Does object focus matter? Examining the temporal sequencing of emotions and strategy use during complex mathematics problem solving

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Abstract

The aim of this study was to explore the nature of academic emotions during complex mathematics problem-solving. The researchers examined the frequency of emotions expressed, the dynamic nature of academic emotions in real time, and whether subsequent learning strategy use varied as a function of emotions' object foci. Complex problem solving has the capacity to elicit a variety of emotions with different object foci (i.e., epistemic, topic, achievement and activity; Chevrier et al., 2019, Di Leo et al., 2019; Muis et al., 2015, 2016). Previous research found that emotions tend to facilitate or constrain the self-regulated learning process, by predicting the cognitive and metacognitive learning strategy students use (Muis, 2007; Muis et al., 2015; Muis et al., 2018; Pekrun, 2006). Researchers have explored the antecedents and consequences of emotions with differing foci, however, previous research has not explored whether the consequences of academic emotions differ as a function of object focus during one complex problem-solving task. One hundred and fifty-two students in grades 3 to 6 from one elementary school within the province of Quebec completed grade-appropriate application-based mathematics problem. Participants were audio-recorded while they completed the complex mathematics problem. The audio-recordings were transcribed and coded to investigate self-regulatory process and the academic emotions expressed. Results revealed that confusion (37.48%), curiosity (34.30%) and frustration (9.52%) were the most frequently expressed emotions during the problem-solving activity. Further, emotion-to-emotion transition analysis revealed that frustration transitioned to negative emotions, and confusion transitioned mostly to negative emotions, however, confusion transitioned to positive emotion when the impasse was resolved. In regard to emotion-to-learning strategy use, both positive and negative emotions had a mix of shallow and deeper cognitive learning strategies that followed. Lastly, results revealed that subsequent learning strategy use does not differ as a function of object foci, with the exemption for boredom. Educational interventions should equip students with the tools and learning strategies to resolve negative emotions, which tend to arise during complex problem solving.

Key words: self-regulated learning, academic emotions, object foci, complex mathematics problem solving

Résumé

Le but de cette étude était d'explorer la nature des émotions académiques lors de la résolution de problèmes mathématiques complexes. Les chercheurs ont examiné la fréquence des émotions exprimées, la nature dynamique des émotions académiques en temps réel, et si l'utilisation subséquente de la stratégie d'apprentissage variait en fonction des objets des émotions. La résolution de problèmes complexe a la capacité de susciter une variété d'émotions avec différents objets ciblés (c.-à-d. épistémique, sujet, réalisation et activité; Chevrier et al., 2019, Di Leo et al., 2019; Muis et al., 2015, 2016). Des recherches antérieures ont révélé que les émotions tendent à faciliter ou à limiter le processus d'apprentissage autorégulé en prédisant la stratégie d'apprentissage cognitif et métacognitif que les élèves utilisent (Muis, 2007; Muis et coll., 2015; Muis et coll., 2018; Pekrun, 2006). Les chercheurs ont exploré les antécédents et les conséquences des émotions avec des objets ciblés différentes, mais les recherches antérieures n'ont pas exploré si les conséquences des émotions académiques différents en fonction de l'objet lors d'une résolution de problèmes complexes. Cent cinquante-deux élèves de la 3e à la 6e année d'une école primaire de la province de Québec ont complété des prolèmes complexes de mathématiques fondé appliqué adaptés au niveau de l'étudiant. Les participants ont été enregistrés pendant qu'ils terminaient les problèmes mathématiques. Les enregistrements audios ont été transcrits et codés pour étudier le processus d'autorégulation et les émotions académiques exprimées. Les résultats ont révélé que la confusion (37,48 %), la curiosité (34,30 %) et la frustration (9,52 %) étaient les émotions les plus fréquemment exprimées pendant l'activité de résolution de problèmes. De plus, l'analyse de l'émotion à l'émotion a révélé que la frustration donne lieu à des émotions négatives, et que la confusion donne lieu principalement à des émotions négatives, mais que la confusion donne lieu à des émotions positives lorsque l'impasse est résolue. En ce qui concerne l'utilisation de la stratégie d'apprentissage par les émotions, les émotions positives et négatives comportaient un mélange de stratégies d'apprentissage cognitif superficielles et plus profondes. Enfin, les résultats ont révélé que l'utilisation ultérieure de la stratégie d'apprentissage ne diffère pas en fonction de l'object, à l'exception de l'ennui. Les interventions éducatives devraient fournir aux élèves les outils et les stratégies d'apprentissage pour résoudre les émotions négatives, qui ont tendance à survenir pendant la résolution de problèmes complexes.

Mots clés: apprentissage autorégulé, émotions académiques, focus objet, résolution de problèmes mathématiques complexes

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CHAPTER 1

Introduction

As interest in the exploration of various facets of teaching, learning and motivational processes that occur within the classroom increase, the critical role that emotions play in educational contexts have become more evident. Emotions are multi-dimensional phenomena that include cognitive, affective, expressive, physiological and motivational features (Scherer, 2000). Emotions have been recognized to be woven into aspects of the teaching and learning process, and as such, it is essential to understand the role of emotions within educational contexts (Schutz & Laneheart, 2002; Schutz & Pekrun, 2007). Early research into emotions within education were centered around test anxiety (Zeidner, 1998) and Weiner's (1985) attributional theory. However, since then, a variety of discrete emotions within classroom settings and education have been explored (Pekrun & Linnenbrink-Garcia, 2014). To illustrate, during complex mathematics problem solving, researchers have found that students experience a wide range of emotions, including both positive (i.e., curiosity and enjoyment) and negative emotions (i.e. frustration, boredom and anxiety; Di Leo et al., 2019; Frenzel et al., 2007). Further, researchers have found that these emotions influence students' motivation, academic achievement, in addition to the learning process (Efklides & Violet, 2005; Schutz & Pekrun, 2007).

Researchers have argued that emotions function to facilitate or constrain the learning process, ultimately impacting academic achievement (Pekrun & Stephens, 2012). For example, positive emotions (i.e., enjoyment and hope) tend to relate positively to academic achievement and success, whereas negative emotions (i.e., hopelessness, frustration, and boredom) typically associate negatively with academic achievement and success (Pekrun et al., 2009, 2011).

Emotions have also been described by their degree of physiological activation and valence, which refer to whether or not the emotion is activating or deactivating (i.e., supports or hinders activity; Shuman & Scherer, 2014; Pekrun, 2006), or positive or negative (i.e., valence; Shuman & Scherer, 2014). With respect to the learning process, emotions have been found to play an important role in self-regulated learning, as emotions predict the types of cognitive and metacognitive learning strategies students use during learning (Muis et al., 2015; Pekrun et al., 2002; Pekrun et al., 2007).

Within the broad category of academic emotions, that is, emotions that arise in academic settings, researchers have further differentiated emotions with respect to their object focus. Object focus refers to which item the emotion is directed towards (Pekrun, 2006). For example, topic emotions are derived from the content of the learning material, therefore the object focus pertains to the learning material (Pekrun & Linnenbrink-Garcia, 2014). Epistemic emotions, on the other hand, are elicited with respect to information-related appraisals, and whether or not new information aligns with existing beliefs, knowledge structures, or recently processed information (Muis et al., 2018). Achievement emotions' object focus are delineated between achievement outcomes (i.e., success or failure) or achievement activities (Pekrun, 2006). Given their contextual nature, researchers consider emotions as temporal, fluid and continuous, as opposed to states that function in a vacuum, unrelated to other affective conditions (D'Mello & Graesser, 2012). As such, researchers characterize emotions as dynamic and have explored how they evolve and transition from one emotion to the next, in addition to how they transition to learning strategies during learning and problem solving (Chevrier et al., 2019; Di Leo et al., 2019; Harley, 2016).

Although theoretical models have been delineated to describe the antecedents and consequences of emotions in various academic contexts (e.g., D'Mello & Graesser, 2012; Munzar et al., 2020; Pekrun, 2006), one critical question that has yet to be explored is whether the consequences of emotions differ as a function of their object focus. Previous research has taken into consideration epistemic and activity emotions in both elementary and university students, (Chevrier et al., 2019; D'Mello & Graesser, 2012; Di Leo et al., 2019), however, there is limited research on the dynamic nature of emotions within elementary students during complex mathematics problem solving, and the current study seeks to support previous work (D'Mello & Greasser, 2012; Di Leo et al., 2019). Therefore, the primary aim of this study was to explore the wide variety of emotions students experience during complex mathematics problem solving, in addition to examine the dynamic nature of emotions as it evolves into other learning strategies and other affective states. The secondary aim of this study was to explore whether consequences of emotions on learning strategies varied as a function of the emotion's object focus.

By better understanding whether the object focus of emotions matters in terms of their consequences, specific interventions can be designed to address the negative consequences of emotions when they arise (Di Leo et al., 2020). For example, when frustration arises during mathematics problem solving, what are the subsequent learning strategies that follow from that frustration? Do the learning strategies differ if the frustration is due to an inability to understand one step to a mathematics problem (epistemic emotion) or due to continuously getting the answer wrong (achievement emotion)? Answers to these questions have important implications with regard to self-regulated learning and the role that emotions play. As such, this research adds substantively to the literature by addressing this critical theoretical question.

Prior to defining the research questions and hypotheses, relevant theoretical and empirical work is reviewed. First, emotions and the broader term affect are defined, followed by Pekrun's (2006) control-value theory of achievement emotions, which explores the antecedents and consequences of achievement emotions within educational settings. Second, the self-regulated learning process and the role of emotions in self-regulation are investigated. Third, emotions and their object focus are defined, with an examination of the antecedents and consequences of each subtype of academic emotion. Finally, the sequential nature of emotions within educational contexts are explored.

CHAPTER 2

Theoretical Frameworks

Emotions

Emotion theorists define emotions as multi-componential, which include cognitive, affective, physiological, motivational, and expressive components (Scherer, 2000). For example, a student may experience anxiety prior to the defence of a doctoral dissertation, which consists of worrying about failing the defence (cognitive), feeling nervous (affective), an increase in blood pressure (physiological), an impulse to persevere despite experiencing anxiety (motivational), in addition to having an anxious facial expression (expressive; Pekrun & Stephens, 2012). More specifically, emotion is considered within the broader term *affect*, which encompasses the concepts of emotions and moods. Moods are defined as low-intensity emotions, as they share similar characteristics with respect to cognitive, affective, physiological, motivational and expressive components (Pekrun, 2006). Further, the term affect is used to represent a variety of variables, including positive or negative states of emotion, which are often referred to as positive affect (i.e., enjoyment, pride, curiosity) or negative affect (i.e., anger, anxiety, boredom; Pekrun & Linnenbrink-Garcia, 2014).

According to Shuman and Scherer (2014), there are two important dimensions that are used to describe affect: *valence* and *activation*. Emotions are distinguished by their pleasantness, with positive emotions (i.e., enjoyment or pride) cultivating more feelings of pleasantness than negative emotions (i.e., anxiety or frustration), which are unpleasant to experience. Activation, on the other hand, refers to the degree of physiological arousal, with activating affective states like anxiety being different from deactivating affective states like boredom. Valence and activation are used to organize affective states within a 2 x 2 grid to group them within four broad categories: positive activating (i.e., enjoyment), positive deactivating (i.e., relief), negative activating (i.e., anxiety), and negative deactivating (i.e., boredom; Feldman Barrett & Russell, 1998; Pekrun & Linnenbrink-Garcia, 2014). Due to the impact emotions have on learning and achievement, theoretical frameworks have been developed to delineate the antecedents of emotions, as well as their consequences within educational settings. One of the most prominent theoretical frameworks is Pekrun's (2006) control-value theory of achievement emotions.

