33; n = 10 females). Random assignment was carried out through an online random number calculator to randomly assign participants to groups, i.e., *GraphPad Software* (graphpad.com). For the entirety of the study, students were separated into two different classrooms based on their assigned condition. That is, all students in the intervention condition remained in the same classroom together and students in the control condition remained together in a separate classroom. Once the questionnaires were completed, the intervention was carried out over two consecutive days (Day 1 and Day 2) and the mathematics problem solving session was carried out the following day (Day 3). While students in the intervention condition received the intervention, students in the control condition were in a separate classroom with their teacher engaging in regular coursework. As such, the control condition was a passive control condition.

One week prior to the study, all participating students completed the following self-report measures: Academic Control Scale (Perry et al., 2001; see Muis et al., 2015a), Task Value

(Eccles et al., 1993; Muis et al., 2015a; Pekrun & Meier, 2011), and Emotion Regulation Questionnaire for Children and Adolescents (Gullone & Taffe, 2012). On Day 1, students were assigned to their condition: intervention or control. Once students were separated into their respective groups on Day 1, they were delivered the first 90-minute intervention training lesson. On Day 2, students in the intervention condition received the second and final 90-minute intervention training lesson. Each lesson was divided into 30-minute segments to best maximize students' attention. On Day 3, all students participating in the study were given the same mathematics problem to complete. Students worked on the problem independently in their regular classroom. All students completed the problem between 9 and 40 minutes. The primary investigator read all the items for questionnaires out loud to the students and clarified and answered any questions they had. Once the study was completed, the primary investigator returned a week later to give the intervention training to students who were assigned to the control condition.

Results

Sample

Sixty-seven fifth-grade students participated in this research study; however, certain data were missing for seven students. More specifically, three students (from the intervention condition) who completed the mathematics problem did not have think-emote aloud data: one student refused to think-emote aloud and two students' audio recorder failed to capture their voices while they were solving the problem. As such, these three students' achievement data were kept but their data were not included in the emotion and learning strategies analyses that incorporated students' think-emote- aloud protocols. Additionally, four students (n = 2 intervention condition) were absent during the mathematics problem solving session and were thus excluded from the study. Overall, achievement results were derived from the mathematics problem scores which included a total of 63 students ($n = 32$ intervention condition) and the emotions and learning strategies analyses derived from the think-emote aloud data included a total of 60 students ($n = 29$ intervention condition).

The mean age of students was 10.84 for both the control and the intervention conditions ($SD = 0.32$, $SD = 0.31$, respectively). Overall, there were a total of 11 students who had an individualized education plan (IEP). In the control condition, there were a total of five students with an IEP ($n = 3$ with adapted curriculum and no diagnosis, $n = 2$ with adapted curriculum and a diagnosis of a specific learning disorder). In the intervention condition, there were a total of six students who were on an IEP ($n = 4$ with adapted curriculum and no diagnosis, $n = 1$ with adapted curriculum and a diagnosis of a specific learning disorder, and $n = 1$ with an adapted curriculum and a diagnosis of autism spectrum disorder).

Preliminary Analyses

Skewness and kurtosis values were examined for normality for prior knowledge, mathematics achievement, learning strategies, and emotions. Prior knowledge, mathematics achievement, and learning strategies were within the acceptable range for skewness and kurtosis (using Tabachnick & Fidell, 2013 criteria of $<|3|$ for skewness and $<|8|$ for kurtosis). Emotions fell within the range of $<|8|$ for kurtosis with a range from -2.37 to 7.05, but were positively skewed and fell outside the range of $<|3|$ for skewness, with a range from -0.85 to 4.84. Normality was not expected for emotions expressed in the think-emote-aloud (see Di Leo et al., 2019). Since the measurement of emotions was on a ratio scale with a meaningful zero, scores were not transformed (see Tabachnick & Fidell, 2013).

Gender differences were then examined across each of the variables within each condition. However, it is important to note that because the method for grouping was random assignment, equal numbers of girls and boys were not specifically assigned to both groups. Although the gender distribution within the intervention condition was fairly equal (n = 17 girls, n = 15 boys), this was not the case for the control condition as there were fewer girls in the control condition (n = 9 girls, n = 22 boys). Overall, no gender differences were found for prior knowledge, learning strategies at the macro level (i.e., planning and goal setting, and cognitive and metacognitive strategies), and positive and negative emotions. However, gender differences were observed for mathematics achievement, but only in the control condition and not the intervention condition. Specifically, within the control condition, girls outperformed boys on math achievement $F(1, 29) = 9.00$, $p = .006$, *partial* $\eta^2 = .24$ (M_{girls} = 70.24%, M_{boys} = 59.27%). Given this difference, prior knowledge was used as a covariate in all analyses.

Think-emote-aloud audio recordings ranged from 9 to 40 minutes. There was no significant difference on length of time spent thinking aloud, $t(1,57) = 1.14$, $p = .19$, between the control condition (M = 20.39 minutes, SD = 7.30) and the intervention condition (M = 18.03 minutes, SD = 6.33).

Task Value and Academic Control

Perceptions of task value and academic control were measured one week before the study commenced to determine whether there were group differences. Univariate analyses revealed no significant differences in perceptions of task value $F(1, 55) = .24$, $p = .62$, *partial* $\eta^2 = .004$ between the control condition (M = 3.93, SD = .78) and the intervention condition (M = 3.82, SD = .85). There was also no significant difference in perceptions of academic control $F(1, 54) = .37$, $p = .55$, *partial* $\eta^2 = .007$ between the control condition (M = 3.97, SD = .69) and the intervention condition (M = 4.08, SD = .69). These results indicate that students in both groups had equal levels of task value and academic control prior to beginning the study.

Emotion Regulation

The Emotion Regulation Questionnaire for Children and Adolescents was administered to establish whether there were differences in students' emotion regulation strategies of cognitive reappraisal and expressive suppression at baseline. Univariate analyses revealed that there were no significant differences in emotion regulation strategies of expressive suppression $F(1, 56) = .17$, $p = .68$ ($M_{control} = 11.39$, $SD = 3.08$, $M_{intervention} = 11.73$, $SD = 3.14$) or in strategies of cognitive reappraisal $F(1, 56) = .10$, $p = .75$ ($M_{control} = 21.28$, $SD = 5.84$), $M_{intervention} = 21.73$ $SD = 4.74$). These results indicate groups were equivalent in emotion regulation strategies prior to the intervention.

Gender differences within groups were also analysed. No gender differences were observed for cognitive reappraisal in the intervention condition ($M_{girl} = 21.12$, $SD = 4.06$; $M_{boy} = 22.43$, $SD = 5.50$) or control condition ($M_{girl} = 21.00$, $SD = 6.82$, $M_{boy} = 21.40$, $SD = 5.60$). There were also no differences for expressive suppression in the intervention condition ($M_{girl} = 11.50$, $SD = 2.07$; $M_{boy} = 12.00$, $SD = 4.11$) or control condition ($M_{girl} = 10.13$, $SD = 3.52$; $M_{boy} = 11.90$, $SD = 2.83$).

Analyses

The purpose of this study was to examine whether a classroom-based intervention targeting confusion and promoting self-regulatory processes would lead to higher mathematics achievement, greater planning, goal setting, cognitive, and metacognitive learning strategies during problem solving, as well as more positive emotions and fewer negative emotions during problem solving. To this end, a series of one-way analysis of covariance (ANCOVAs) was conducted to establish whether there were group differences on mathematics achievement, learning strategies used, and experienced emotions. Prior knowledge was used as a covariate for all analyses. Table 10 presents the means and standard deviations for each variable by condition.

Mathematics Achievement

An ANCOVA was conducted to address this study's first hypothesis that students in the intervention condition would perform better on the mathematics problem than students in the control condition. Results revealed a significant difference between groups on mathematics achievement after controlling for prior knowledge, $F(1, 60) = 5.45$, $p = .02$, *partial* $\eta^2 = .08$. Specifically, students in the intervention condition ($M = 65.26$, $SE = 3.78$) performed significantly better than students in the control condition ($M = 52.63$, $SE = 3.84$) with a medium effect size.

Learning Strategies

Three one-way ANCOVAs were conducted to examine the effectiveness of the intervention on learning strategies captured using the think-emote-aloud transcripts after controlling for prior knowledge. There was a significant difference between groups on planning and goal setting $F(1, 57) = 20.38$, $p < .001$, *partial* $\eta^2 = .26$, cognitive learning strategies $F(1, 57) = 6.93$, $p = .01$, *partial* $\eta^2 = .11$, as well as metacognitive learning strategies $F(1, 57) = 10.23$, $p = .002$, *partial* $\eta^2 = .15$. Specifically, the intervention condition engaged in more planning and goal setting ($M = 10.16$, $SE = 1.01$), cognitive learning strategies ($M = 31.90$, $SE = 2.54$), and metacognitive learning strategies ($M = 30.16$, $SE = 2.73$) than the control condition ($M = 3.81$, $SE = 0.98$; $M = 22.65$, $SE = 2.41$; and $M = 17.98$, $SE = 2.64$, respectively), with large effect sizes for all three macro processes. Table 11 presents the frequency of each learning strategy by condition.

Supplemental analyses were conducted to identify whether specific micro-level learning strategies were implemented more frequently among students in the intervention condition. Only significant results are presented. Results revealed that students in the intervention condition implemented the following learning strategies more frequently than students in the control condition: prior knowledge activation $F(1, 58) = 32.56$, $p = .001$, *partial* $\eta^2 = .36$, ($M_{intervention} = 2.48$, $SD = 2.31$; $M_{control} = .10$, $SD = .30$); identifying important information, $F(1, 58) = 8.22$, $p = .006$, *partial* $\eta^2 = .12$, ($M_{intervention} = 1.62$, $SD = 1.76$; $M_{control} = .58$, $SD = .96$); planning, $F(1, 58) = 19.44$, $p < .001$, *partial* $\eta^2 = .25$, ($M_{intervention} = 8.55$, $SD = 6.63$; $M_{control} = 2.87$, $SD = 2.67$); hypothesizing, $F(1, 58) = 12.87$, $p = .001$, *partial* $\eta^2 = .18$, ($M_{intervention} = .69$, $SD = 1.00$; $M_{control} = .03$, $SD = .18$), summarizing, $F(1, 58) = 4.93$, $p = .03$, *partial* $\eta^2 = .08$, ($M_{intervention} = 1.24$, $SD = 1.19$; $M_{control} = .68$, $SD = .75$); and monitoring, $F(1, 58) = 16.19$, $p < .001$, *partial* $\eta^2 = .22$, ($M_{intervention} = 18.21$, $SD = 9.44$; $M_{control} = 10.03$, $SD = 6.04$).