Control-Value Theory of Achievement Emotions (CVT)

In his integrative framework, Pekrun (2006) proposed that perceptions of control and task value serve as two central antecedents to emotions experienced in educational contexts. Control is defined as the perception of controllability the student has in relation to the achievement-related task or outcome. Pekrun (2006) further delineates appraisals of control into action control and outcome control. Action control pertains to the expectancy that an action can be started and performed (Pekrun, 1988), whereas action outcome expectancies suggest that an individual's actions will produce a positive outcome or will inhibit a negative outcome. Task value is defined as the subjective importance the student places on the achievement-related task or outcome (i.e., the perceived importance of mathematics for a learner).

Pekrun (2006) further proposed that perception of control and task value appraisals interact and, in turn, predict which achievement emotions are elicited during learning. For example, if a student believes learning physics is important and also believes that they can successfully complete the learning tasks in the physics class, they will experience positive emotions like enjoyment or curiosity, as they have high perceptions of control and task value. Conversely, students who have low perceptions of control and task value will experience negative emotions like boredom. Further, students who have perceptions of low control and high task value may experience negative emotions like anxiety, anger, hopelessness or frustration. Although control and value appraisals represent proximal antecedents to achievement emotions, distal antecedents like achievement goals, beliefs, gender, as well as academic tasks and features of the achievement setting can impact achievement emotions (Pekrun & Perry, 2014).

These hypothesized relations between control, value, and emotions have been empirically supported (Goetz et al., 2010; Muis et al., 2015). For example, researchers have shown the negative relationship between test anxiety and measures of perceived control (i.e., self-efficacy, academic self-concept; Davis et al., 2008; Zeidner, 1998). Other studies have tested the control-value theory to support the notion that high perceptions of control within achievement settings elicit positive emotions like enjoyment, hope, and pride, and negatively predict emotions like anger, anxiety, shame, hopelessness, and boredom (Hall et al., 2006; Pekrun et al., 2011; Pekrun et al., 2004). Further, studies have supported perceptions of value are positively related to both negative and positive achievement emotions, and that success and failure can exacerbate these emotions (Frenzel et al., 2007; Goetz et al., 2006, Pekrun et al., 2011). However, researchers found that individuals with low perceptions of value for a given task tend to experience boredom, and when individuals increase their perceptions of value, boredom is less likely to be experienced (Pekrun et al., 2010).

In addition to the antecedents of emotions in achievement situations, Pekrun (2006) further delineated the consequences of emotions when they arise. Indeed, considerable attention has been paid to the functional importance of emotions. Both positive and negative emotional states can consume attentional resources by focusing attention to the object of the emotion (Ellis & Ashbrook, 1988). For example, if negative emotions arise that are task irrelevant, this draws attention away from the task, which can negatively affect performance (Meinhardt & Pekrun, 2003). In contrast, positive emotions about the task at hand can facilitate learning by boosting motivation and performance. As such, several studies demonstrated that emotions predict a wide range of cognitive processes that are relevant to academic learning, such as attention, memory storage and retrieval, strategies used during problem solving, motivation, and self-regulated learning (Chevrier et al., 2019; Clore & Huntsinger, 2009; Di Leo et al., 2019; Lewis et al., 2008; Muis et al., 2015, 2016).

In regard to emotions and motivation, researchers have noted relations between affect in students' intrinsic and extrinsic motivation, with motivation relating positively to academic outcomes, in addition to hindering negative academic outcomes (Pekrun & Stephens, 2012). Specifically, positive affect relates to fostering motivation to learn and improve performance, whereas negative affect may cultivate negative self-appraisals, which in turn hinders motivation and performance (Olafson & Ferraro, 2001). Given the impact emotions have on various aspects of the learning process, researchers have explored the critical role emotions play in the self-regulated learning process (Muis et al., 2018).

Self-Regulated Learning

Self-regulated learning (SRL) refers to the process in which a student takes "metacognitive control of cognitive, behavioural, motivational, and emotional conditions/states through the iterative processes of planning, monitoring, evaluation, and change" (Hadwin, Järvelä & Miller, 2018). Muis (2007) extended Winne and Hadwin's (1998) and Pintrich's (2000) models of SRL, by defining self-regulated learning as a process that occurs over four cyclically linked phases: task definition, planning and goal setting, enactment, and evaluation. In the first phase, individuals develop a perception of the learning task, which is affected by external conditions (i.e., learning environment) and internal conditions (i.e., prior knowledge, emotion, and motivation). During the planning and goal setting phase, individuals set goals and identify appropriate strategies to use in relation to the task at hand. In the third phase, individuals implement their plan by enacting learning strategies as they work through the task. In the last phase, evaluation, individuals metacognitively monitor and evaluate the processes and outcomes of each phase, which can result in adaptations to previous phases like initial perceptions of the task, goals set for achieving the task, and how one proceeds with completing the task. This is the feature that drives the cyclical nature of self-regulated learning (Muis, 2007).

Emotions and Self-Regulated Learning. Given the relationship between emotions and learning strategies, Pekrun (2006) proposed that emotions predict the cognitive and metacognitive strategies students use while self-regulating their learning. Typically, research has demonstrated that positive emotions facilitate deep processing learning strategies (i.e., elaboration), whereas negative emotions lead to shallow processing strategies (i.e., rehearsal; Di Leo et al., 2019; Muis et al., 2015, 2016; Pekrun, 2006; Pekrun & Stephens, 2010, 2012). For example, Muis et al. (2015) explored the antecedents and consequences of emotions that arise during complex mathematics problem solving. More specifically, Muis and colleagues explored whether emotions can predict self-regulated learning strategies across all four phases of self-regulated learning. Seventy-nine fifth grade students completed a complex mathematics problem over three to four days, with students working on the problem in 1.5 to 2-hour intervals. Self-regulatory processes were captured by recording students' verbal utterances as they attempted to solve complex mathematics problem.

The researchers found that perceptions of control and value predicted achievement emotions during problem solving. These emotions in turn predicted self-regulatory processes across the four phases of self-regulated learning. More specifically, the researchers found that confusion negatively predicted the use of both shallow and deep cognitive strategies. Further, Muis et al. found that confusion behaved like boredom such that it reduced processing strategies overall. In regard to curiosity, the researchers found that curiosity positively predicted metacognitive strategies in addition to shallow cognitive strategies. Further, with respect to surprise, they found that surprise led to a reduction in planning and goal setting in addition to shallow and deep cognitive strategies. The researchers highlighted this was due to the fact that surprise behaved more like confusion than curiosity in that specific sample of students. Moreover, in regard to enjoyment, the researchers found it was not a significant predictor of any of the cognitive or metacognitive strategies. Lastly, frustration related positively to shallow cognitive strategies, anxiety related positively to shallow cognitive and metacognitive strategies and boredom related negatively to planning and goal setting, deep processing and metacognitive strategies. Shallow, deep and metacognitive learning strategies used during mathematics problem then positively predicted mathematics achievement. Although Muis et al. (2015) were able to explore the antecedents and consequences of achievement emotions during complex mathematics problem solving, the relationship between the object focus and their consequences was not considered. As Pekrun (2006) theorized, an emotion’s object focus plays an important role in terms of the consequences of that emotion.

Emotions and Their Object Focus

Pekrun (2006) proposed that emotions can be categorized as a function of their object focus: achievement emotions are associated with the success or failure outcomes of an achievement-oriented task; topic emotions are associated with the learning content; social emotions arise in relation to other people, which include emotional states like admiration or jealousy. Most recently, educational psychologists have taken an interest in epistemic emotions, which relate to knowledge-generating features of cognitive activities (Pekrun & Stephens, 2012). Within educational contexts, Pekrun (2006) argued that identifying the object focus is important as it determines if the emotions students experience is associated with the learning task or something else. As such, categorizing object focus can aid in the development of appropriate educational interventions (Pekrun, 2006).

Achievement Emotions. Pekrun (2006) defines achievement emotions as "emotions that are tied directly to achievement activities or achievement outcomes" (p.317). Pekrun further delineated achievement emotions into *activity* and *outcome emotions*. Activity emotions arise during engagement in an activity, whereas outcome emotions comprise of prospective outcome emotions, which are related to future successes or failures, as well as retrospective outcome emotions, which are associated with previous successes and failures. Given that both activity and outcome emotions occur within achievement settings, they are categorized within the broad definition of achievement emotions. Further, achievement emotions do not only pertain to academic settings (i.e., athletic settings), which makes them distinct from other academic emotions (Pekrun & Stephens, 2012).

Unlike phylogenetic emotions that have been conserved throughout generations, achievement emotions are constrained with respect to culturally defined demands within settings, and as such are considered a recent product of society (Campos et al., 1992; Pekrun & Stephens, 2010). In the past, research on achievement emotions focused on achievement outcomes, like the emotions that students experience from completing a difficult mathematics problem or a challenging science test. However, Pekrun (2006) considers emotions relating to achievement-related activities in the definition of achievement emotions, as they pertain to acquiring competency-based standards in a particular academic subject. Examples of activity related achievement emotions include the enjoyment that emerges from learning, the frustration that occurs while solving a difficult problem, or the boredom students experience in their least favourite class (Pekrun et al., 2002, 2006). It is important to differentiate achievement frustration, in which the object focus pertains to the personal failure and the inability to complete the task at hand, and epistemic frustration, which has an object focus that relates to the cognitive incongruity that resulted from the unsolved problem (Brun & Kuenzle, 2008). Epistemic emotions, and their antecedents and consequences, are further explored below.

Epistemic Emotions. Epistemic emotions are defined as emotions that are elicited as a result of information-based appraisals relating to whether or not new information aligns with existing beliefs, knowledge structures, or recently processed information (Muis et al., 2018). Philosophers have argued that some emotions have an object focus that are always epistemic, including surprise, curiosity, and confusion (Brun & Kuenzle, 2008). Surprise is elicited when there is a discrepancy between incoming information and prior knowledge, beliefs or expectations (Scheffler, 1977). When these discrepancies occur, cognitive disequilibrium arises, which D'Mello and Graesser (2012) define as a condition where the learner experiences uncertainty with respect to an impasse, contradiction, dissonance, incongruity or random event encountered during learning. Further, learners experience surprise when confronted with information that is unexpected or incomprehensible (Foster & Keae, 2015; Meyer et al., 1997; Reisenzein & Studtmann, 2007). As such, surprise functions to alert oneself of the difficulty of integrating information into established knowledge structures (Munnich & Ranney, 2018). Further, the research on surprise has branched out into two areas: (1) the sense-making approach, which highlights the need of understanding and integrating surprising events into already established knowledge structures (Foster & Keane, 2015); and (2) the probability approach, which includes disconfirming expectations, the probability of an event occurring, scheme-discrepant events, or events of contrasting probabilities (Reisenzein & Studtmann, 2007). Lastly, surprise can be positive or negative in valence, and thus is categorized overall as a neutral emotion.

Curiosity is driven by ameliorating the gap between what one knows and what one wants to know. As such, learners become motivated to search for and make sense of new information, despite the novelty and complexity associated with the information (Silvia, 2010; Litman, 2005; Loewenstein, 1994). Researchers have differentiated two types of curiosity: deprivation-based, and interest-based (Lauriola et al., 2015; Litman, 2005, 2008). Deprivation-based curiosity is driven by the need to mitigate the unpleasant experience of uncertainty or lack of knowledge. Interest-based curiosity is driven by a need for new information in order to increase pleasant feelings with respect to the task at hand. Given that curiosity can be positive or negative in valence, it is categorized as a neutral emotion.

When learners encounter information that is highly novel, complex, as well as incomprehensible, confusion arises (Silvia, 2010). Ellsworth (2003) defines confusion as the result of appraisals of uncertainty, which are derived from information that is novel, complex, conflicting, or unfamiliar. Although confusion may be unpleasant to experience, researchers have argued that it is essential for complex learning and problem-solving activities, as well as producing strong arguments (D'Mello & Graesser, 2012). D'Mello and Graesser (2012) explored the impasse-related emotions elicited during complex learning tasks and found confusion arises as the primary emotion when a learner encounters an impasse. When the impasse is resolved, enjoyment is experienced, however, if the impasse is not resolved, frustration is experienced.

Pekrun, Muis and colleagues expanded on these core epistemic emotions to additionally include the following discrete emotions as potentially epistemic in their object focus: enjoyment, frustration, anxiety and boredom (Muis et al., 2015; Pekrun et al., 2017). Examples highlighted by Muis et al. (2015, 2018) include the experience of joy when new information is compatible with beliefs or previously acquired knowledge; or anxiety, anger or frustration when information is incompatible with established beliefs, views or knowledge.

Moreover, epistemic emotions serve important functions with respect to learning. Brun and Kuenzle (2008) highlight five functions of epistemic emotions: (1) to motivate learners to engage in cognitive activities to re-evaluate epistemic aim or standards; (2) salience and relevance, as to narrow the learner's attention to the concept that elicited the emotion; (3) epistemic access to facts and beliefs, where the elicited emotion can provide an additional form of knowledge for the learner that was otherwise inaccessible; (4) nonpropositional contributions to knowledge and understanding, in which epistemic emotions can lead to the reorganization of knowledge, formation of new categories, in addition to new guidelines of inquiry and justification; and (5) epistemic efficiency, wherein epistemic emotions are thought to aid in information processing and are essential to execute certain cognitive functions.

With respect to epistemic emotion antecedents, Muis et al. (2018) proposed five different antecedents: appraisals of control and value; novel information; complexity of information; and achievement or impasse of an epistemic aim. First, Pekrun’s (2006) definitions for appraisals of control and value still hold with respect to epistemic emotion antecedents. Second, novelty is the primary antecedent to epistemic emotions. Learners may perceive incoming information as new, novel or unique during learning. This, in turn, may elicit surprise if that information is unexpected for the learner (Foster & Keane, 2015). Third, D’Mello et al. (2014) suggest complexity as an antecedent to confusion when learners engage in complex learning tasks, like understanding difficult texts, complex mathematics problem solving, or generating cohesive arguments. Previous research has suggested that confusion is unavoidable when learners attempt complex learning tasks (D’Mello et al., 2014). Lastly, with respect to achievement or impasse of epistemic aims, Muis et al. (2018) argued that when an epistemic aim is blocked or achieved, this can trigger epistemic emotions (i.e., joy when a knowledge claim is successfully validated).

With respect to the consequences of epistemic emotions, Muis et al. (2018) proposed the following five: planning and goal setting; motivation; cognitive and metacognitive strategies; learning outcomes; and revisions to control, value, and beliefs about knowledge and knowing. In regard to the first consequence, planning and goal setting, if epistemic emotions are activated in Phase 1 of the self-regulated learning process, they can predict the epistemic aims as well as the objectives the learner has established for the task. Second, for motivation, researchers proposed that emotions relate to a learner’s disposition towards knowledge, like the need for cognition, which is defined as a learner’s desire to engage in effortful thinking (Cacioppo et al., 1996). Muis et al. (2018) proposed that epistemic emotions like joy or curiosity can enhance need for cognition with the expectation that further joy will arise when a cognitive demanding task is completed.

Third, in accordance with Pekrun's (2006) control-value theory, Muis et al. (2018) suggested that epistemic emotions predict the cognitive and metacognitive strategies employed during learning. More specifically, under conditions of cognitive incongruity, when learners experience surprise, confusion and curiosity, it is predicted that higher rates of metacognitive and deep cognitive strategies would be used to resolve the incongruity, especially when learners have high perceptions of control. With respect to anxiety and frustration, it is predicted that learners would employ less effortful strategies, resulting in the use of shallow processing strategies (Pekrun et al., 2011; Pekrun & Stephens, 2012). Fourth, epistemic emotions draw attention and importance to the object that elicited the emotion, which in turn leads to an increase in learning outcomes (Elgin, 2008; Morton, 2010). However, theorists have argued that these same emotions can also draw attention away from the learner's task (Meinhardt & Pekrun, 2003), thus negatively impacting learning outcomes (Ellis et al., 1995). Further, researchers have suggested that the reason why negative emotions can negatively impact learning outcomes is largely due to the limited cognitive resources that individuals allocate during learning (Ellis & Ashbrook, 1988).

Lastly, Muis et al. (2018) suggested that epistemic emotions may change learners' perceptions of control and value, in addition to beliefs about knowledge and knowing. Muis et al. (2018) suggests that this occurs when a learner has a high perception of control and sets a certain epistemic aim. When the learner engages with information and experiences confusion, it may lead to a decrease in capacity to understand, thus leading the learner to adjust their perception of control. To serve as a protective mechanism, this learner may also decrease their perceptions of the value of the task when confusion cannot be resolved in order to avoid subsequent frustration (Munzar et al., 2020).

Recently, researchers have explored the antecedents and consequences of epistemic emotions in relation to learning (Chevrier et al., 2019; Di Leo et al., 2019; Muis et al., 2015, 2016). For example, Chevrier et al. (2019) examined the antecedents and consequences of epistemic emotions as 114 undergraduate students thought aloud while reading contradictory texts about climate change. Results demonstrated that epistemic aims, epistemic congruity, and appraisals of novelty and complexity of information served as the antecedents for epistemic emotions. However, the majority of epistemic emotions were triggered by appraisals of information novelty and complexity. With regard to consequences of epistemic emotions, curiosity increased the use of metacognitive strategies, critical thinking, knowledge elaboration and rehearsal strategies, with both critical thinking and rehearsal positively predicting learning achievement. Further, researchers in this study found no relation between enjoyment and subsequent learning strategy use, whereas anxiety was related to knowledge elaboration, and boredom was negatively related to critical thinking and rehearsal.

Topic Emotions. Subject domains like science contain controversial topics (i.e., climate change, biological evolution, vaccination). As such, previous research has explored the specific emotions triggered as a result of the domain specific content. These emotions are categorized as *topic emotions*, as they are elicited from the content of the learning material during study or while attending a class (Pekrun & Linnenbrink-Garcia, 2014). Further, topic emotions are differentiated with respect of the object focus, when compared to other academic emotions. To illustrate, emotions triggered from learning about the tragedies from World War II in history class, or anxiety associated with learning mathematics, are categorized as topic emotions (Goldin, 2014). Moreover, previous research has explored the topic emotions elicited with respect to controversial topics in science: anger, frustration and fear have been reported when individuals learn about genetically modified foods (Broughton & Nadelson, 2012), in addition to sadness and anger when learning about the reclassification of Pluto as a dwarf planet (Broughton et al., 2013).

Although topic emotions are within the broad category of academic emotions, researchers have highlighted the need to distinguish emotion subtypes to better understand their unique contribution to the learning process. Further, topic emotions can manifest with an opposite valence than other academic emotions. For example, a student can experience positive emotions towards science class, but experience negative emotions towards the concept of evolution. The manifestation of negative emotions of certain topics could be associated with the topic being controversial or threatening to the identity of the student rather than an association of the discipline itself (Sinatra, Broughton et al., 2014). Unlike achievement and epistemic emotions, topic emotions do not directly relate to learning and problem-solving processes. Topic emotions, however, can affect students’ engagement by influencing their interest and motivation within the academic domain (Ainley, 2007).

Conceptual change researchers have centered around reducing negative topic emotions to ensure that learners are more focused on integrating new information rather than disengaging from learning altogether (Linnenbrink & Pintrich, 2002). Specifically, topic emotions relate to individuals’ acceptance or rejection of scientific viewpoints, in addition to their willingness to engage with specific controversial topics. Researchers have found that positive topic emotions are associated with more acceptance and engagement with topics, which in turn fosters greater conceptual change. In contrast, negative topic emotions relate to lack of engagement and reduced conceptual change (Sinatra, Kienhues et al., 2014).

In summary, it is clear that emotions with a different object focus have different consequences across a variety of learning contexts. However, what is not clear is whether emotions with different object foci during the same learning task has similar or different consequences. To date, research has not addressed this possibility. To fully assess the sequential nature of emotions and their possible consequences, we situate our hypotheses and methodology using D'Mello and Graesser's (2012) model of affective dynamics.

Sequential Dynamics of Emotions

D'Mello and Graesser (2012) developed a model that differentiates the dynamic nature of epistemic emotions during complex learning. The authors predicted that when a learner is in a state of engagement/flow, defined as a cognitive-affective state (i.e., positive valence and moderate level of arousal in which a learner experiences a high level of engagement in the task), the learner will experience confusion when they encounter cognitive incongruities, contradictions or an impasse. Learners resolve cognitive incongruity through the use of cognitive and metacognitive learning strategies, and upon resolution, the learner will return into a state of engagement/flow. Conversely, if the learner is unable to resolve confusion, the affective state will transition into frustration. If frustration continues due to a lack of resolution, frustration will transition to boredom, which would lead to disengagement in the task.

D'Mello and Graesser (2012) conducted a study amongst university students with results supporting their hypothesis in relation to the dynamic nature of emotions. Emotions and emotion transitions were measured through an affective judgement protocol, wherein, participants provided judgements on their affective states while their faces were video recorded. Participants were given the definitions of the affective states and provided judgements of their affective states at that instant (fixed judgements), in addition to the affective states that occurred in between video segments of fixed affective states, which captured transitory affective states (spontaneous judgements). The researchers found that upon resolution of productive confusion through the use of cognitive and metacognitive learning strategies, students were able to engage in deeper learning of the material. However, when individuals could not resolve confusion, this led to lower performance on the learning task.

In regard to hopeless confusion, this indicated that the impasse was not resolved, which resulted in confusion transitioning into frustration and boredom. In relation to the emotional state transitions of surprise, previous research has noted that surprise is temporary and, as such, may transition into another affective state quickly (Baker et al., 2007). Moreover, the intensity of surprise experienced by learners may predict subsequent cognitive and metacognitive learning strategies. To illustrate, high perceptions of surprise predict more cognitive effort to explain the surprising event (Foster & Keane, 2015), whereas low perceptions of surprise have been shown to lead to no change in self-regulatory behaviour (Muis et al., 2018).

Overall, previous research has proposed that various emotions dynamically transition into other affective states, or cognitive and metacognitive learning strategies. As such, the current study seeks to explore, in real time, the dynamic nature of emotions during complex learning. Although previous studies have explored emotional state transitions with respect to activity and epistemic emotions in elementary students (Di Leo et al., 2019) and epistemic emotions in adults (Chevrier et al., 2019), the current study seeks to explore emotion state transitions of achievement, activity, topic, and epistemic emotions amongst elementary students during a complex mathematics problem solving task.

The Current Study

The nature of complex problem solving has the tendency to stimulate and elicit a variety of emotions with different object foci, like epistemic, topic, activity, and achievement emotions (Chevrier et al., 2019; Di Leo et al., 2019; Muis et al., 2015, 2016). Further, emotions have been found to predict the various phases of self-regulated learning and the cognitive and metacognitive learning strategies used during (Muis, 2007; Muis et al., 2015; Muis et al., 2018; Pekrun, 2006). Although researchers have independently explored the antecedents and consequences of various emotions with different foci, previous research has not examined the consequences as a function of object focus during one learning task.

With respect to the consequences of academic emotions, researchers have explored the trajectory of emotions as they evolve into other affective states and learning strategies among elementary (Di Leo et al., 2019) and university students (Chevrier et al., 2019). The former study focused on transitions of achievement and epistemic emotions, while the latter focused on epistemic emotions during learning. As such the aim of current study is explore the consequences of academic emotions as a function of object focus. To achieve this, we explored the trajectory of achievement, activity, topic, and epistemic emotions as they evolved into other emotions or learning strategies among elementary students as they completed complex mathematics problems.