Emotions

Emotions expressed in the think-emote-aloud transcripts were coded to obtain the frequency of each emotion per participant. As predicted, there was no significant difference in the frequency of confusion experienced between groups $t(58) = 3.41$, $p = .73$. A series of one-way ANCOVAs were then conducted to examine the effect of the intervention on emotions experienced after controlling for prior knowledge. It was hypothesized that students in the intervention condition would experience a lower frequency of negative emotions (i.e., frustration, anxiety, boredom, hopelessness, shame, and anger) than students in the control condition and that students in the intervention condition would experience a higher frequency of positive emotions (i.e., curiosity, enjoyment, pride, relief, and hope) than students in the control condition. Only significant results are presented.

Results revealed a significant difference between groups on frustration $F(1, 57) = 4.19$, $p = .04$, *partial* $\eta^2 = .07$, curiosity $F(1, 57) = 11.90$, $p = .001$, *partial* $\eta^2 = .17$, enjoyment $F(1, 57) = 4.60$, $p = .04$, *partial* $\eta^2 = .08$, pride $F(1, 57) = 18.37$, $p < .001$, *partial* $\eta^2 = .24$, and relief $F(1, 57) = 7.24$, $p = .009$, *partial* $\eta^2 = .11$. Specifically, students in the control condition more frequently expressed frustration ($M = .83$, $SE = .22$) than students in the intervention condition ($M = .19$, $SE = .23$). Students in the intervention condition more frequently expressed curiosity ($M = .41$, $SE = .08$), enjoyment ($M = .52$, $SE = .12$), pride ($M = .60$, $SE = .08$), and relief ($M = .41$, $SE = .10$) than students in the control condition who expressed curiosity ($M = .04$, $SE = .08$), enjoyment ($M = .16$, $SE = .12$), pride ($M = .15$, $SE = .07$) and relief ($M = .04$, $SE = .09$) less frequently. Large effect sizes were observed for curiosity, pride, and relief, and medium effect sizes were observed for frustration and enjoyment. Table 12 presents the frequency of each emotion by condition.

Supplemental Qualitative Exploration of Think-Emote-Aloud Transcripts

Students' transcripts were further examined to provide a better understanding of the expressions of emotions and the use of learning strategies between both groups. This qualitative data is used to demonstrate the frequencies and patterns of emotions and learning strategies. Initially, all transcripts were included for these supplemental explorations and were separated by condition for comparative purposes. In total, 60 student transcripts were examined with 29 transcripts from the intervention condition and 31 transcripts from the control condition. The goal of this qualitative exploration was to identify ways students dealt with and managed a high frequency of confusion. To do this end, students' transcripts were further separated by the frequency of confusion expressed. Specifically, of the 60 students' transcripts, 16 students in the intervention condition and 21 students in the control condition expressed confusion at least one time. Within-subject investigations revealed that expressions of confusion ranged from zero to eight times in the intervention condition and from zero to seven times in the control condition. Students who did not express confusion at all were then eliminated from this exploration. Given that Di Leo et al. (2019) found that confusion and frustration occurred frequently among fifth grade students during mathematics problem solving and that confusion frequently transitioned to frustration, it was important to investigate whether students who expressed a high frequency of confusion (three or more expressions of confusion) also expressed a high frequency of frustration (three or more expressions of frustration). Therefore, to examine how high levels of confusion impact students during problem solving, transcripts of students who expressed a high frequency of confusion were explored.

Results revealed that in the intervention condition, 16 of 29 students (55.17%) expressed at least one instance of confusion. Of those who expressed confusion, 6 of 16 students (37.50%) expressed confusion at least three times. Of those who expressed a high frequency of confusion, 3 of 6 students (50%) expressed at least one instance of frustration but no students (0%) expressed more than two instances of frustration. In contrast, 21 of 31 students (67.74%) in the control condition expressed at least one instance of confusion. Of those who expressed confusion, 9 of 21 students (42.86%) expressed it at least three times. Of those who expressed a high frequency of confusion, 6 of 9 students (66.67%) expressed at least one instance of frustration and 4 of 9 students (44.44%) expressed a high frequency of frustration. See Tables 13 and 14 for the frequency of confusion and frustration among students who expressed confusion three times or more.

These data indicate that the students in the intervention condition who expressed a high frequency of confusion did not also express a high frequency of frustration. In contrast, in the control condition, four out of nine students who expressed a high frequency of confusion also expressed a high frequency of frustration. This may suggest that students in the control condition may not have had the appropriate strategies to overcome their confusion and, as such, experienced a high frequency of frustration. Even though some students in the intervention condition experienced a high frequency of confusion, they might have felt more comfortable with their state of confusion, perhaps because confusion had been normalized during the intervention training and they might have expected to experience it during problem solving. This is an idea that is worth further exploring in future studies. Moreover, students in the intervention condition received training on various learning strategies and were given a list of strategies that could be implemented to resolve confusion. Therefore, it might not matter how frequently a student experiences confusion during problem solving, but it is how the student reacts to it that matters - emotionally and cognitively. The following sections provide descriptions and examples of students' reaction to confusion. First, examples from students in the control condition are provided followed by examples from students in the intervention condition.

Reactions to Confusion among Students in the Control Condition

Numerous observations were made among students in the control condition. The first pertains to monitoring confusion. When students experienced confusion, they were not likely to metacognitively acknowledge their state of confusion and how their confusion re-occurred. Another observation was that when students in the control condition expressed confusion, they expressed being stuck and did not demonstrate knowing what to do next. It was observed that following these states of confusion, students expressed other negatives emotions (e.g., frustration, anxiety, boredom) and engaged in help-seeking behaviour. An example can be seen in the following excerpt:

After reading the problem, this student in the control condition expressed confusion at the onset of problem solving and then immediately expressed frustration and boredom and a desire to avoid or disengage from the task: “Oh my God, oh my God, I don’t feel good about this. It looks hard. I literally understand nothing. I don’t get it. 10% of the garden?! This is complicated. Oh my goodness I literally understand nothing. I really don’t want to do this, I don’t feel like doing it. Ugh oh my God. In my opinion, I find this boring.”

This student did not acknowledge the confusion and did not engage her regulatory processes to identify what strategy to use to attempt to overcome the confusion. This student then re-read one sentence of the problem and immediately asked a teacher for help, “I have a question”. Here, the student engaged in re-reading and help seeking, which are considered shallow strategies. After receiving help from the teacher, the student began to solve the problem and became confused again when calculating, “One fifth of 100, oh 50. But I have 45 squares. Oh wait. 45 divided by 2, what makes…? Oh this is so confusing, I want to stop.”

This is a clear example of when a student experiences recurring confusion and has difficulty resolving it independently. This also provides evidence for emotional-state transitions (Di Leo et al., 2019; D’Mello & Graesser, 2012), particularly patterns of confusion to frustration and boredom and then a desire to disengage. This example supports Muis’ et al. (2015a) argument that young students might not have the skills necessary to successfully resolve their confusion without an intervention to help students develop a foundation of skills and to provide them with the tools and strategies to address their confusion when it arises.

Another student in the control condition also exhibited frustration and boredom and then a desire to give up after the second instance of confusion: “I don’t even know if I did it right” then told the research assistant “I don’t think I can finish it. I’m basically doing trial and error and I’m calculating but it’s still not working.” This student re-started his calculations at every instance of confusion. Although re-calculating is a learning strategy and the student evaluated the efficacy of the strategy, this student continued to implement the same strategy despite its lack of success and then wanted to stop working on the problem altogether. The research assistant encouraged the student to continue. The student continued solving the problem and again expressed confusion and then frustration: “The cabbage, wait, did I put the cabbage? I don’t have turnips?? What? Ugh! Can I stop?” Research assistant: “Are you done?” Student: “I’m not done. I don’t have room for turnips, I don’t know where I can put them.” Research assistant: “Just do your best.” The student then attempted to solve another aspect of the problem (potatoes): “Let me see potatoes, I don’t even know about potatoes. It was a quarter of the garden. That is umm.. I’m stuck. I’m gonna re-start one more time.” This student’s strategy to resolve his confusion was to restart without identifying the source of his confusion. He did not acknowledge the confusion and did not appear to know what strategies to implement to resolve the confusion. He remained in a confused state and had subsequently expressed frustration, boredom and a desire to stop after his recurrent states of confusion.

This example provides additional evidence of the deactivating nature of boredom, and further supports D’Mello and Graesser’s (2012) model that confusion can be unproductive when it persists or when the student does not feel capable of managing or overcoming the impasse on their own. This pattern of confusion-frustration-boredom was often observed among students in the control condition.

Reactions to Confusion among Students in the Intervention Condition

In contrast to students in the control condition, when students in the intervention condition experienced confusion, they were likely to engage their metacognitive knowledge by acknowledging their state of confusion and devise a plan of what to do next. Once confused, it was observed that students engaged in self-regulated learning, acknowledged and monitored their emotions, particularly their state of confusion, monitored their progress and the learning strategies they selected, and evaluated whether the strategy was successful. Finally, it appeared that confusion served as a cue to alarm students that a learning strategy needed to be implemented or perhaps that a strategy needed to be changed. Presented below are numerous examples of how students in the intervention condition reacted to and attempted to resolve their confusion.

The following is an example of a student who worked through her confusion using strategies that were taught during the training: “Okay so I’m confused. I’ll start with what I know, that um, potatoes are one fourth of the garden. But how many spaces does she have in her garden? I don’t feel that good. I don’t know how much she has, like how big her garden is? I’m gonna fill in this paper thing (referring to the worksheet she was given to help work through confusion). So, stop, take a breath. How do I feel right now? I feel confused and unsure what is my problem. I don’t know if I should… I don’t know how much space does she have in her garden. Um, I have control, I have strategies to help me figure it out. I have a list of strategies. I’m gonna ask a teacher. I don’t feel that confident right now, I feel like it’s a little confusing for me. Um okay, I’m gonna break down the question and I’m also going to read the question again. So, the strategy that I’m gonna be using right now is ask a teacher” Here, the student experienced confusion and verbally acknowledged her state of confusion and reflected on how it made her feel. She then decided to look at the worksheet and the list of learning strategies that were provided to all students in the intervention condition. She engaged in self-regulated learning as she took responsibility of her problem solving and selected the strategies to try and decide her course of action.

After asking for help, this student counted the squares in the garden. “So, I know that there’s a hundred squares in all. So now I’m gonna work on the potatoes. I feel better now. So, it worked, my strategies worked. Now I feel like I’m kind of relieved because now I’m able to get past my problem.” This student monitored her emotions and evaluated whether her strategy worked and how that made her feel. Two minutes later, this student expressed confusion again. “So, one fifth, maybe it’s a half of 10? I think I’m confused. Let me rethink it. I know it’s a quarter but I’m not sure what I’m supposed to do right now. Now I’m feeling again confused. But this time, I’m not gonna ask a teacher, I’m gonna use another strategy. I’m gonna break it down another way and think about it another way.” In the face of recurring confusion, this student had not expressed any other negative emotions and continued to solve the problem by re-calculating and evaluating her work. At the end of the problem, the student reflected on her problem solving: “I stopped and took a deep breath and told myself I have control. And for emotions, I was a little proud of myself.” This student took the cue of feeling confusion to then stop and think about how to overcome it and identify which strategies might work best.

Indeed, there is evidence that students in the intervention condition attempted different strategies once they expressed a state of confusion. Another example of this was observed among a student who expressed confusion eight times while problem solving. The following excerpt is one instance of her confused state, her reflection on her emotional state, and the actions she took to overcome her confusion: “Wait, what am I doing? What am I doing? Okay now I’m just going crazy. Okay so re-read was a good strategy, I just didn’t re-read properly. I’m feeling unorganized and this usually happens to me in all my problems where it’s one part of the problem that messes up all my calculations and I'm confused and I don't know what I'm gonna do. Usually I'm in resource and they help me out, and I have other tools that can help or I'd be standing next to the teacher with other students and we'd be helped, but I mean, now I can't do that, so I have to re-read." This student acknowledged her confusion, monitored her emotions, and identified one strategy to engage in.

Like many students in the intervention condition, this student also reflected on the emotions she experienced and the learning strategies she used after completion of the problem: "So, I'm done. I sometimes felt, actually, usually I feel anxious. I felt anxious before the test. I felt a little frustrated, I have to be honest because at some points in the test I had trouble getting the answer. I felt confused a lot and I used the list of strategies. So I did use the deep breath one, I did re-read, I asked an adult for help, I reviewed my work, and I broke down the question. 1, 2, 3, 4, 5. I used 5 strategies. And now that it's done, I feel proud." This student reflected on her problem-solving experience and expressed having experienced frustration as a result of having difficulty finding the correct answer. She also reflected on the fact that she experienced confusion and used numerous strategies to overcome it and evaluated whether it worked.

Another student in the intervention condition read the problem and expressed some anxiety, "I'm not the best at fractions so I'm kind of scared". She then re-read and identified the important information in the text and planned her next action, "I'll start with what I know" and then the student wrote down the important information (i.e., the quantity of space in fractions that each vegetable takes up within a 10 x 10 grid), which consisted of the fractions. She then stated the following: "I may have to use the strategy list after if I really get stuck" perhaps suggesting that while she might be in a mild state of confusion, it was not sufficient to immediately implement a strategy on the strategy list. However, she did make a plan to consult the list if she felt it was necessary – thus engaging her regulatory processes and metacognitive knowledge (knowing when to apply a strategy). Later, as the student carried out her calculations, she expressed confusion again and identified the reason for her confusion: "Now I'm doing the carrots, okay now I'm confused. Let me look at my strategies list. Taking a deep breath. Okay, so I need to figure out what I'm stuck on and why I'm confused. So I think I'm confused because I kind of forgot what 0.20 is."

This student became confused again and stated: "I'm really not sure about the carrots, I don't think that's right. I really don't know actually, I'm feeling confused, like really confused." This student's confusion appeared to be significant enough as she once again looked at her list of possible strategies: "I'm gonna look at my strategies. Stop and take a deep breath. I think I'm gonna re-do the calculations because I don't think I did that right. So let me try this again. I think I'll do better this time." Here, the student experienced recurring confusion and stopped to review the list of strategies, evaluated her work thus far, changed her strategy of attacking the problem, and expressed a sense of hope for the outcome.

Similar to the previous student, once this student completed the problem, she reflected on some of the emotions that she experienced and the strategies that she implemented: "I'm done now. I felt surprised when I got the paper because I didn't think it would be a lot of fractions. So I was a little bit curious. I was proud and relieved when it was over. I was really confused. From my strategy list, I stopped and took a deep breath at the beginning when I didn't understand and figured out what I was stuck on. I re-read the problem, highlighted important information, summarized the important information, re-calculated, and checked and reviewed my work."

This final reflection was a common occurrence among students in the intervention condition, perhaps as they had been monitoring their emotions and strategy use throughout problem solving, it was natural to review their experience and express it verbally, thus further activating metacognitive processes. This type of post-problem-solving reflection might be helpful for students in developing self-regulated learning skills as they demonstrate the capacity to be aware of their problem-solving experience, how they felt, what strategies they used, what worked, and what might not have worked.

Discussion

Confusion, a negative activating emotion, can be related to optimal achievement outcomes when students appropriately implement learning strategies to resolve the confusion (D'Mello et al., 2014). However, confusion has been demonstrated to have detrimental effects on learning especially among elementary students (e.g., Di Leo et al., 2019, Muis et al., 2015a). Given this, research calls have been made to teach elementary students appropriate skills to resolve their confusion when it occurs during learning (Di Leo et al., 2019; Muis et al., 2015a). Therefore, the purpose of this study was to develop an intervention that teaches fifth-grade students about emotions (e.g., curiosity, enjoyment, confusion, frustration, boredom), and to equip them with the self-regulated learning strategies they can use to overcome confusion during mathematics problem solving through explicit instruction. To this end, we aimed to integrate emotions and cognitive processes within the same intervention as a cognitive-emotional strategy instruction rather than administer traditional cognitive strategy instruction interventions that focus solely on cognitive processes. As such, a key goal of this intervention was to emphasize cognitive-emotional relations and model self-regulated learning techniques to provide students with a repertoire of strategies that can be implemented specifically to resolve confusion.

Pekrun's (2006) control-value theory of achievement emotions, D'Mello and Graesser's (2012, 2014) framework, and empirical evidence from cognitive strategy instruction methods (e.g., Montague, 1992; 2008; Montague, Applegate, & Marquad, 1993) served as the foundations from which to develop the intervention. Overall, results were consistent with hypotheses in that students in the intervention condition scored higher on the mathematics problem, engaged in more cognitive and metacognitive learning strategies, and experienced more positive and fewer negative emotions. Each of these results are discussed in turn, followed by a discussion of broader educational implications. We end with limitations and future directions.

Learning Strategies

Previous research on cognitive strategy instruction has demonstrated the effectiveness of interventions designed to improve independent and self-regulated use of strategies (see review, MacArthur, 2012). Specifically, strategy instruction in the area of mathematics has been shown to increase the repertoire of effective strategies and to improve strategic knowledge, application of strategies, and problem-solving performance and accuracy (Case et al., 1992; Krawec, Huang, Montague, Kressler, & Melia de Alba, 2012; Montague, 2008; Montague et al., 2011). Consistent with this literature, this intervention was successful in teaching students a variety of strategies necessary to help them solve a complex mathematics problem. In addition to promoting self-regulated learning, our goal was to normalize the experience of confusion, and to bring students' attention to the kinds of learning strategies they could implement when they experienced confusion. Results from our research provide evidence that direct instruction with modeling plus scaffolded practice improved students' implementation of these strategies, particularly following confusion. That is, results revealed that, across the four phases of self-regulated learning, students in the intervention condition engaged in more cognitive and metacognitive learning strategies than those in the control condition. This provides evidence that the intervention was beneficial in students' implementation of learning strategies during complex mathematics problem solving.

Specifically, compared to the control condition, students in the intervention condition activated more prior knowledge and identified more important information during the task definition phase of self-regulated learning. Students in the intervention condition also made more plans during the planning and goal-setting phase of learning, and hypothesized and summarized more in the enactment phase of self-regulated learning compared to students in the control condition. Finally, students in the intervention condition monitored their progress more than students in the control condition. By training students to implement strategies across the various phases of self-regulated learning, this helped to foster better learning outcomes.

Interestingly, analyses revealed two trends whereby students in the intervention condition engaged in less help-seeking and more self-questioning. This could indicate that students in the intervention condition demonstrated more self-regulated learning and took responsibility over their mathematics problem solving as they more frequently self-questioned and had fewer instances of asking a teacher for help. This intervention could have implications for teachers of large classroom settings who might not have the time to provide "just in time help" when students experience difficulties when solving complex mathematics problems. By training students self-regulatory skills during problem solving, they may be more capable of resolving impasses on their own with the appropriate strategies.