The current study explores the following research questions: (1) Which and to what frequency are emotions expressed during complex-problem mathematics problem solving? (2) Which emotion-to-emotion transitions exist during complex mathematics problem solving? (3) Which emotion-to-learning strategy transitions exist during complex mathematics problem solving? (4) Do the consequences of emotions during complex problem solving differ as a function of object focus? Based on previous research (Di Leo et al., 2019), for the first research question we predicted that the two most frequently expressed emotions during complex mathematics problem solving are confusion and frustration. For the second research question, following previous theoretical and empirical work (Muis et al., 2018; Munzar et al., 2020; Silvia, 2010), we predicted that confusion and curiosity would follow surprise, and that frustration would follow confusion. For the third research question, we predicted that shallow processing strategies would follow negative emotions, with the exception of confusion wherein metacognitive processing strategies were expected to occur. We further predicted that more cognitive demanding learning strategies would follow positive emotions. For the last research question, given its exploratory nature, no specific hypotheses was proposed.

CHAPTER 3

Methodology

Participants

One hundred fifty-two students (n = 64 girls) from grades 3 to 6 (M_{age} = 9.78 years old, SD = 1.22) from one elementary school in the province of Quebec participated in the study. With parental consent, students gave their assent to participate. Students spent an equal amount of time learning in French and English, such that the language of instruction was 50% in the English language and 50% in the French language. The elementary school adopted a class schedule in which students would spend half of the week learning in English, and the remainder of the week learning in French. Therefore, each grade had one English teacher responsible for teaching half of the academic subjects and one French teacher responsible for teaching the other half of the required subjects. In this school, in grades 3 through 6, mathematics is taught in English. The teachers for both English and French classes were female for all of the grade levels in this study. Most students spoke English as their first language, and the remainder were first-language French speakers but were fully fluent in English. The majority of the sample was of Caucasian descent, with a mix of socio-economic status ranging from lower class to upper middle class. All mathematics problems were administered and completed in English, as it is the language of instruction for the mathematics class. Twenty-one students in the study were on individualized education plans (IEP) and were given adapted versions of the problem and, in some instances, a teacher aid was provided to meet learning needs.

Table 1.

Gender and age of students by grade.

Grade	Male	Female	Total	Age	SD
3	22	16	38	8.22	.42
4	23	22	45	9.26	.50
5	18	8	26	10.40	.50
6	25	18	43	11.18	.38
Total	88	64	152	9.78	1.22

Materials

Demographics. Information relating to students' age (derived from date of birth) and sex (girl or boy), was collected from the parental consent forms (Appendix A).

Emotions and Self-Regulatory Processes. Students' emotions and self-regulatory processes that arose during complex mathematics problem solving were captured using a Type 1 think aloud protocol, i.e. thinking aloud while completing the learning task (Ericsson & Simon, 1998). The think-alouds ranged in length from three minutes and forty-one seconds to sixty-five minutes and twenty-nine seconds, which were then transcribed verbatim. The transcriptions ranged from 2 to 32 pages in length. The transcriptions were then segmented into meaningful components, comprised of either a clause or a sentence that contained a thought or idea. Two research assistants coded the transcripts for micro-level learning strategies by using a coding scheme developed for mathematics problem solving (Muis et al., 2015). Prior to coding the transcripts, the principal investigator trained the research assistants to attain an acceptable level of inter-rater agreement. As a group, the research assistants and the principal investigator underwent various phases of coding transcriptions. There was a mix of simple to challenging transcriptions in terms of length and complexity of segments. The first phase of coding was conducted together through discussion, which resulted in a two-way random intraclass correlation coefficient (ICC) of .90. The second phase involved independent coding of four transcriptions, which resulted in an ICC of .65, which suggested some differences across raters. Differences in coding were then discussed at length. For the next phase of coding two research assistants coded a new sample of 10% of the total transcripts. The transcripts that were coded for this round of inter-rater agreement included two to three files per grade, with a mix of simple to complex transcripts to code as well as a variation in regard to the length of the transcripts. A two-way random intraclass correlation coefficient (ICC) of .73 was attained. Differences were again discussed at length. The last phase of coding required the group to independently code another 10% of the total transcriptions, in which the coders attained an acceptable level of agreement with an ICC of .78.

During coding, the research assistants took into consideration the context in which the learning strategy was used, which included the sentence expressed before and after each identifiable learning strategy. Twenty-three micro-level learning strategies were coded, which were categorized under one of the four macro-level learning strategies: task definition, planning/goal setting, enactment, and monitoring/evaluation (Greene & Azevedo, 2009). See a complete list of the micro-level learning strategies that were coded as a function of the macro-level learning strategy, along with an example in Table 2.

The transcripts were then coded for epistemic, topic, achievement, and activity emotions. The emotions and object focus coding scheme (see Table 3 and Table 4) was developed using the control-value theory of achievement emotions (Pekrun, 2006; Pekrun et al., 2007; Pekrun &

Stephens, 2010) and using D'Mello and Graesser's (2011, 2012) definitions of emotions (see Di Leo et al., 2019). The coding scheme, established by Di Leo et al. (2019), identified 13 emotions (i.e., surprise, curiosity, enjoyment, pride, hope, relief, confusion, frustration, boredom, anxiety, hopelessness, shame, and anger). The principal investigator, along with six research assistants, independently coded one complex and lengthy transcript. The group then discussed as coding of each emotion to establish a clear protocol. Two of the trained research assistants then independently coded another 10% of the transcripts. A two-way random intraclass correlation coefficient (ICC) of .79 was achieved for emotion coding, and an intraclass correlation coefficient (ICC) of .80 was achieved for object foci coding. As was previously done for learning strategies, the context in which the emotion expressed was considered, including the sentence expressed before and after the emotion.

Mathematics Problem Solving Task. Teachers chose one application-based mathematic problem for students to solve, as they reflected the content that students learned, which was appropriate for each grade level. In total, four problems were chosen, one for each grade level. The grade 3 application problem required students to determine the value of various objects found in a treasure chest by using a legend that decoded the value of different symbols. Students had to determine which three objects were worth the most. This problem required learners to apply their knowledge of addition and place value, use their analysis and reasoning skills to determine which objects have the most value, in addition to justify their reasoning for their choice of objects to take from the treasure chest. The grade 4 application problem centered around the various transactions of a pet store; the number of cats sold over the course of three days was detailed. Students determined whether another purchase was possible given how many cats were initially available in the pet store, and the previous transactions that occurred during that week. This problem required learners to apply their knowledge of addition, use their analysis skills to discern important information from the problem, and justify their reasoning as to whether or not another transaction was possible.

The grade 5 and 6 classes completed the same application problem, which centered around identifying computer tablets that are defective for the computer tablet manufacturer. To achieve this, students were provided the range of serial numbers associated with defective computer tablets and were required to apply divisibility rules to identify specific defects with each computer tablet (e.g., tablets with serial numbers that are divisible by 2 have problems with screen colour). There were four defects in all: screen colour issues, faulty keyboards, faulty charging mechanisms and tablets that had issues with their on/off switch. This problem required learners to apply their knowledge of divisibility rules to large numbers (i.e. 24901) and justify their reasoning for which tablets needed to be recalled by the computer tablet manufacturer. For this problem, students were required to use long division to identify which tablets were defective. Students in all grades were required to solve the application problem by hand; only students with IEPs were allowed scaffolding tools (i.e., multiplication tables, calculators) as directed by their IEP. To help students, each problem contained the guiding cues that students were asked to fill out, it included the following: “what do I know”, “what am I looking for”, and “it is essential to think about…” The purpose of these prompts was to scaffold proper problem-solving behaviour for students.

Procedure

This study gained approval from the Research and Ethics Board at McGill University. For each grade, data collection took place over two days. Day one consisted of training students on how to execute the think out loud protocol during mathematics problem solving; this protocol required students to verbalize any thought that came to mind while attempting the mathematics problem. Students then listened to a practice think-aloud audio file, which demonstrated inappropriate and appropriate think out loud examples (Muis et al., 2016). Students wore Apple Ear Pods equipped with microphones, which were connected to digital recording devices to capture verbalizations.

Day two consisted of students attempting the mathematics problem selected by their teacher. Teachers presented the problem to the students and then read the instructions out loud to the class. Students were instructed to work on the problem independently and to raise their hand if they had any questions. Dividers were placed between students to ensure they could not see one anothers work. To answer questions, trained research assistants, the principal investigator, and the classroom teacher circulated the classroom during the problem-solving session. Students were prompted to continue thinking out loud if there were silent for more than five seconds. Once students completed the mathematics problem, they were given a $10 iTunes gift card as compensation for their participation in the study.

Table 2.

Coding scheme for learning strategies in think aloud protocol.

Level (micro/macro)	**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.	"…because she sold, which also means take away"

Identifying Important Information	Recognizing the usefulness of information.	"Um… so Cabossa does not have enough cats to fill the order."
Reading	Reading the problem, or its components, word for word.	"On Monday morning Cabossa had 1234 talking cats and 456 evil cats in her store. On Monday she sold 787 cats. On Tuesday she sold 542. On Wednesday morning Professor Potirus ordered 3-370 cats from her. Does Cabossa have enough cats to fill?"
Level 2- Planning and Goal Setting	The learner begins to devise a plan to solve the problem and sets goals.	i.e. planning to use means-end 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.	"So, we'll start to read." "Okay, I'll restart." "And I'm going to do the what I know later."
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.	"Okay so I'm going to try to figure this out."
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 doubt it would be divisible by 3"
Summarizing	Summarizing what was just read in the problem statement.	"Ummm… okay, so basically the numbers 24901…"
Help Seeking	Asking for help from a teacher, peer, or other source. Help seeking for information versus help seeking for evaluation.	"Are we trying to make like, between these numbers, we want to know which ones are in each?"
Coordinating Informational Sources	Using other sources of information to help solve the problem.	"There we go I got the list right there."

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.	"Sorry I'm going to highlight that." "Writing this down."
Calculating/Measuring	Solving equations, measuring, or other similar features.	"Now I'm going to do 1, 2, 3, 4, 5, 6." "So 9 and 2 is um 11 and then 6 and 4 is 10 so it makes 21."
Re-Reading	Re-reading a section of the problem, word for word. Important that it is word for word, otherwise it is summarizing.	[reading] "Circles are worth 1. Squares are worth 10. The triangles are worth 100 and the diamonds are worth 1000."
Making Inferences	Making inferences based on information read or products created from solving the problem.	"Squares worth 10. That's 20." "Because she only has 361 cats left…" "Is it divisible by 3, cause then I know if its divisible by 6"
Goal-directed search		"So, what am I looking for? Um what am I looking for? I am looking for, I'm looking for the uh, wait let me see." "So, now I'm gonna find, now I'm gonna find what, I'm gonna find numbers that are divisible by 2 out of 24901 and 24910…"
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.	"What are all these numbers divisible by?"
Monitoring	Monitoring something relative to goals.	"Okay, so basically all the divisibility rules…"

		"Okay and now there'll be another 10."
Judgment of Learning	Learner is aware that something is unknown, not fully understood, or difficult to do.	"Okay…huh… no, I don't get it." "This is pretty easy, but kind of confusing." "Okay, I feel like I'm doing something wrong"
Self-Correcting	Correcting one's mistakes.	"And that's the—1000 1500. No, 1100 1050."
Evaluation	Judging whether goals have been met, whether a particular strategy is working, whether the answer is correct, whether the work is neat, etc. Judgement of all facets that fall under monitoring.	"Wait a minute. One sec I wrote something wrong." "Not divisible by 2."
Control	Changing strategy when monitoring or evaluation results in a determination that goal has not been met.	"Okay I'm just going to do the subtraction." "I guess I'll divide it by 2 twice."
Task Difficulty	Statements reflecting the difficulty or easiness of a task.	"This is like pretty easy." "This is really hard."