Another important finding was that students in the intervention condition implemented more monitoring strategies than students in the control condition. It is likely that this intervention promoted metacognitive awareness during problem solving. Interestingly, there were no group differences in evaluation of calculations or final products (i.e., answers). Perhaps students at this school already received effective instruction on the importance of checking and evaluating one's work and thus no group differences were detected. Alternatively, perhaps our intervention was not effective in increasing these particular strategies during problem solving. Finally, there were no group differences in students' calculating, measuring, highlighting, labelling, drawing, and writing, which are common strategies during mathematics problem solving. This was expected and demonstrates that our intervention had an effect on only those strategies that were taught as part of the intervention.

Emotions

Previous research has shown that positive emotions predict an increase in cognitive and metacognitive learning strategies and academic achievement (Muis et al., 2015a; Pekrun, 2006). In line with this, evidence has also demonstrated that confusion, a negative activating emotion (Linnenbrink, 2007; Pekrun, 2006), can be unproductive for learning when it is not resolved (D'Mello & Graesser, 2012). This is especially true among elementary students as confusion leads to more subsequent negative emotions such as frustration, boredom, and hopelessness (Di Leo et al., 2019; Muis et al., 2015a). An observation made from the qualitative exploration of transcripts pertained to students' emotional awareness and recognition. It was observed that students in the intervention condition monitored their emotions and reflected on their emotions once they completed components of the problem as well as the whole problem, which might have in part contributed to the learning strategies they implemented and to their greater overall achievement on the problem.

In support of our hypotheses, students in the intervention condition expressed more positive emotions and fewer negative emotions than students in the control condition. Specifically, students in the intervention condition expressed more curiosity, enjoyment, pride, and relief and less frustration than students in the control condition. The five most frequently expressed emotions among students in the intervention condition were primarily positive emotions (i.e., three out of five) whereas the five most frequently expressed emotions among students in the control condition were all negative emotions. That is, the most commonly occurring emotions in the intervention condition were confusion (34.4%), pride (11.26%), curiosity, relief, and boredom (all 7.95%). In contrast, the five most frequently occurring emotions in the control condition were confusion (45.59%), frustration (19.12%), boredom (11.76%), anxiety (6.62%), and hopelessness (4.41%). These findings suggest that the intervention was successful in promoting positive emotions during mathematics problem solving.

These findings are particularly noteworthy. As discussed previously, it was not expected that students in the intervention condition would experience less confusion than students in the control condition. Rather, it was expected that students would react differently to confusion when it arose in terms of implementation of strategies to resolve confusion. Resolution of confusion more likely led to relief, joy, or other positive emotions rather than more negative emotions (Munzar & Muis, under review). That is, we expected students in the intervention condition to be less likely to fall into a cyclical trap of confusion-frustration-boredom-disengagement, as has been reported in previous studies (D'Mello & Graesser, 2012; Di Leo et al., 2019) than to students in the control condition. Our findings support previous research and provide evidence that this intervention was successful in helping students overcome the negative implications of confusion.

It may also be the case that, because the intervention focused on the normalization of confusion and the ability to manage that confusion through implementation of learning strategies, when students did experience confusion, they were more capable of regulating that emotion compared to students in the control condition. As previous research has shown, when elementary students experience confusion and are not able to resolve it, their perceptions of control decrease (Munzar & Muis, under review). This decrease in perceptions of control may then lead to more confusion (Pekrun, 2006). In contrast, when students are able to resolve confusion, their perceptions of control increase and they may cognitively reappraise their confusion (Munzar & Muis, under review). Although we did not measure perceptions of control during or following problem solving, evidence from our think-emote-aloud transcripts (as seen above) support this.

As such, it is possible that by teaching students to be more aware of their emotional states, when negative emotions arise, they might be more likely to take action to regulate them. Indeed, awareness is the foundation of self-regulated learning (Muis, 2007) and it is likely that the intervention helped promote awareness. Given that there were no significant differences in emotion regulation strategies between both groups prior to the intervention, it is fair to say that the differences in the frequency of positive emotions could be related to the components of the intervention that helped promote awareness, including monitoring and labelling of emotions. Overall, these findings indicate that the intervention was effective in promoting more positive emotions and fewer negative emotions.

Confusion. With regards to confusion, results revealed no difference in the overall amount of expression of confusion between groups. This was not surprising as confusion is the result of a cognitive incongruity or impasse (D'Mello & Graesser, 2011, 2012; Muis et al., 2018). Because the mathematics problem was the same for both groups, we expected that all students would experience relatively similar occurrences of confusion. Furthermore, differences were not expected since this intervention was not meant to reduce the experience of confusion during mathematics problem solving, but rather the negative emotions that are most likely to occur following confusion, such as frustration, boredom, and hopelessness. An important goal of the intervention was to normalize the experience of confusion, thus, it was explicitly stated that confusion is normal and is expected to occur especially during problem solving. Moreover, as noted above, students were explicitly taught learning strategies they could implement to resolve confusion. As previous research has shown, when confusion is resolved through appropriate learning strategies, this leads to higher levels of enjoyment and better learning outcomes (D'Mello et al., 2014; Munzar & Muis, under review).

These results are consistent with previous research that confusion commonly occurs during problem solving among elementary students (Di Leo et al., 2019; Muis et al., 2015a). To further understand confusion, it is critical to identify the source of confusion to be able to control and manage it during a learning task (Järvenoja, & Järvelä, 2005). Indeed, examination of the transcripts revealed a trend wherein students in the intervention condition questioned the source of their confusion when it arose, whereas students in the control condition expressed confusion but did not attempt to identify its source. Although we were able to trace whether students identified the source of their confusion, (i.e., monitoring and evaluating their confusion), we were unable to gather information to identify each student's specific causes of confusion as not all students verbally expressed what they were confused about. Future work should identify the source of confusion and evaluate whether there are differences in the consequences of various sources.

Finally, not all students expressed confusion. It is possible that the mathematics problem administered was not sufficiently complex to elicit confusion among a greater number of students. Alternatively, perhaps some students did not express confusion for fear of appearing incapable or perhaps some students (particularly those in the control condition) did not realize that they were confused and thus did not express it. Future research could implement a mathematics problem that is optimally challenging but that has a component of the problem that intentionally evokes confusion. This would provide greater understanding of how students react to confusion and attempt to resolve it after receiving cognitive-emotional strategy instruction.

Relations Between Emotions and Learning Strategies

According to Pekrun (2006; Pekrun & Stephens, 2012), emotions predict the types of cognitive and metacognitive learning strategies students use during learning and problem solving (Pekrun et al., 2007). These emotions can hinder or facilitate learning (Baker et al., 2010; D'Mello & Graesser, 2011; Pekrun, Goetz, Daniels, Stupinsky, & Perry, 2010). That is, positive emotions, such as enjoyment and curiosity, can facilitate learning (Muis et al., 2015a; Pekrun, Elliot, & Maier, 2009) whereas negative emotions, like boredom and frustration, can hinder learning (Pekrun et al., 2011). These relations are said to occur through self-regulatory processes including motivation and cognitive and metacognitive learning strategies (Op't Eynde, De Corte, & Verschaffel, 2007; Pekrun, Goetz, Titz, & Perry, 2002).

Although Pekrun (2006; Pekrun & Stephens, 2014) proposed that emotions predict learning strategies, it could also be the case that teaching students the appropriate learning strategies to use when specific emotions arise facilitates more positive emotions after resolution of negative emotions. In this way, patterns of relations between emotions and learning strategies may be more reciprocal than linear. The positive increase in emotions in the intervention condition could have been a function of successful implement of the learning strategies students were taught. If students experienced greater success due to these strategies, this could increase the experience of positive emotions. Reciprocally, an increase in positive emotions may have also increased use of those strategies, resulting in a positive feedback loop in the intervention condition. Future research could test this hypothesis via an in-depth analysis of sequential relations between emotions and learning strategies (Di Leo et al., 2019). Indeed, the increase in cognitive and metacognitive processes and positive emotions may have been one key factor in the increase in students' problem-solving achievement in the intervention condition compared to students in the control condition. This is discussed next.

Mathematics Problem Solving Achievement

To our knowledge, this study is the first to incorporate theoretical considerations of academic emotions into an intervention to promote self-regulated learning and learning outcomes among elementary students during mathematics problem solving. Although emotions and cognitive processes have been increasingly integrated within theoretical models of self-regulated learning (Efklides, 2011; Muis et al., 2018), they have not been integrated in practice through interventions for mathematics learning and problem solving. As such, findings from this research fill a gap in the educational psychology literature. Unlike previous interventions (e.g., Krawec et al., 2012; Montague, 2008; Perels, Dignath, & Schmitz, 2009; Perels, Gurtler, & Schmitz, 2005), this intervention was developed to take into consideration the role that emotions play in facilitating or constraining self-regulated learning. Moreover, in addition to normalizing the experience of confusion, students were taught to reflect on both their cognitive processes and emotional experiences. This combined training led to significantly higher performance on the mathematics problem among students who received the intervention compared to students in the control condition.

Indeed, what might have contributed to the success of this intervention was its integrated nature to support regulatory strategies including the monitoring of cognitive processes and of emotions. Previous research has demonstrated that monitoring progress is a particularly critical part of the self-regulated learning process (Winne & Perry, 2000). The mechanisms that underlie self-regulation, whether it be for behaviour, cognitions, learning, or emotions are the same (e.g., Perry, Hutchinson, Yee, & Määttä, 2017) and involve metacognition, motivation, strategic action (Winne, 2018), and understanding, labelling and controlling emotions (Perry et al., 2017). Given this, incorporating emotional awareness into the intervention may have helped students to regulate their confusion, thereby freeing up more cognitive resources to continue to implement the learning strategies necessary to succeed. Students in the intervention condition were taught that when faced with confusion, they can purposefully select from their repertoire of strategies, when to apply them, to monitor their progress, and evaluate whether the strategies were effective. This intervention focussed on having students bringing awareness to their emotional state and understand that emotions occur and are indeed part of learning and problem solving. Although directly controlling emotions (e.g., through cognitive reappraisal or expressive suppression) was not a component of the intervention, the intervention did promote the controlling of emotions indirectly, whereby students recognized and labelled their confusion and were taught to control it through applying learning strategies to resolve the confusion.

Bringing one's awareness and attention to one's emotional state and to internal and external experiences of the present moment through mindfulness techniques is an emerging area of research (Diamond & Lee, 2011; Kabat-Zinn, 2003). Specifically, classroom- and school-based mindfulness interventions are gaining popularity as they have demonstrated effectiveness in promoting students' regulation for attention, inhibition, emotional regulation and overall emotional well-being and mental health (e.g., Britton, Lepp, Niles, Rocha, Fisher, & Gold, 2014; Flook, Smalley, Kitil, Galla, Kaiser-Greenland, Locke, et al., 2010; Greenberg & Harris, 2012;

Kaiser-Greenland, 2010; Kuyken, Weare, Ukoumunne, Vicary, Motton, Burnett, et al., 2013; Mind and Life Education Research Network (MLERN), et al., 2012; Van de Weijer-Bergsma, Formsma, Bruin, & Bögels, 2012). Such interventions are drawn from cognitive-behavioural theoretical frameworks, which emphasize the reciprocal relationship between emotions and cognitions (Beck, 2011). As such, these interventions include mindful awareness of one's emotional state, actively describing and labeling emotions, and engaging in regulating and managing the emotional state such as through cognitive reappraisal or through mindfulness techniques including acceptance of the emotion or thought and deep breathing (e.g., Burrows, 2017; Diamond & Lee 2011; Willis & Dinehart, 2014). Indeed, parallels can be drawn between mindfulness interventions and interventions to promote emotional regulation through strategies such as attentional deployment (i.e., distraction, concentration), cognitive change (i.e., reappraisal), and response modulation (i.e., suppression) (Gross, 1998). Empirical evidence reveals that mindfulness interventions have beneficial effects for students' emotion-regulation skills and overall regulatory skills (e.g., Flook, et al., 2010). Findings from our research that incorporated mindfulness techniques do draw awareness to one's present state, provide evidence that this intervention was successful in promoting the monitoring of emotions and monitoring of learning strategies during the academic task. We discuss the educational implications next.

Educational Implications

There are several educational implications of this research. First, it is important to recognize that many school- and classroom-based programs aim to promote emotional awareness and development and emotion regulation within elementary and secondary schools (e.g., Broderick & Frank, 2014; Metz, Frank, Reibel, Cantrell, Sanders, & Broderick, 2013). Many programs focus on recognizing emotions and emotional competence (Buckley & Storino, &

Saarni, 2003), emotion regulation (Garner & Hinton, 2010; Metz et al., 2013), and mindfulness (Mendelson, Greenberg, Dariotis, Gould, Rhoades, & Leaf, 2010; Schonert-Reichl & Lawlor, 2010; Schonert-Reichl, Lawlor, Abbott, Thomson, Oberlander, & Diamond, 2015; Zenner, Herrnleben-Kurz, & Walach, 2014). However, these programs are often couched in social relations rather than specifically during learning and are aimed at improving emotional development, social-emotional functioning, and school readiness rather than improving the ability to regulate and manage one's emotions that arise specifically from academic tasks. Our intervention takes this approach to becoming more aware of one's emotions during a learning context and focuses on helping students to manage those emotions through various learning strategies. As such, these broader curricular objectives could readily be refocused on specific learning contexts with some teacher training for implementation.

Second, numerous school programs exist, particularly at the secondary level, that teach strategies for general academic success and that help students learn how to learn (e.g., *Mind Pop Program - Mind, plan, organize, and prioritize* [Clark & Leech-Pepin, 2017]). Additionally, in the province of Québec, mathematics problems are structured to help students activate prior knowledge, identify what they know from the problem statements, evaluate what they need to do to solve the problem, and justify their solutions. Although providing prompts for students helps, not all students take advantage of these prompts or know how to use them (Losenno, Muis, Munzar, Denton, & Perry, under review; Muis et al., 2015a). As such, students need direct and explicit instruction with modeling, and practice with scaffolding to support the development of these skills (Carnine, 1997; Perry, et al., 2018). Although some teachers engage in direct instruction of learning strategies to support the development of self-regulated learning, not all teachers do this (Perry, Brenner, & MacPherson, 2015). Indeed, teaching students strategies for learning is a complex task for teachers, and they need to be supported in this regard (Perry et al., 2018). As Coburn and Penuel (2016) suggested, one way to support teachers' implementation of self-regulated learning-promoting practices is through research-practice partnerships with teachers.

Finally, a unique feature of this research was that it was conducted in an authentic learning environment, i.e., in the students' regular classrooms. Many interventions that aim to promote self-regulated learning to improve mathematics problem solving have taken place outside the classroom with little connection made to the natural setting of students' regular courses and classrooms (e.g., Perels et al., 2005). This has implications on the problem-solving skills students transfer from one context to another (Mayer & Wittrock, 1996). Implementing such an intervention within a classroom setting conveys the generalizability of our results to the students' everyday academic lives and suggests a promising future for this intervention that can be integrated into the curricula.

Methodological Contributions

A methodological strength of this study pertains to the use of the think-emote-aloud protocol. Students' emotions and cognitive processes were captured in real time as they solved the mathematics problem. Research on emotions and self-regulated learning is undeniably rich with a variety of measurement strategies, including offline and online measures of both emotions and learning strategies. Offline measures are taken before or after a learning episode, whereas online measures are taking during learning (Schraw, 2010). Given the dynamic nature of self-regulated learning (Winne et al., 2002; Winne & Hadwin, 1997) and emotional experiences during learning (D'Mello et al., 2006; D'Mello & Graesser, 2011; 2012; Muis, 2007; Muis et al., 2018; Winne et al., 2002), it was critical to capture these events as they unfolded during learning rather than rely on reports gathered after learning. Moreover, previous research has criticized the use of offline self-report measures to capture the cognitive and metacognitive strategies used during learning (Winne et al., 2002). As such, we chose to measure learning strategies and emotions simultaneously as they occurred during problem solving.

Traditionally, researchers have used either a think-aloud protocol to capture learning processes or an emote-aloud protocol to capture emotions, but our study is the first to merge both protocols into one. Combining these protocols allowed for the opportunity to capture students' emotions and cognitive processes concurrently. Implementing a think-emote-aloud protocol allowed us to further evaluate whether our intervention was effective in promoting students' learning strategy use. However, requiring students to think-emote aloud may have also increased their cognitive load during problem solving, which can have negative effects on learning outcomes (Sweller, 1988; 1994; Sweller, Ayres, & Kalyuga, 2011). Future research should compare mathematics problem solving performance after implementation of the intervention between students who think-emote aloud and those who do not. On the one hand, performance differences may arise in favour of the group who does not think-emote aloud, which may be attributed to a lower cognitive load. On the other hand, performance differences may favour the think-emote aloud group given more of a focus on verbalizing emotions, which may draw greater awareness to emotions and more strategy implementation when confusion arises. Despite this potential difference, we still believe it was fruitful to adopt this approach for the initial evaluation of this intervention. Future research could implement other methods that capture these processes in an unobtrusive manner. For instance, self-report instruments coupled with video data of students as they solve the problems could be used to capture emotions. Students could then be interviewed to further probe what they were doing, what they were feeling, or why they were feeling a particular emotion, and if and how they managed that emotion.

Limitations and Future Directions

Although the results of the current study contribute to the literature on improving problem-solving and self-regulated learning skills in elementary students, it is important to consider the limitations of this research study. The first limitation pertains to the length of the intervention. Although the present intervention was effective at demonstrating immediate results, it was conducted within one week and could be considered a brief intervention. Other cognitive strategy instruction interventions have ranged in length between less than one week to over one month (see Xin & Jitendra, 1999). As many strategy instruction interventions have aimed to enhance metacognitive and cognitive strategies among students with mild to severe learning difficulties or deficits, more time was provided for them to learn and practice the strategies. This was not a longitudinal design and the intervention was completed within one week, thus the maintenance of these skills was not assessed at multiple time points after the intervention. It is possible that these skills might not be maintained over time without practice and teacher support. Therefore, future studies could investigate the length of time that is ideal for such training among inclusive classrooms, and assess the maintenance of the intervention over time.

Another limitation is that there was no within-subject analysis for pre- and post-intervention time points. Although significant results were found between groups, we were unable to determine whether there were intervention effects at the individual level. It would be interesting to identify the extent to which an individual improved based on the intervention. This could reveal aspects of the intervention that are effective or perhaps not effective for students with certain learning profiles. In addition, assessment of cognitive and emotional regulation strengths and weaknesses at the individual level would be beneficial to determine what skills or deficits the students currently possess and whether deficits improve post-intervention. Pre-intervention assessment could determine such strengths and weaknesses, and the pre- and post-intervention within-subject analysis could provide information regarding specific factors that helped contribute to better self-regulated learning strategies and better achievement. Furthermore, it would be interesting to assess how each student engaged in problem solving before the intervention and determine whether their overall strategies improved. Even though the think-emote-aloud provided rich information, it would be beneficial to interview students after they solved the problem. Students could be directly asked how they dealt with the confusion they experienced, how they think it affected them, and how they felt being confused. This could help researchers gain more understanding of the role of confusion during learning.

Additionally, a researcher delivered this intervention within a classroom setting. As noted above, teachers' role in promoting self-regulated learning is critical (Azevedo, Moos, Greene, Winters, & Cromley, 2008; Paris & Paris, 2001), thus future work should train teachers on how to improve students' self-regulation of emotions and learning during mathematics problem solving. It would be ideal for teachers to continuously model self-regulated learning strategies and emotional processes, model monitoring and labelling of their emotions as they experience them while engaging in an academic task such as mathematics problem solving. Teachers' modeling of emotion regulation through emoting aloud during problem solving tasks can help promote students' emotional awareness during academic tasks. This may then help students understand and use appropriate language for the emotions they experience. Continuously thinking and emoting aloud and modeling may promote students' understanding of how emotions and learning strategies play a role in learning.