Table 3.

Coding scheme for emotions in think-aloud protocols.

Code	Description/Definition	Example
Curiosity	Interest, intrigue	"Let's see. What are all these numbers divisible by?" "Is it divisible by anything else?"
Enjoyment	Excited, enthusiastic, happy	"Oh great! Noooooo. Oh that's good there's another page." "Yay! It works! Awesome."
Surprise	Astonished, amazed	"Ouuu that's a big number" "So. Ok. If there's 25 wow" "So 1, 2, 2 just 2 wow. That's really surprising."

Confusion	Puzzled, mixed up	"Wait no I don't know if its divisible. I thought it was divisible by 3 but I'm not sure anymore." " I don't know what to do there." "Uh I don't think it was minus."
Frustration	Irritated, dissatisfied	"If I knew cause it wasn't ooof. Sorry I just realized I did a ton of work for nothing." "Ugh this is so annoying!"
Boredom	Dull, monotonous	"Falling asleep. Too many numbers." "Ok. I am very very tired."
Anxiety	Worried, nervous	"Very bad very bad very bad. Running out of time. I am in trouble. I'm in trouble. I'm in really big trouble."
Pride	The state of being proud. A feeling of happiness when you do something good or difficult.	"It's perfect, it works… that's one of them." "Yes! 4,5…that one works!
Relief	The removal or lightening of something painful or distressing.	"Not divisible by 4. Ok great." "4 left to do yes. Yes. Finally. Finally."
Hope	To want or something to happen or be true and think that it could happen or be true.	"Hope I'm using the right trick for 8."
Hopelessness	Having no hope, no expectation of good or success. Incapable of solution, management, or accomplishment.	"I'm just going to write anything I want, I don't care" "… and no one is helping"
Anger	To become angry.	"This is really frustrating me. I just really hate, like, doing long math stuff, it just bothers me" "Okay… oh my god. AHHHHHH, I just *(inaudible)* I'm tired."
Shame	A feeling of guilt, regret, or sadness that you have because you know you have done something wrong.	"That's kinda dumb. Ok. Dumb, dumb me." "Um. This is really sad."

Table 4.

Coding scheme for object focus in think-aloud protocol.

Object Focus	Description	Example
Achievement	Object focus is related to achievement outcomes, which includes prospective outcome emotions (i.e., related to future successes or failures) and retrospective outcome emotions (i.e., related with previous successes and failures; Pekrun, 2006).	*Frustration*: "okay… this one doesn't work either. (*sighs*). Pretty frustrating, right? Erase, erase, erase, erase. Ughhhhh."
Activity	Object focus is related to achievement activities, in which emotions arise during engagement in an activity (Pekrun, 2006).	*Boredom*: " 'Kay ummm… this is just going to keep on going, and going, and going, so let's just keep going."
Topic	Object focus is related to domain specific content (i.e., content of learning material; Pekrun & & Linnenbrink-Garcia, 2014).	*Anger*: "I just really hate, like, doing long math stuff, it just bothers me."
Epistemic	Object focus is related to whether or not new information agrees with existing beliefs, knowledge structures, or recently processed information (Muis et al., 2018).	*Curiosity*: "…wait, one sec, what does 'inclusive' mean? What does inclusive mean?"

CHAPTER 4

Results

Analytical Approach

The dynamic relations between emotions and learning strategies that occur during complex mathematics problem solving were analyzed using two-way Chi-square analyses. Specifically, the current study explored the emotion-to-emotion and emotion-to-learning strategy transitions, in addition to the variation of subsequent learning strategies as a function of object focus. The Chi-square analysis examined whether observed frequencies of categorical variables differed significantly from expected frequencies within a distribution. As such, this analysis supported the exploration of emotion-to-emotion transition and whether a certain emotion (i.e., enjoyment) could be expected to follow another emotion (i.e., surprise) more often than statistically expected. In addition, this analysis explored whether a specific object focus of an emotion was more likely to be associated with a subsequent learning strategy. It is important to note that when observed frequencies are different than expected frequencies, the value of χ^2 is large and the null hypothesis is rejected (Tabachnick & Fidell, 2013). The Chi-square analysis test was used to examine whether the likelihood of observed emotion-to-emotion transition, emotion-to-learning strategy transition, or variations of subsequent learning as a function of object focus, was a due to chance.

Expressed Emotions and Learning Strategies

To address the first research question, regarding which emotions were experienced during mathematics problem solving, the emotions that were expressed during think aloud were examined. Overall, there were 2289 instances of expressed emotions and 16307 learning strategies. With respect to the 2289 instances of expressed emotions, the most frequently expressed emotions included confusion (*n*=858, 37.48%), and curiosity (*n*=784, 34.30%). The next most frequently expressed emotions were frustration (*n*=218, 9.52%), surprise (*n*=147, 6.42%) and enjoyment (*n*=58, 2.53%) (see Table 5 for the overall frequency of each emotion). For the 16307 instances of learning strategies, the most frequently expressed learning strategies included monitoring (*n*=4157, 25.49%), evaluating (*n*=3210, 19.70%), calculating (*n*=2674, 16.40%), planning (*n*=1183, 7.25%), and highlighting / labelling colouring / drawing (*n*=672, 4.12%) (see Table 6 for the overall frequency of each learning strategy).

Table 5.
Frequency of verbalized emotions by object focus.

	Achievement	**Activity**	**Epistemic**	**Topic**	**Total**
Curiosity	0	0	784	0	784
Confusion	0	0	858	0	858
Surprise	0	0	147	0	147
Enjoyment	38	14	4	2	58
Frustration	113	104	1	0	218
Boredom	8	31	0	0	39
Anxiety	11	11	0	0	22
Pride	53	4	0	0	57
Relief	7	10	0	0	17
Hope	14	2	0	0	16
Hopelessness	24	4	0	0	28
Anger	1	8	0	3	12
Shame	24	9	0	0	33
Total	293	197	1794	5	2289

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

Learning Strategy	Frequency	Percentage (%)
Prior Knowledge Activation	208	1.27
Identifying Important Information	595	3.65
Reading	435	2.67
Making/Restating a Plan	1183	7.25
Setting/Restating a Goal	108	.66
Hypothesizing	234	1.43
Summarizing	25	.15
Help Seeking: Information	267	1.64
Help Seeking: Evaluation	28	.17
Coordinating Informational Sources	15	.09
Highlighting/Labeling/Colouring/Drawing/Writing	672	4.12
Calculating/Measuring	2674	16.40
Re-Reading	232	1.42
Making Inferences	371	2.28
Goal-directed search	14	.09
Self-questioning	547	3.35
Monitoring	4157	25.49
Judgement of Learning	495	3.04
Self-Correcting	418	2.56
Evaluation	3210	19.68
Control	259	1.58
Task Difficulty	160	.98
Total	16307	100

Emotion to Emotion and Emotion to Learning Strategy Transitions

To address the second and third research questions, which related to how emotions dynamically transitioned from one emotion to another emotion or learning strategy, Chi-square analyses were conducted. This statistical analysis was used to determine which emotions and learning strategies were most likely to occur following an experience of an emotion. First, the frequency of emotions expressed in the overall sample was determined. The frequency of two-state emotional transitions, which 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 then assessed. A multiple 2x2 contingency table was created to test for the statistical difference between the observed frequency of a learning strategy or emotion immediately following an emotion with the expected frequency of that follow up learning strategy or emotion, in addition to considering its frequency in the overall sample. Due to the number of analyses that were made, Type I errors were controlled for by setting alpha to 0.01. Below, only statistically significant findings are presented, first for the emotion-to-emotion transitions (see Table 7) and then to the emotion-to-learning strategy (see Table 8) transitions, by each emotion.

Curiosity. The emotions that followed curiosity more often than statistically expected were: surprise, $\chi^2(1) = 21.50, p < .0001$ and frustration, $\chi^2(1) = 4.69, p = .030$. The learning strategies that followed curiosity more often than statistically expected were: monitoring, $\chi^2(1) = 74.20, p < .0001$, planning $\chi^2(1) = 22.43, p < .0001$, self-questioning, $\chi^2(1) = 4.96, p = .026$ and judgement of learning $\chi^2(1) = 19.08, p < .0001$.

Confusion. The emotions that followed confusion more often than statistically expected were: anxiety, $\chi^2(1) = 23.83, p < .0001$, frustration, $\chi^2(1) = 17.62, p < .0001$ and curiosity $\chi^2(1) = 11.29, p = .0008$. The learning strategies that followed confusion more often than statistically expected were: evaluation, $\chi^2(1) = 6.87, p = .009$, calculating $\chi^2(1) = 11.25, p < .0008$, planning, $\chi^2(1) = 7.06, p = .008$, judgement of learning $\chi^2(1) = 18.27, p < .0001$, self-questioning $\chi^2(1) = 30.31, p < .0001$, and identifying important information $\chi^2(1) = 14.49, p < .0001$.

Surprise. The emotions that followed surprise more often than statistically expected were: surprise, $\chi^2(1) = 7.81, p = .005$, enjoyment, $\chi^2(1) = 10.55, p = .0011$, hopelessness $\chi^2(1) = 5.44, p = .019$, and anger $\chi^2(1) = 14.29, p = .0002$. The learning strategies that followed surprise more often than statistically expected were: calculating $\chi^2(1) = 14.41, p = .0002$ and judgement of learning $\chi^2(1) = 4.90, p = .026$.

Frustration. The emotions that followed frustration more often than statistically expected were: frustration, $\chi^2(1) = 23.33, p < .0001$, and anger $\chi^2(1) = 10.02, p = .0015$. The learning strategies that followed frustration more often than statistically expected were: monitoring $\chi^2(1) = 112.97, p < .0001$, calculating $\chi^2(1) = 5.63, p = .018$, self-questioning $\chi^2(1) = 35.39, p < .0001$ and judgement of learning $\chi^2(1) = 29.82, p < .0001$.

Enjoyment. The emotion that followed enjoyment more often than statistically expected was frustration, $\chi^2(1) = 80.98, p < .0001$. The learning strategy that followed enjoyment more often than statistically expected was calculating $\chi^2(1) = 12.14, p = .0005$.

Anxiety. No emotion followed anxiety. The learning strategy that followed anxiety more often than statistically expected was evaluation $\chi^2(1) = 6.96, p = .008$.

Shame. Only anxiety followed shame more often than statistically expected, $\chi^2(1) = 124.83, p < .0001$. No learning strategies followed anxiety more often than statistically expected.

Boredom. Only one emotion followed boredom more often than statistically expected: frustration, $\chi^2(1) = 96.20, p < .0001$. Only one learning strategy followed boredom more often than statistically expected: evaluating $\chi^2(1) = 5.49, p = .019$.

Hope. No emotions followed hope more often than statistically expected. Only one learning strategy followed hope more often than statistically expected: monitoring $\chi^2(1) = 4.88, p = .027$.

Hopelessness. No emotions followed hopelessness more often than statistically expected. The learning strategies that followed hopelessness more often than statistically expected were: monitoring, $\chi^2(1) = 7.80, p = .005$, and self-questioning, $\chi^2(1) = 4.59, p = .032$.

Pride. No emotions followed pride more often than statistically expected. Only one learning strategy followed pride more often than statistically expected: monitoring, $\chi^2(1) = 4.04, p = .04$.

Anger. No emotions followed anger more often than statistically expected. Only one learning strategies followed anger more often than statistically expected and that was calculating, $\chi^2(1) = 6.93, p = .008$.

Relief. No emotions followed relief more often than statistically expected. Only one learning strategies followed relief more often than statistically expected and that was calculating, $\chi^2(1) = 4.75, p = .029$.