However, the quality and effectiveness of the training is dependent on the individual who is teaching the skills (Dignath et al., 2008). Findings from meta-analyses revealed that the effect sizes of self-regulated learning training programs were smaller when teachers trained students than when researchers trained students (Dignath & Büttner, 2008; Dignath et al., 2008). Taken together, even though cognitive strategy instruction has shown to be beneficial for students, it cannot be assumed that teachers implicitly know how to provide this type of training and know what and how to model the specific skills. Indeed, research on teacher beliefs, knowledge, and classroom practice of self-regulated learning reveal that there are gaps in teachers' knowledge, personal practice, and classroom practice of self-regulated learning (e.g., Dignath-van Ewijk & van der Werf, 2012; Lombaerts et al., 2009; Perry et al., 2007; Spruce & Bol, 2015) and possibly might also not have training about monitoring academic emotions. Therefore, teachers likely need to receive explicit and direct training on how to teach young students skills to promote the monitoring of their emotions and self-regulated learning skills. While there are teacher-training programs to promote self-regulated learning in the classroom (e.g., Perels, Merget-Kullman, Wende, Schmitz, & Buchbinder, 2009), there continues to be a lack of empirically-tested training programs (Dignath & Büttner, 2008). Therefore, future research might endeavour to design and test teacher training and professional development programs aimed at training teachers to promote self-regulation of learning and academic emotions as students solve complex problems.

Conclusion

Many studies that have aimed to improve mathematics skills through strategy instruction administered specifically to students with special educational needs (e.g., Case et al., 1992; Cassel & Reid, 1996; Montague, 2008) as these students have specific difficulties acquiring and implementing skills to carry out mathematics problems (Carnine, 1997). Although strategy instruction has been shown to be effective for students with mathematics difficulty and special educational needs (Kroesbergen & Van Luit, 2003), less research has been conducted with a mixed group of students with diverse needs. Delivering an intervention that is classroom-based makes it so that the training provided within the intervention is available to all students rather than to a select few who are typically removed from the classroom to receive the training. To explore whether this intervention would be effective among a group of students with and without special needs, this intervention was conducted within an inclusive classroom among a diverse sample of students with various learning profiles, levels of ability, and needs. Specifically, 19% of the students in the intervention condition had an individualized education plan (IEP) with adapted curriculum objectives (including one student with a learning disorder and one student with autism spectrum disorder). Our findings demonstrate that a strategy instruction intervention that incorporates emotions (i.e., cognitive-emotional strategy instruction) was successful in promoting high achievement outcomes among students with various learning profiles. The results of this research extend previous research through delivering strategy instruction to students with diverse learning profiles and demonstrated the effectiveness of a classroom-based intervention.

Collectively, these findings provide insight into cognitive-emotional strategy instruction and the need of explicitly teaching young students self-regulated learning strategies to overcome their confusion. Previous interventions focused solely on the cognitive component of problem solving and excluded the emotional components. This study is of the first to include emotions and target confusion within an intervention for mathematics problem solving among elementary students. As such, this research adds to the current literature on the relations between emotions and self-regulated learning and broadens the literature on cognitive strategy instruction as it incorporates emotions. This intervention promoted the use of cognitive and metacognitive strategies within a classroom context, which is critical for self-regulated learning intervention efficacy (Hattie et al., 1996). The focus of the intervention was to teach students how to be active learners and conscious of their emotions and progress during problem solving. The results of this study extend previous findings of strategy instruction and offers suggestions for furthering exploration in this field. It is important that in moving forward, pedagogical design and academic interventions are affectively supportive and promote active awareness and mindfulness of academic emotions and learning strategies.

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Table 8.
Coding scheme for learning strategies in think-emote-aloud protocol

Level (Macro) / Micro	**Definition**	**Examples**
Level 1 – Task Definition	A learner generates a perception about the task, context, and the self in relation to the task. External and internal conditions play a major role.	Prior knowledge activation, beliefs, motivation, and knowledge of strategies are activated during this level.
Prior Knowledge Activation	Searching for or explicitly recalling relevant prior knowledge.	"Oh I remember now! 0.20 means 20 out of 100." "100 divided by 20, which is 5. I already know that." "This is percentage because 10 is a tenth of 100 and 100 always goes with percentage." "And a quarter of a hundred is 25. I know that because of money." "100 divided by 4 that equals to 25. I'm not even going to do the calculation because I know what it equals to because you know, it's one of the things that you remember."
Identifying Important Information	Recognizing the usefulness of information.	"It's the same area as the cabbage. I have to write that down because it's good information, it's important." "Hold on I need to remember this, let me write it down. Onions and herbs are half so they equal 5."

Level 2 – Planning and Goal Setting	The learner begins to devise a plan to solve the problem and sets goals.	E.g., Planning to use means-ends analysis, trying trial and error, identifying which part of the problem to solve first, solving it within a specific amount of time.
Level (Macro) / Micro	**Definition**	**Examples**
Making / Restating a Plan	Stating what approach will be taken, what strategy will be used to solve the problem, or what part of the problem will be solved in some sequence. This includes restating plans.	"I'm going to highlight the things I'm going to put in there so I remember it and I don't have to keep looking for it." "I think I'm going to ask an adult, but first, I'm going to do my other strategies" "First, I'm going to highlight the important information."
Setting / Restating a Goal	A goal is modeled as a multifaceted profile of information, and each standard in the profile is used as a basis to compare the products created when engaged in the activity. This includes restating goals.	"I need to fill in 25 of the spaces for potatoes." "I have to colour in 10." "I need to do onions and herbs. So it's a half, so I need to stop at the half part."
Level 3 – Enactment	Enactment occurs when the learner begins to work on the task by applying tactics or strategies chosen for the task.	
Hypothesizing	Making predictions.	"I think the garden is worth 100." "Carrots is 0.20 of the garden, so I guess that's 20%."
Summarizing	Summarizing what was just read in the problem statement.	"So basically, I have to help her plant her garden with all the vegetables and stuff." "Turnips is the same as the cabbage. So that means the cabbage is 1 fifth so turnips will be the same."
Help Seeking	Asking for help from a teacher, peer, or other source. Help seeking for information or help seeking for evaluation.	"Do I write P for potatoes?" "Wait, so I have a question. Are the onions and herbs the same?"

Level (Macro) / Micro	**Definition**	**Examples**
Highlighting / Labeling / Colouring / Drawing / Writing	Highlighting information, labeling information as part of the problem-solving process, or taking notes in reference to the problem. Making a drawing to assist learning or as part of solving the problem.	"Okay, let me put the 10 beets [writing] b,b,b,b,b,b,b,b,b,b." "This is beets, this is potatoes, this is cabbage [writing]." "I'm highlighting this with my yellow highlighter." "I'm just going to write cabbage equals 1 fifth of the garden [writing] 1 fifth of the garden."
Calculating / Measuring	Solving equations, measuring, or other similar features.	"Ok, long division. 5 goes into 1 zero times. 5 goes into 10 two times, minus that by ten equals 0. Bring down the 0. 5 goes into 0 zero times. So, 20 times 1 equals 20 and so 20 squares are cabbage." "10, 20, 30, 40, 50, 60, 70, 80, 90, 100, that's 100 squares in the grid."
Re-Reading	Re-reading a section of the problem, word for word. Important that it is word for word, otherwise it is summarizing.	"I'm going to go back to the first page. Onions and herbs are half of the area for the beets[re-reading]" "OK. I'm going to re-read the whole entire problem."
Making Inferences	Making inferences based on information read or products created from solving the problem. self-explanation). Explaining why something was done. Key word is "because."	"So, um, that should be, if I'm right, it should be 5 because beets are 10." "Turnips equals to 20 because 1 fifth of a hundred is 20. So, let's do that." "I'm guessing that 0.20 is 20 because it's not a whole, but it's 20, so yeah."

Level (Macro) / Micro	**Definition**	**Examples**
Level 4 – Monitoring and Evaluation	Various types of reactions and reflections are carried out to evaluate the successes or failures of each level or products created for the task, or perceptions about the self or context. Reaction and reflection also includes judgments and evaluations of performance on a task as well as the attributions for success or failure.	Products created are compared to the standards set via metacognitive monitoring. Monitoring and evaluation can include any facet listed above (e.g., progress, motivation, plans, goals, strategies, products like answers or drawings made).
Self-Questioning	Posing a question.	"Where did I go wrong?" "Carrots 0.20 of the garden. Well is that 20%?" "So how many squares are there in the grid?" "So now what am I going to do?"
Monitoring	Monitoring something relative to goals.	"Now I'm going to make sure I have all of them. 1,2,3,4,5,6,7,8,10. Ok." "I am working on the 1 fifth for cabbage." "So, I found carrots, cabbage, beets, and potatoes. So, I'm missing onions and herbs, and turnips." "The turnips is my last one. After this, I'll be done" "Turnips, I did that. It's only onions and herbs I have left"
Judgment of Learning	Learner is aware that something is unknown or know; not fully understood, or completely understood.	"I think I'm feeling pretty confident with what I'm doing now" "Okay, I think I'm getting it" "I have no clue what I'm doing right now."

Level (Macro) / Micro	**Definition**	**Examples**
Self-Correcting	Correcting one's mistakes.	"I messed up. I'm going to get my eraser and erase this." "[counting from 1] … 17, 18, 19, 20, 21, 22, oops I passed it. … [counting from 1] … 18, 19, 20." "Now, let's go on to 0 on 20. No, oops, 0 point 20."
Evaluation	Judging whether goals have been met, whether a particular strategy is working, whether the answer is correct, whether the work is neat, etc. Judgment of all facets that fall under monitoring.	"So, potatoes are 1 fourth of the garden. So that would be 100 divided 4 is 25. So yes, that's good okay." "So, I don't think I got it. I think I have to do it over again." [after calculating] "20. Perfect! Which means I got it right." [checking over work] "So 10% of 100 equals 10. Ok so I got that right."
Control	Changing strategy when monitoring or evaluation results in a determination that goal has not been met.	"Okay. I'm just going to do this a different way." [after starting to count the squares in the grid] "So, 1,2,3,4,5,6,7,8… [counting to 37 by digit]. Wait. Maybe I can go by tens. Maybe I can count by tens. 10, 20, 30, 40… [counting to 100 by tens]."
Task Difficulty	Statements reflecting the difficulty or easiness of a task.	"So this is pretty easy." "This just got tricky." "It looks so simple but it's really hard."

Table 9.
Coding scheme for emotions in think-emote-aloud protocol

Emotion	Description/Definition	Example
Curiosity	Interest, intrigued	"Wait, how about the turnips?" "Hmm I wonder if 1 fifth could be about 50? or another 25? Or maybe…" "Ooooh, how many squares are there in here [referring to the grid]. Let me see"
Enjoyment	Excited, enthusiastic, happy	"I'm enjoying this right now because I like math very much" "So I feel calm and kind of enjoying this" "I'm happy I know what I'm doing"
Surprise	Astonished, amazed	"So that's one line for the beets. Woah what? One line?... Alright" "I feel surprised that I actually got the answer right"
Confusion	Puzzled, mixed up	"So 10% every ten? What? Wait. That doesn't make sense" "Just by the look of it, I feel a bit confused because there's a lot squares and I'm a bit confused at what to do with them" "I'm so confused right now, I just can't count. We have to colour it in and it confuses me because, uhhhh, how do I do this?!"

Frustration	Irritated, dissatisfied	"Okay then beets are wrong. No no no no no. Ugh! I feel annoyed" "Okay, I'm annoyed right now" "Ah I did it all wrong! Argh, I have to erase all of it"
Boredom	Dull, monotonous	"Yeah, this problem is pretty easy and I'm pretty bored" "I'm bored to death by this math problem" "In my opinion, I find this boring"
Anxiety	Worried, nervous	"What's really worrying me is I don't know if I'm getting the 100 divided by 5. I don't know if I'm getting that right." "So I'm not the best at fractions so I'm kind of scared" "I feel nervous because of all the percentages"
Pride	The state of being proud. A feeling of happiness when you do something good or difficult.	"[at the end of the problem] I'm proud of myself" "I feel proud that I finished"
Relief	The removal or lightening of something painful or distressing.	"Finally, finally, finally, finally I am done! Hallelujah" "I am relieved that it's over" "I think I am doing okay so far, I am feeling relieved"
Hope	To want something to happen or be true and think that it could happen or be true.	"So if that's 20 of a hundred, it's 20 squares. I hope so" "I'm not the best at fractions, so hopefully I get them right"
Hopelessness	Having no hope, no expectation of good or success. Incapable of solution, management, or accomplishment.	"I'm probably gonna get this all wrong" "I give up"

		"I keep doing this wrong, this is impossible"
Anger	To become angry.	No participant expressed anger in this study.
Shame	A feeling of guilt, regret, or sadness that you have because you know you have done something wrong.	No participant expressed shame in this study.

Table 10.
Means and standard deviations for each variable by condition

	Intervention Condition	Control Condition
	Mean (*SD*)	Mean (*SD*)
Prior knowledge	76.06% (5.68)	77.91% (6.49)
Math achievement	65.09% (20.83)	52.81% (21.49)
Planning and goal setting	10.10 (6.99)	3.87 (3.30)
Cognitive learning strategies	31.57 (16.22)	22.94 (191.06)
Metacognitive learning strategies	29.83 (19.35)	18.29 (9.05)
Surprise	.24 (.51)	.13 (.34)
Enjoyment	.52 (.79)	.16 (.45)
Curiosity	.41 (.57)	.03 (.18)
Pride	.59 (.50)	.16 (.37)
Hope	.21 (.49)	.03 (.18)
Relief	.41 (.73)	.03 (.18)
Confusion	1.79 (2.41)	2.00 (2.28)
Anxiety	.34 (.55)	.29 (.94)
Frustration	.17 (.38)	.84 (1.64)
Boredom	.41 (.63)	.52 (.85)
Hopelessness	.10 (.31)	.19 (.60)
Anger	0 (0)	0 (0)
Shame	0 (0)	0 (0)

Note. Prior knowledge and mathematics achievement are presented as percentages. Learning strategies and emotions are presented in frequencies, i.e., number of times they were expressed within the think-emote-aloud transcripts.

Table 11.
Frequency of learning strategies in the think-emote-aloud protocols by condition

	Intervention Condition			Control Condition		
	Frequency	Range	Percentage	Frequency	Range	Percentage
Prior Knowledge Activation	72	0-9	3.25	3	0-1	0.20
Identifying Important Information	47	0-6	2.12	18	0-3	1.19
Making / Restating a Plan	248	0-29	11.20	89	0-9	5.89
Setting / Restating a Goal	45	0-7	2.03	31	0-4	1.40
Hypothesizing	20	0-3	0.90	1	0-1	0.06
Summarizing	36	0-4	1.63	21	0-2	1.39
Help Seeking	10	0-2	0.45	28	0-7	1.85
Highlighting / Labeling / Drawing / Writing	245	0-23	11.06	198	0-16	13.08
Calculating / Measuring	296	0-28	13.36	284	0-27	18.76
Re-Reading	42	0-9	1.90	58	0-4	3.83
Making Inferences	134	0-11	6.05	100	0-10	6.61
Goal-Directed Search	0			0		
Self-Questioning	110	0-13	4.97	74	0-12	4.89
Monitoring	528	0-42	23.84	311	0-24	20.54
Judgment of Learning	99	0-20	4.47	67	0-7	4.43
Self-Correcting	48	0-6	2.17	41	0-7	2.71
Evaluation	169	0-30	7.63	132	0-10	8.72
Control	21	0-4	0.95	16	0-3	1.06
Task Difficulty - Difficult	21	0-4	0.95	28	0-6	1.85
Task Difficulty - Easy	24	0-4	1.08	14	0-4	0.92
Total Learning Strategies	2,215	0-42	100	1,514	0-24	100

Table 12.
Frequency of emotions that occurred within each group

	Intervention Condition			Control Condition		
	Frequency	Range	Percentage	Frequency	Range	Percentage
Surprise	7	0-2	4.64	4	0-1	2.94
Enjoyment	15	0-3	9.93	5	0-2	3.68
Curiosity	12	0-2	7.95	1	0-1	0.74
Pride	17	0-1	11.26	5	0-1	3.68
Hope	6	0-2	3.97	1	0-1	0.74
Relief	12	0-3	7.95	1	0-1	0.74
Confusion	52	0-8	34.44	62	0-7	45.59
Anxiety	10	0-2	6.62	9	0-5	6.62
Frustration	5	0-1	3.31	26	0-5	19.12
Boredom	12	0-2	7.95	16	0-3	11.76
Hopelessness	3	0-1	1.99	6	0-3	4.41
Anger	0	0	0	0	0	0
Shame	0	0	0	0	0	0
Total emotions	151	-	100	136	-	100

Table 13.
Frequency of confusion and frustration among students who expressed a high frequency of confusion in the intervention condition

Student	Frequency of Confusion	Frequency of Frustration
1	5	0
2	5	0
3	5	0
4	5	1
5	8	1
6	8	1

Table 14.
Frequency of confusion and frustration among students who expressed a high frequency of confusion in the control condition

Student	Frequency of Confusion	Frequency of Frustration
1	3	4
2	3	6
3	4	0
4	5	1
5	5	5
6	6	1
7	6	2
8	7	0
9	7	5

Chapter 4

Final Discussion

General Discussion

Emotions are not only omnipresent in learning and in mathematics problem solving, but they are also influential. Emotions predict the learning strategies students engage in as they learn and problem solve, which subsequently impacts their performance and achievement. Positive emotions, such as curiosity and enjoyment, have been typically observed as beneficial for learning whereas negative emotions including confusion, boredom, frustration, and hopelessness, have been typically observed to hinder learning and achievement. However, certain negative emotions, such as confusion and anxiety, can have positive effects on learning and achievement depending on the intensity and persistence of the emotion.

Today, although there is greater awareness of the significant impact emotions have in academic contexts, this has not always been the case. Much research in education placed a central focus on cognitive processes involved in learning without acknowledging affective contributions or even including them into empirical research. Early efforts to address this lack of empirical consideration of emotions in learning has led to a burgeoning of research on the effect of emotions on academic performance. However, this interest was mainly directed towards anxiety in the context of learning and performance, with other academic emotions being entirely overlooked. Additionally, early research on academic emotions in learning contexts was largely conducted with samples of adult learners or university students with less focus on younger students. As such, calls have been made to expand the understanding of various academic emotions among elementary students and to further integrate emotional experiences and cognitive processes in theory but also into practice. This dissertation responds to calls made within educational psychology to expand our understanding of academic emotions among young students and to better integrate emotions into learning and cognitive theories in practice. The empirical work presented in this dissertation addressed several gaps in the literature and contributed to the broadening of our understanding of academic emotions during problem solving among elementary students. Contributions are detailed in the following section.

Contributions

The work in this dissertation was drawn from theoretical frameworks in the fields of developmental, educational, cognitive, and clinical psychology, and from the learning sciences. Together, the various frameworks informed my research questions and hypotheses, research design, measures, analyses, and interpretation of the results. Throughout each chapter, I have aimed to add to, refine, and extend theoretical knowledge and practical applications. This research is unique given that each empirical study was conducted with elementary students in authentic classroom settings wherein cognitive/metacognitive processes and emotional experiences were captured in real-time. Further, I have made numerous contributions, which I elaborate below.

I began my dissertation with a literature review (Chapter 1) to delineate the progression of the field's understanding of emotions in educational contexts, synthesized relevant theoretical frameworks, and identified gaps in the literature. Conclusions of this review included: (1) the need for the integration of emotions into research on learning and cognitive processes in theory and in practice, (2) to examine the antecedents and consequences of emotions during problem solving with elementary-aged students, (3) to evaluate whether patterns of emotional dynamics identified with adults during complex learning could be observed with elementary students, and (4) to design a classroom-based intervention that incorporates academic emotions and promotes students' learning and achievement.