Variations in Subsequent Learning Strategies as a Function of Object Focus

To address the fourth research question, we examined whether the consequences of emotions on learning strategies varied as a function of object focus. The following emotions were statistically different than expected with respect to object foci: enjoyment, $\chi^2(3) = 27.55, p < .0001$, frustration, $\chi^2(3) = 8.34, p = .040$, boredom, $\chi^2(3) = 26.34, p < .0001$, pride, $\chi^2(3) = 27.81, p < .0001$, hopelessness, $\chi^2(3) = 8.56, p = 0.036$, and anger, $\chi^2(3) = 76.68, p < .0001$. It is important to note that although the researchers explored four object foci (i.e., achievement, activity, epistemic and topic), there were not enough frequencies of epistemic or topic object foci to conduct the analysis. As such, the following analysis centered around differences between achievement and activity object foci and subsequent learning strategy use.

Enjoyment. Of the 58 times that enjoyment was expressed the object focus was achievement-related 38 times, activity-related 14 times, topic-related four times and epistemic-related two times. When monitoring followed enjoyment, which occurred six times, the object focus of enjoyment was achievement-related four times and activity-related two times. This difference was not statistically significant, $\chi^2(1) = .11, p = 0.74$. Evaluation followed enjoyment for a total of six times. Of these six, the object focus was achievement-related five times and activity-related one time. This difference was not statistically significant, $\chi^2(1) = .29, p = 0.59$. Lastly, calculating followed enjoyment 11 times. The object focus was achievement-related seven times and activity-related four times. This difference was not statistically significant $\chi^2(1) = .40, p = 0.53$.

Frustration. Of the 218 times that frustration was expressed, the object focus was achievement-related 113 times, activity-related 104 times and topic-related one time. When monitoring followed frustration, which occurred 31 times, the object focus was achievement-related 13 times and activity-related 18 times. This difference was not statistically significant, $\chi^2(1) = 1.12, p = 0.29$. When evaluation followed frustration, which occurred 28 times, the object focus was achievement-related 19 times and activity-related nine times. This difference was not statistically significant, $\chi^2(1) = 2.48, p = 0.12$. When calculating followed frustration, which occurred 32 times, the object focus was achievement-related 17 times and activity-related 15 times. This difference was not statistically significant, $\chi^2(1) = .012, p = 0.91$. When self-questioning followed frustration, which occurred 17 times, the object focus was achievement-related ten times and activity-related seven times. This difference was not statistically significant, $\chi^2(1) = .29, p = 0.59$. When judgement of learning followed frustration, which occurred 15 times, the object focus was achievement-related six times and activity-related nine times. This difference was not statistically significant, $\chi^2(1) = .82, p = 0.37$.

Boredom. Of the 39 times boredom was expressed, the object focus was achievement-related eight times and activity-related 31 times. When evaluating followed boredom, which occurred nine times, the object focus was achievement-related two times and activity-related seven times. This difference was not statistically significant, $\chi^2(1) = .013, p = 0.91$. When calculating followed boredom, which occurred five times, the object focus was achievement-related four times and activity related one time. This difference was statistically significant, $\chi^2(1) = 7.91, p = 0.005$.

Pride. Of the 57 times pride was expressed, the object focus was achievement-related 53 times and activity-related 4 times. When monitoring followed pride, which occurred 18 times, the object focus was achievement-related 15 times and activity-related three times. This difference was not statistically significant, $\chi^2(1) = 1.51, p = 0.22$. When evaluating followed pride, which occurred 13 times, the object focus was achievement-related ten times and activity-related three times. This difference was not statistically significant, $\chi^2(1) = 3.03, p = 0.081$. When calculating followed pride, which occurred seven times, the object focus was achievement-related five times and activity-related two times. This difference was not statistically significant, $\chi^2(1) = 3.41, p = 0.065$. When highlighting, labelling, colouring or drawing followed pride, which occurred seven times, the object focus was achievement-related three times and activity-related one time. This difference was statistically significant, $\chi^2(1) = 1.61, p = 0.21$.

Hopelessness. Of the 28 times hopelessness was expressed, the object focus was achievement-related 24 times and activity-related four times. When monitoring followed hopelessness, which occurred ten times, the object focus was achievement-related eight times and activity-related one time. This difference was not statistically significant, $\chi^2(1) = .059, p = 0.81$.

Anger. Of the 12 times anger was expressed, the object focus was achievement-related one time and activity-related eight times. When calculating followed anger, which occurred three times, the object focus was achievement-related two times and activity-related one time. This difference was not statistically significant, $\chi^2(1) = 3.70, p = 0.054$.

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

	Emotion-to-emotion transition	**Frequency**
Curiosity	Curiosity → Surprise	9
	Curiosity → Confusion	8
	Curiosity → Frustration	7
	Curiosity → Curiosity	7
	Curiosity → Enjoyment	2
	Curiosity → Pride	1
Confusion	Confusion → Confusion	18
	Confusion → Frustration	17
	Confusion → Curiosity	10
	Confusion → Surprise	8
	Confusion → Anxiety	5
	Confusion → Boredom	4
	Confusion → Hopelessness	3
	Confusion → Shame	2
	Confusion → Pride	1
Surprise	Surprise → Surprise	3
	Surprise → Confusion	2
	Surprise → Enjoyment	2
	Surprise → Pride	1
	Surprise → Hopelessness	1
	Surprise → Anger	1
	Surprise → Frustration	1
Frustration	Frustration → Frustration	7
	Frustration → Confusion	3
	Frustration → Curiosity	3
	Frustration → Enjoyment	1

	Frustration → Anger	1
	Frustration → Surprise	1
Enjoyment	Enjoyment → Enjoyment	3
	Enjoyment → Frustration	1
Shame	Shame → Anxiety	2
	Shame → Confusion	1
Boredom	Boredom → Frustration	2
	Boredom → Surprise	1
Relief	Relief → Boredom	1
	Relief → Enjoyment	1
Anxiety	Anxiety → Hope	1
Hope	Hope → Anger	1
Hopelessness	Hopelessness → Boredom	1
	Hopelessness → Confusion	1
	Hopelessness → Frustration	1
Pride	Pride → no emotion	0
Anger	Anger → no emotion	0

Table 8.
Frequency of emotion-to-learning strategy in think-aloud protocol.

	Emotion-to-learning strategy transition	**Frequency**
Curiosity	Curiosity → Evaluating	203
	Curiosity → Monitoring	157
	Curiosity → Calculating	112
	Curiosity → Judgement of Learning	37
	Curiosity → Self-questioning	30
	Curiosity → Identifying Important Information	26
	Curiosity → Planning	25
	Curiosity → Hypothesizing	22
	Curiosity → Control	20
	Curiosity → Self-correcting	17
	Curiosity → Highlighting, labelling, colouring, drawing and writing	17
	Curiosity → Prior Knowledge Activation	13
	Curiosity → Help-Seeking Information	11
	Curiosity → Re-reading	11
	Curiosity → Making Inferences	8
	Curiosity → Reading	7
	Curiosity → Task Difficulty	7
	Curiosity → Setting/Restating a Goal	5
	Curiosity → Help-Seeking: Evaluation	2

	Curiosity → Summarizing	1
Confusion	Confusion → Evaluating	131
	Confusion → Monitoring	126
	Confusion → Calculating	118
	Confusion → Identifying Important Information	42
	Confusion → Self-questioning	42
	Confusion → Help-Seeking: Information	35
	Confusion → Control	29
	Confusion → Highlight, labelling, colouring, drawing and writing	24
	Confusion → Planning	23
	Confusion → Self-correcting	23
	Confusion → Re-reading	22
	Confusion → Reading	21
	Confusion → Hypothesizing	15
	Confusion → Prior Knowledge Activation	14
	Confusion → Making Inferences	8
	Confusion → Task Difficulty	8
	Confusion → Setting/Restating a Goal	8
	Confusion → Help-Seeking: Evaluation	1
	Confusion → Coordinating Informational Services	1
	Confusion → Goal-Directed Search	1
Surprise	Surprise → Monitoring	25
	Surprise → Evaluating	23
	Surprise → Calculating	18
	Surprise → Judgement of Learning	6
	Surprise → Planning	9
	Surprise → Reading	6
	Surprise → Control	5
	Surprise → Help-Seeking: Information	5
	Surprise → Self-correcting	5
	Surprise → Self-questioning	4
	Surprise → Making Inferences	3
	Surprise → Task Difficulty	3
	Surprise → Highlighting, labelling, colouring, drawing and writing	2
	Surprise → Identifying Important Information	2
	Surprise → Re-reading	1
	Surprise → Prior Knowledge Activation	1
Frustration	Frustration → Calculating	32
	Frustration → Monitoring	31

	Frustration → Evaluating	28
	Frustration → Self-questioning	17
	Frustration → Judgement of Learning	15
	Frustration → Planning	14
	Frustration → Reading	9
	Frustration → Highlighting, labelling, colouring, drawing and writing	6
	Frustration → Self-correcting	6
	Frustration → Control	6
	Frustration → Help-Seeking: Information	4
	Frustration → Hypothesizing	3
	Frustration → Coordinating Informational Services	1
	Frustration → Re-reading	1
	Frustration → Making Inferences	1
	Frustration → Task Difficulty	1
Enjoyment	Enjoyment → Calculating	12
	Enjoyment → Evaluating	6
	Enjoyment → Monitoring	6
	Enjoyment → Task Difficulty	4
	Enjoyment → Identifying Important Information	2
	Enjoyment → Hypothesizing	2
	Enjoyment → Planning	1
	Enjoyment → Highlighting, labelling, colouring, drawing and writing	1
	Enjoyment → Self-questioning	1
	Enjoyment → Judgement of Learning	1
	Enjoyment → Reading	1
	Enjoyment → Setting/Restating a Goal	1
	Enjoyment → Control	1
Shame	Shame → Monitoring	7
	Shame → Evaluating	3
	Shame → Calculating	3
	Shame → Control	3
	Shame → Highlighting, labelling, colouring, drawing, and writing	2
	Shame → Self-questioning	2
	Shame → Judgement of Learning	1
	Shame → Identifying Important Information	1
	Shame → Reading	1
	Shame → Hypothesizing	1
	Shame → Coordinating Informational Services	1

	Shame → Re-reading	1
Boredom	Boredom → Evaluating	9
	Boredom → Monitoring	7
	Boredom → Calculating	5
	Boredom → Re-reading	2
	Boredom → Planning	1
	Boredom → Self-questioning	1
	Boredom → Prior Knowledge Activation	1
	Boredom → Control	1
Relief	Relief → Monitoring	4
	Relief → Evaluating	3
	Relief → Calculating	3
	Relief → Highlighting, labelling, colouring, drawing and writing	2
Anxiety	Anxiety → Evaluating	6
	Anxiety → Monitoring	4
	Anxiety → Planning	1
	Anxiety → Identifying Important Information	1
	Anxiety → Reading	1
	Anxiety → Help-Seeking: Information	1
	Anxiety → Control	1
Hope	Hope → Monitoring	6
	Hope → Evaluating	2
	Hope → Calculating	2
	Hope → Identifying Important Information	1
	Hope → Reading	1
	Hope → Hypothesizing	1
	Hope → Re-reading	1
Hopelessness	Hopelessness → Monitoring	9
	Hopelessness → Calculating	3
	Hopelessness →Self-questioning	2
	Hopelessness → Planning	2
	Hopelessness → Highlighting, labelling, colouring, drawing and writing	1
	Hopelessness → Identifying Important Information	1
	Hopelessness → Setting/Restating a Goal	1
	Hopelessness → Control	1
	Hopelessness → Task Difficulty	1
Pride	Pride → Monitoring	18
	Pride → Evaluating	13
	Pride → Calculating	7

	Pride → Highlighting, labelling, colouring, drawing and writing	4
	Pride → Identifying Important Information	3
	Pride → Help-Seeking: Information	2
	Pride → Planning	1
	Pride → Self-questioning	1
	Pride → Prior Knowledge Activation	1
	Pride → Hypothesizing	1
Anger	Anger → Calculating	3
	Anger → Monitoring	1
	Anger → Identifying Important Information	1
	Anger → Reading	1
	Anger → Task Difficulty	1
	Anger → Planning	1

CHAPTER 5

Discussion

The purpose of this study was first, to examine which emotions were elicited during a complex mathematics problem-solving task, as well as to explore the sequential dynamics of emotions in real time. Second, to assess whether there are variations in subsequent learning strategies as a function of object focus. To date, most research has explored the role of emotions during learning from a more static ad hoc self-report of emotions experienced during learning. Fewer studies have examined how emotions dynamically arise and unfold as learning progresses throughout the task. Moreover, current theoretical and empirical work has classified emotions by their object focus (i.e., topic emotions, achievement emotions, epistemic emotions) to determine whether an emotion relates to the task at hand or to extenuating circumstances. However, during learning, it is often the case that individuals will experience multiple emotions of a different object type that are all related to the task at hand.