Following the review, two empirical manuscripts were presented to address the gaps in the literature. The first empirical manuscript (Chapter 2) comprised of two studies, which contributed to the literature by: (1) enhancing understanding of relations between emotions, learning strategies, and learning outcomes with elementary students during complex mathematics problem solving within a classroom setting, (2) demonstrating that emotions predict the planning, cognitive, and metacognitive learning strategies elementary students implement during problem solving, (3) establishing patterns of emotional state transitions among elementary students during problem solving, and (4) extending the model of affective dynamics by identifying the learning strategies that immediately follow an emotion during problem solving.

Additionally, the contributions I have made all pertain to elementary students. Given that the majority of previous research examined academic emotions among adult learners, it was unclear whether relations between emotions, learning, and achievement observed among adult students were similar to younger students. Conclusions from Chapter 2 were important in identifying patterns of relations, particularly with regard to confusion, among elementary students during complex problem solving. Although previous studies with adults have demonstrated that confusion may be productive for learning if the appropriate learning strategies are implemented to resolve confusion, my findings indicated that confusion may be primarily unproductive for elementary students as they might not have yet acquired the appropriate learning strategies or know how and when to implement them to effectively resolve their confused state.

These conclusions propelled me to design an intervention for elementary students to help them overcome their confusion when it arises during mathematics problem solving through the application of appropriate self-regulated learning strategies. This intervention is the first of its kind as it integrated a direct focus on academic emotions within cognitive strategy instruction. Additionally, I extended previous methods that measure cognitive processes or emotional experiences during a task through merging think-aloud and emote-aloud protocols for a combined think-emote-aloud protocol. By using a think-emote-aloud protocol, rather than offline self-report measures, allowed for the collection of rich information with regard to the interplay between emotions and cognitive and metacognitive processes during learning.

Furthermore, this intervention can be used as a promising starting point for teacher training and be part of the curricula and overall classroom culture. Although emotions are discussed in schools and within classrooms, they are discussed with regard to social-emotional functioning or to the emotion regulation of intense emotions that can be disruptive to the student and their peers within classroom and overall school environment. The majority of classroom-based interventions focusing on emotions aimed at improving emotional regulation for students' overall mental health and well-being, but neglect emotions that arise directly from academic tasks or from prospective and retrospective achievement outcomes. Teaching students about the various academic emotions, how and when they are likely to occur, what the emotional experience might feel like and how it may impact learning can have a multitude of benefits. It might promote not only the normalization of any and all academic emotions as they arise during learning and problem solving, but it also might promote the awareness, identification, and subsequently the management of such emotions. Including academic emotions in the conversation between teachers and students as well as between researchers and teachers helps illuminate the fact that emotions are a normal part of the learning and problem solving process. This is a specific topic that has not yet been implemented in practice. Future directions to advance the literature are outlined next.

Future Directions

Each manuscript in this dissertation outlined limitations and offered suggestions for future research. In this section, I will elaborate on those previously stated and propose more recommended avenues for research. The first pertains to the reciprocal relation between emotions and learning strategies. Conclusions from Chapter 2 revealed that emotions predict learning strategies. Conclusions from Chapter 3 revealed that students who engaged in more self-regulated learning strategies also experienced more positive emotions, fewer negative emotions, and better achievement. Although researchers have conceptualized patterns of relations between emotions and learning strategies as reciprocal (see Pekrun, 2006), most empirical work has treated them as uni-directional whereby emotions are antecedents to learning strategies. Evidence from this research suggests that these relations may be more reciprocal than uni-directional; an increase in positive emotions may have increased use of learning strategies, and reciprocally, greater success due to these strategies could increase the experience of positive emotions resulting in a positive feedback loop in the intervention condition as reported in Chapter 3. Future research could test this hypothesis via an in-depth analysis of sequential relations between emotions and learning strategies.

Another avenue for future research is related to the generalizability and transference of self-regulatory skills. An important research question to investigate is which strategies learned by the student during training can be transferable to spontaneous and appropriate application of the strategies within the classroom and whether a cognitive-emotional strategy instruction within the context of mathematics could be generalized to other academic activities such as reading comprehension. This intervention promoted self-regulated learning within a specific context, i.e., during mathematics problem solving and when confusion was experienced. Learning self-regulated strategies within a specific context to then be generalized to other contexts is an important developmental and educational process for young students. The strategies they engage in to effectively carry out the task such as identifying important information in the text, use of prior knowledge, re-reading, self-questioning, summarizing, and monitoring could then be transferred to other domains such as sciences or other activities such as reading comprehension. While strategy instruction can differ from one content area to another, future interventions could be developed for different content areas with specific strategies grounded in that area. Equally as important as the strategies that are being instructed is the method by which strategies are instructed. Research has demonstrated that children learn through explicit instruction of a task, having the steps broken down and modeled by a teacher, practice and master the steps. Therefore, it is equally crucial for teachers who serve as the models to have the necessary training on how to teach these skills as it is for interventions that are developed to promote such skills.

With regards to interventions that focus on academic emotions, it would be important to investigate the efficacy of interventions targeting the experience of other emotions that could be detrimental for students, such as frustration or boredom. Given the importance of mindful awareness and monitoring of emotional experiences during academic tasks in the management of emotions, it is worthwhile to continue to investigate ways to best promote students' awareness of their emotions specifically pertaining to their academic activities. Although the intervention in Chapter 3 had a focus on confusion, it might be important for future research to design interventions for other frequently occurring and unproductive emotions among young students, and in particular, frustration and boredom.

Methodologically, progress has been made with regard to the measurement of emotions as researchers are incorporating more techniques other than offline self-report measures.

Presently, there is an increase in the use of interdisciplinary methods to study emotions in learning contexts that include physiological (e.g., galvanic skin response, heart rate) and online trace methodologies (e.g., think-aloud protocol, emote-aloud protocol, eye-tracking, facial expression) to capture experiential activity that occurs during learning. Moving forward, it would be important to carry out research on emotions in learning contexts through a triangulation of methods or mixed methods approaches. For instance, video data could be collected to measure facial expressions, and students be interviewed post-study on their emotional experiences. Another approach is the experience sampling method, which is a real-time assessment of momentary emotional experiences. At different time points, the participant is signalled to report on their current emotional state during an activity or as they perform a task. Additional methods or techniques that may be beneficial to implement include physiological indicators like arousal (e.g., heart rate) to study and capture emotions as they are experienced in real time and to measure discrete emotional states such as boredom, curiosity, and engagement, which have previously been more challenging to capture.

Furthermore, it would be advantageous to assess whether differences exist for relations between emotions and learning strategies and achievement among students with specific learning profiles or neurodevelopmental disorders (e.g., specific learning disorder, attention-deficit/hyperactivity disorder). Students with significant learning difficulties might experience a greater frequency of negative emotions during learning and problem solving and thus might need a tailored intervention to target their emotional experiences in a specific way. For example, without changing the goal of the cognitive-emotional intervention, perhaps such interventions can be modified to accentuate the cognitive-behavioural techniques such as cognitive reappraisal or reframing to help manage negative emotions while problem solving. Overall, research differentiating of patterns or commonalities among students with similar learning profiles could be helpful in informing interventions to best support problem solving for students with specific learning profiles. Given that think- or emote-aloud protocols may add to a student's cognitive load, other unobtrusive forms of measurement approaches could prove highly useful when designing and evaluating appropriate forms of intervention.

Addressing these research gaps and furthering the literature will require the integration of theoretical knowledge from various domains. It is important that more research is carried out at the intersection of emotion and cognition to continue to evaluate relations between emotions, self-regulated learning, and achievement among young students. This is of critical importance as many young students are developing foundational skills in their formative academic years. These strategies and skills will continue to develop as they advance through higher levels of education and it would be of great benefit to provide a strong early foundation.

Conclusion

The research I have conducted fulfills the requirement of a dissertation with regard to advancing theory by integrating emotions into theories of learning, by methodologically combining think-aloud and emote-aloud protocols to capture both cognitive processes and emotional experiences, and in practice by designing a cognitive-emotional strategy instruction intervention. My research provides insight into the role that emotions play during complex problem solving in an authentic classroom setting with elementary-aged students. Overall, this research expands our understanding of the role and importance of academic emotions in problem solving and the efficacy of including emotions in educational interventions. It will be advantageous that emotions are part of the conversation in schools and within classrooms to promote a culture of emotional awareness and to monitor and manage one's emotions as they relate to academic tasks. It is my hope that in addressing the gaps in the literature, this research has created the enthusiasm necessary in furthering empirical research on emotions and continuing to include them in educational contexts in both research and practice.

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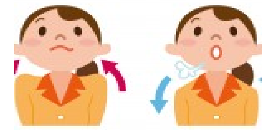
Appendix A

Intervention worksheet and list of emotions and learning strategies

Step 1:

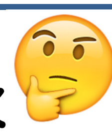
STOP

Take a **breath**!



Step 2:

THINK



HOW do I feel right now? ____

WHAT is my problem? ____

Step 3:

SAY

"I have control"

"I have strategies to help me figure it out"

Step 4:

LIST strategies

1. ______________________________

2. ______________________________

3. ______________________________

Step 5:

USE a strategy

Step 6:

DID it work?

Yes! Move on!

No. That's okay! Go back to step 1

List of possible **STRATEGIES**	
Stop and take a deep breath	☐
Tell myself I have control	☐
Figure out what my problem is	☐
Re-read the question	☐
Highlight the important information	☐
Summarize the important information	☐
Summarize what I need to do to solve the problem	☐
Summarize what I need to do to move on	☐
Picture a story of the math problem in my head	☐
Organize the problem into sections with titles and headings	☐
Re-calculate	☐
Check / review my work	☐
Check / review my final answer	☐
Ask my teacher	☐
	☐

What do I FEEL? **Emotions**
Surprised
Curious
Enjoyment / Happy
Hope
Proud
Relieved
Confused
Frustrated
Anxious / Nervous
Bored
Anger
Hopeless