A critical question that researchers have raised is whether object focus matters with regard to their consequences from a self-regulatory perspective (Muis et al., 2018). As Muis et al. (2018) argued, when emotions arise during learning, they signal to the learner that something is going well or that something needs to be adjusted or regulated. The central questions raised in this research were to explore in more depth the kinds of emotions younger students experience when engaging in a complex task, and whether object focus matters when emotions arise during a learning task that are central to the task at hand (and not due to extenuating circumstances). Better understanding of whether the consequences of epistemic anxiety, for example, are the same as those from achievement anxiety is critical in moving forward to develop interventions that target regulation of emotions and learning (Di Leo & Muis, in press).

Expressed Emotions

Consistent with previous research (Di Leo et al., 2019; D'Mello & Graesser, 2012), results from this study revealed that the most frequently expressed emotions during a complex task were confusion (37.48%), curiosity (34.25%) and frustration (9.52%). The next most frequently expressed emotions were surprise (6.42%), enjoyment (2.53%), pride (2.49%), boredom (1.70%), and hopelessness (1.22%). With regard to the second research question that explored the sequential dynamics of emotions, the emotion-to-emotion transitions identified support D'Mello and Graesser's (2012) model of affect dynamics with adults, as well as with children (Di Leo et al., 2019). Specifically, in this study, confusion transitioned into frustration, in addition to anxiety and curiosity. Frustration transitioned into anger, and confusion transition into frustration in addition to anxiety and curiosity. Moreover, in contrast to the findings of Di Leo et al. (2019), in this sample, curiosity transitioned into surprise and frustration; surprise transitioned into anger, enjoyment, surprise, and hopelessness; and shame transitioned into anxiety statistically more than expected. Finally, with regard to object focus, results from this study suggest that object focus does not matter; the consequences of the same emotion with a different object focus did not differ (with the exception of boredom). We discuss each of these results in the context of relevant theoretical and empirical work.

Emotions and Their Transitions to Other Emotions

Consistent with previous research, our results demonstrated that elementary students from grades three through six experience a wide range of emotions (Di Leo et al., 2019; Muis et al., 2015), and when given complex learning tasks, confusion is most likely to occur (Di Leo et al., 2019; D'Mello & Graesser, 2012). However, unlike the pattern found with Di Leo et al.'s

(2019) study wherein students expressed frustration and confusion the most, in our study, students experienced a relatively equal level of curiosity and confusion. Moreover, frustration was experienced much less than what Di Leo et al. (2019) reported. This suggests that students experienced cognitive incongruities throughout the problem-solving process, which triggered confusion (D'Mello & Grasser, 2012). But rather than this confusion transitioning to frustration more often than not, it may be the case that students in our sample were able to regulate their learning to overcome confusion and subsequently experienced curiosity (Munzar et al., 2020). However, consistent with previous research, these students also experienced frustration following confusion (Di Leo et al. 2019; D'Mello & Grasser, 2012; Munzar et al., 2020) but to a much lesser extent.

To explain why curiosity followed confusion more than expected, a better understanding of the learning situation may provide insight. Teachers chose the problems that students were asked to solve and given how well students did on these problems, we might infer that students were given a grade-level appropriate complex mathematics problem that was not too challenging. Under this condition, students would not experience as much frustration given that most were able to successfully complete the problem despite confusion that arose during learning. When confusion arose, it may also be the case that students asked for more adult support to help them resolve confusion and, as such, experienced more curiosity following confusion as opposed to frustration. This was particularly evident with students from grades three and four who often asked for help, more so than students in grades five and six. For those students who were unable to overcome the cognitive incongruity, wherein confusion transitioned into frustration, those students could have been in the upper grades who asked for less help (see Losenno et al., 2020).

Another interesting pattern that we noted was with regard to surprise. Recall that surprise is defined as an emotion that occurs when an event is highly novel or unexpected. These highly novel or unexpected events can trigger cognitive incongruity (i.e., an unexpected answer to a math problem, or a piece of information in a problem that was not expected). As Silvia (2010) suggested, two emotions are likely to occur following surprise: curiosity is experienced if appraisals about the incongruity lead the individual to believe that incongruity can be resolved; or confusion is experienced if appraisals of the incongruity lead the individual to believe that resolution may be difficult. To our surprise, in contrast to Muis et al.'s (2018) theoretical model and Silvia's (2010) empirical work, the findings of this study did not replicate the transition patterns expected. Although surprise transitioned to anger, enjoyment, surprise, and hopelessness, these subsequent emotions could suggest that other affective states could support the aforementioned appraisals. Anger, surprise and hopelessness could be experienced following surprise if an impasse is perceived to be difficult to resolve, whereas enjoyment could be experienced when the impasse is perceived to be feasible to resolve.

A third pattern that we found noteworthy was with regard to curiosity. Recall that curiosity is defined as a neutral emotion, as it could be characterized as positive or negative depending on whether there is interest or deprivation with respect to the information gaps or discrepancies (Litman et al., 2005). Empirical research has found that curiosity correlates positively with learning, such as the use of exploratory behaviours and deeper learning strategies, and also predicts other positive emotions (Berlyne, 1954; Di Leo et al., 2019; Litman, 2005; Lowenstein, 1994; Lowry & Johnson, 1981). In the current study, curiosity transitioned to surprise and frustration. Di Leo et al. (2019) found that curiosity was followed by anxiety more often than statistically expected. However, in this study curiosity transitioned to surprise and frustration. As noted by Di Leo et al. (2019), given that the sample of participants were elementary students, curiosity could operate similarly to confusion if students did not know how to regulate the emotion once it arises. In that case, curiosity could transition into frustration as found in this study and noted in previous work (D'Mello & Graesser, 2012).

To provide an alternative explanation, it may also be the case that the kind of curiosity that students experienced in this study was more of a deprivation kind (Lauriola et al., 2015; Litman, 2005, 2008), which logically would transition into frustration if they were not able to fill the knowledge gap. Alternatively, curiosity derived from a cognitive incongruity may have transitioned to confusion without us capturing that transition. Students were not asked to emote aloud and, as such, we may have missed some transitions that occurred. In this case, appraisals of the situation may have led students to transition to confusion followed by frustration rather than curiosity directly to frustration.

Emotions and Their Transitions to Learning Strategies

As theorized by Pekrun (2006) and empirically tested by Muis et al. (2015), positive emotions typically foster deep processing learning strategies (i.e., elaboration, critical thinking, monitoring, evaluation), whereas negative emotions typically lead to the use of shallow processing learning strategies (i.e., rehearsal). In the patterns of emotion-to-learning-strategy transitions that were observed, we found that enjoyment transitioned to calculating more often than statistically expected. This finding differs from previous research, which found that enjoyment positively predicted metacognitive strategies. That is, following enjoyment learners were more likely to monitor their progress during complex problem solving than engage in any other learning strategy (Di Leo et al., 2019). Although our results differ from Di Leo et al.'s

(2019) results, it is important to note that our sample included a broader range of students (grades three through six in our study versus grades five and six in Di Leo's study) who had varying levels of problem-solving skills. It may be the case that younger students are less likely to engage in deeper processing strategies as they have not learned or mastered them yet. This speaks to the importance of understanding what kinds of strategies young children commonly use during complex problem solving and interpreting strategy use at an age-appropriate level.

With regard to frustration, this negative emotion has been theorized to predict shallow learning strategies (Pekrun, 2006), which is consistent with Muis et al.'s (2015) findings. In line with Muis et al.'s (2015) findings, frustration in our sample transitioned to one shallow cognitive strategy, calculating. However, the students in this study transitioned to three metacognitive strategies: monitoring, self-questioning, and judgement of learning. Although this is contrary to Muis et al.'s (2015) findings, Di Leo et al. (2019) also found that frustration transitioned to other metacognitive learning strategies. To explain this, we highlight that differences across studies may be a function of how relations between emotions and learning strategies were statistically modeled. Although Muis et al. (2015) captured learning strategies via think aloud, emotions were reported after learning in terms of their level of intensity (and not frequency). In contrast, in this study and in Di Leo et al.'s (2019) study, both learning strategies and emotions were captured in using a think aloud wherein relations were modeled as a function of frequency and not intensity. Moreover, as proposed by D'Mello and Graesser (2012), frustration is elicited when an impasse is not resolved. Perhaps when students in our sample experienced frustration, they realized that the impasse was indeed not resolved and engaged in metacognitive strategies to resolve the impasse (see Munzar et al., 2020).

For confusion, recall that learners experience confusion when they encounter information that is highly novel, complex, and perceived as incomprehensible (Silvia, 2010). In relation to problem solving, confusion arises when the task is challenging and appropriate for the grade level, but not too challenging such that frustration immediately follows and then transitions to boredom (D’Mello & Graesser, 2012). Further, confusion functions as the primary emotion when a learner encounters an impasse, which are common during complex learning tasks (D’Mello et al., 2014). With respect to the learning strategies that follow confusion, in this sample, planning, calculating, identifying important information, in addition to self-questioning, judgement of learning and evaluation followed more statistically often than expected. Although this is counter to previous work, wherein confusion negatively predicted planning and cognitive learning strategies (Muis et al., 2015), it does support Di Leo et al.’s (2019) findings wherein confusion positively predicted metacognitive learning strategies, and supports D’Mello and Graesser’s (2012) and Munzar et al.’s (2020) models.

As D’Mello et al. (2014) argued, confusion plays a critical role in relation to complex problem solving and can be beneficial for learning when confusion is resolved. When students in our study experienced confusion, they engaged in metacognitive learning strategies to determine whether the learning strategies employed were appropriate in relation to the problem they were solving. As such, they could have engaged in metacognitive learning strategies to overcome the impasse. In regard to planning, calculating and identifying important information that followed occurrences of confusion, students could have created a new plan with respect to problem solving or referred to the original problem in order to identify relevant information to help solve the impasse. Further, calculating could have followed confusion as another means to resolve the impasse, in which students double checked or started their calculations from the beginning if they perceived the source of the impasse was due to calculation errors.

With regard to curiosity, as previously stated, curiosity is viewed as a neutral emotion (Litman et al., 2005), with empirical research suggesting that it correlates positively with exploratory behaviours in relation to learning and deeper learning strategies (Di Leo et al., 2019; Muis et al., 2015; Pekrun, 2006). Consistent with Muis et al.'s (2015) findings with respect to curiosity, which was a positive predictor of metacognitive learning strategies, this study found monitoring, self-questioning, judgement of learning, in addition to planning followed curiosity more statistically often than expected. This suggests that curiosity promotes the self-regulated learning process particularly with regard to promoting more metacognitive processes, which are critical for complex problem solving.

For surprise, recall that this emotion is elicited when an event is highly novel or unexpected, and in turn triggers cognitive incongruity. Under conditions of cognitive incongruity, researchers suggest that higher rates of cognitive and metacognitive strategies should follow to resolve the incongruity, and ultimately lead to deeper learning (D'Mello et al., 2014; Muis et al., 2018; Pekrun et al 2011; Pekrun & Stephens, 2012). In regard to surprise, Muis et al. (2015) found that surprise was a negative predictor of planning and goal setting, as well as shallow and deep cognitive learning strategies. However, in our sample, surprise transitioned more often than statistically expected to deep metacognitive learning strategies, like judgement of learning, in addition to enactment strategies like calculating. This finding suggests that students attempted to resolve cognitive incongruities by employing more metacognitive strategies.

Finally, anxiety, a negative activating emotion, has been associated with a reduction in effortful strategies and an increase in strategies that require less cognitive effort. This reduction in effortful strategies is due to the depletion of cognitive resources that are exhausted by the negative emotions, which leads to the use of learning strategies that require fewer cognitive resources (Pekrun & Stephens, 2012). Consistent with previous work, anxiety was a positive predictor of metacognitive learning strategies (Muis et al., 2015); in our sample, anxiety was followed by evaluation, more often than statistically expected. Given that anxiety is the result of the combination of high value and low control (Pekrun, 2006), anxiety could hinder intrinsic motivation and activate extrinsic motivation to avoid failure (Pekrun, 2006). In particular, when engaged in a high value task, students could be motivated by the fear of failure and implement strategies that aid in their success with the problem-solving task. Consequently, students would engage in metacognitive strategies to correctly solve the problem (Pekrun et al., 2011). The increase in more effortful strategies following anxiety in our sample may be explained by this phenomenon.

In summary, across all emotions, the learning strategies that most frequently followed were monitoring, evaluating and calculating. More specifically, curiosity, confusion, surprise, and frustration had a high frequency of metacognitive learning strategies that followed. Shame was the only emotion that did not have a learning strategy that followed. Given that both monitoring and evaluating are metacognitive learning strategies, this trend suggests that emotions prompt students to assess whether they progress well or not with respect to the task at hand. This further corroborates the role of emotions in the self-regulated learning process (Muis et al., 2018; Pekrun et al., 2007), which in turn facilitate or constrain learning (Baker et al., 2010; D’Mello & Gresser, 2011; Pekrun et al., 2010).

Does Object Focus Matter?

Researchers have highlighted the need to understand whether object focus matters within the context of self-regulated learning (Muis et al., 2018) and, as such, the current study is the first of its kind to address this question. Clore and Huntsinger (2009) suggested that through the Affective Processing Principle, the influence of emotion on cognitive processes can vary depending on the object focus. They suggested that if goals were the object focus of the emotion, positive emotions simulate, and negative emotions hinder the pursuit of said goals. Further, if the object focus of the emotion is the task at hand, Clore and Huntsinger (2009) posited that positive emotions "may process information in a global or local fashion, depending on their relative accessibility" (p.43), whereas negative emotions would not. Although the aforementioned study explored object focus similar to achievement and activity, it is unclear to what extent object focus could impact shallow or deep cognitive strategies used during complex problem solving.

In like manner, the current study only explored variations in subsequent states as a function of achievement and activity emotions. Although our goal was to explore four different object foci, only enjoyment had occurrences of all four object foci, followed by anger, which only had occurrences of achievement, activity and epistemic emotions. This limited our ability to fully assess whether the consequences of emotions differed by object focus. Indeed, we found only one statistically significant finding with respect to boredom. When boredom was expressed as an achievement emotion, students engaged in more calculations compared to when they experienced it as an activity emotion. No other differences in consequences occurred as a function of object focus. Within the context of complex mathematics problem solving among elementary students, object focus does not seem to matter in relation to subsequent state at least during complex mathematics problem solving with a sample of elementary students from grades three through six. When the more general target of the emotions is the task at hand, their specific object does not appear to lead to different consequences. This has important theoretical implications.

Given that achievement outcome and activity emotions fall within the broader category of academic emotions within Pekrun's (2006) control-value theory, results suggest that there is no difference between achievement outcome and activity emotions in relation to subsequent states during a learning task. Further, achievement and activity emotions have the same antecedents and consequences as described by Pekrun's (2006) theory. As such, results of this study are consistent with the notion that achievement and activity emotions should have similar consequences (i.e. not differ as a function of object foci) in the context of self-regulated learning. However, it is important to note that for the current study, we were unable to explore between object foci that were topic and epistemic in nature. As such, future studies should explore whether subsequent states differ in relation to a broader range of emotions of varying foci.

One question remains as to why differences were found for boredom. Previous research has highlighted that boredom emotion results in disengagement in the learning process (Linnenbrink-Garcia & Pekrun, 2011) in addition to negatively predicting the use of all learning strategies (Muis et al., 2015). The findings from this study are consistent with previous research, as no deep cognitive or metacognitive learning strategies differed as a function of boredom's object foci within our sample. However, we did find that different strategies followed boredom depending on its object focus. This finding supports the notion proposed by Goetz et al. (2014) that boredom is more complex than once thought. Goetz et al. (2014) proposed five subtypes of boredom that differ with respect to valence and arousal: indifferent, calibrating, searching, reactant and apathetic boredom. Goetz and Frenzel (2006) also differentiate boredom with respect to the achievement setting. They suggested that in non-achievement settings, boredom types with lower negative valence (i.e., indifferent boredom) may be more prevalent than other boredom types. With respect to the boredom subtypes with higher negative valence (i.e., reactant boredom), they tend to be more strongly related with achievement settings. Although Goetz and colleagues do not specifically differentiate boredom with respect to object focus, the findings of this study support the notion that in achievement or non-achievement settings (i.e., achievement or activity object foci), boredom behaves differently with respect to subsequent learning strategy use. This could be due to the fact that when different boredom subtypes are elicited (and therefore differing in activation and arousal), it impacts the use of subsequent learning strategies. Therefore, with our sample, the difference in subsequent state as a function of achievement or activity object foci could be due to the fact that different boredom subtypes were elicited.

Educational Implications

Given that confusion is consistently reported as the most experienced emotion during complex problem solving among elementary-aged children, research is needed wherein educational interventions are developed to address the adverse effect of negative emotions during complex problem solving. To expand, negative emotions are complex and dynamic in nature and can either evolve into other productive or unproductive affective or cognitive states. If for example, a student experiences confusion that transitions into curiosity, this would suggest that the student engaged in effortful learning strategies to resolve the confusion. However, if confusion transitions into boredom, which has been related to disengagement of effortful learning strategies, this would negatively impact achievement. Educational interventions should target the dynamic nature of emotions, such that learners are equipped with the learning strategies to resolve negative emotions (Di Leo & Muis, 2020).

Limitations

The questions explored in this study add to the current theoretical and empirical landscape within the broader emotions literature. However, there are some limitations. It is important to note that students were not explicitly asked to emote out loud (D'Mello & Graesser, 2012). As such, some emotions and dynamic state transitions could have been missed. Further, given the dynamic nature of emotions, these affective states could only be experienced momentarily and subconsciously (Pekrun, 2006), therefore making it difficult to capture objectively. Given the sample of participants were elementary students, and emotions may evolve quickly into other affective states, the participants may not have recognized the primary, secondary or tertiary emotions experienced such that they could be verbalized and therefore captured accordingly for research purposes. Further, if these emotions were not recognized and verbalized, this would have impacted the emotional state transitions that occurred within the transcriptions. Likewise, the emotions were analyzed linearly, without considering the possibility of emotions occurring simultaneously.

Lastly, variations of subsequent states as a function of object focus was explored, however, participants were not explicitly asked to emote out loud. This could have resulted in many affective states with differing object foci could have been experienced and not verbalized in our sample. This, in turn, could have impacted coding of transcriptions with respect to the frequency of emotions and object foci identified within the sample. Moreover, the sample of participants in this study were elementary students. For this reason, students may not have been equipped to recognize the various academic emotions experienced during complex problem solving, and accordingly did not verbalize them. This could be the reason why there was a low frequency of object foci within the sample. Moreover, the low frequency of object foci in combination with the 23 self-regulated learning codes made it challenging to find a relationship between object foci and the cognitive processes within the context of self-regulated learning.

If the emote out loud protocol were used (D'Mello & Graesser, 2012), individual differences between participants with respect to the level of emotional expression could have been explored, and thus analyzed to see whether or not that impacts the current research questions. Future studies could look into implementing the emote out loud protocol when exploring research questions relating to emotions. With respect to working with children, researchers should explore the proper emote out loud protocol to use, such that students understand how to spontaneously label their emotions. This could serve researchers twofold: (1) there would be an increase in the frequency of emotions expressed; (2) with appropriate language, students would be able to differentiate between emotions they have difficulty expressing, in addition to differentiating between affective states that are difficult for researchers to code. Further, future work should look into the use of more than one technique that could capture information related to the emotions experienced while students attempt complex mathematics problem solving. Potential techniques could include the following: recording students to assess facial expression and physical arousal (i.e., galvanic skin response) to capture and then examine emotions as they occur in real time (Azevedo, 2009).

Conclusion

The aim of this research was twofold: first, to examine which emotions were experienced and to explore the trajectory of emotions as they evolve into other affective states and learning strategies among elementary students during complex mathematics problem solving; second, to explore whether there is a variation in subsequent state as a function of object focus. The results of this study revealed that emotion-to-emotion transitions provided further support for D'Mello and Graesser's (2012) model of dynamic affect, in addition to Di Leo et al.'s (2019) findings. Further, results showed that the emotion-to-learning strategy transitions provided support for the role of emotions in the self-regulated learning process. Lastly, this study is the first to explore the variation of subsequent states as a function of object focus. Most interesting, boredom was the only emotion that had a variation in the enactment learning strategy with respect to object focus. This supports the notion that boredom is a complex emotion (Goetz et al., 2014), with differing object foci eliciting a different subtype of boredom (Goetz & Frenzel, 2006).

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APPENDIX A: PARENTAL CONSENT/CHILD ASSENT FORM AND DEMOGRAPHICS

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INFORMED CONSENT

Dear Parent/Legal Tutor,

I am a professor in the Department of Educational and Counselling Psychology at McGill University. My areas of expertise include learning and motivation across the lifespan. I am conducting a multi-year research study in collaboration with Mrs. Harwood (Grade 3), Mrs. Laframboise (Grade 4), Mrs. Szollozy (Grade 5) and Mrs. Kavanagh (Grades 5/6) at Dorset, and we would like to ask your permission to have your child participate. All children from Grades 3 through 6 are invited to participate. This study began in May 2017 and will continue until June 2019. Children in Grade 3 who sign up this September 2017 may participate until the end of Grade 4. Children in Grade 4 may participate until the end of Grade 5. Those in Grade 5 may participate until the end of Grade 6, and those in Grade 6 may participate this year. The purpose of this research is to examine how student characteristics (achievement, motivation, emotion and behaviour) and features of classroom contexts (tasks, instructional practices, interpersonal interactions) relate to self-regulated learning through the elementary grades. "Self-regulated" describes individuals who control their thoughts and actions to achieve goals and respond productively in their environment. Specifically, we are interested in understanding: (a) how children's self-regulated learning responds to variations in classroom experiences across time and contexts; and, (b) how teachers' instructional practices support self-regulated learning.

The specific purpose of this research is to understand how children's classroom experiences help them develop strategies for learning and problem solving in mathematics. The outcomes of this study will be highly valuable for teachers and students. For teachers, the information that we gather from this study may help to inform mathematics instruction designed to better meet the needs of all students. For students, they may learn how to better regulate their learning and emotions, which may lead to better learning outcomes in mathematics.

What would your child have to do?

For the 2017-2018 and 2018-2019 academic years, your child will be asked to participate in two sessions – one in October, and one in May. Before the session begins, your child will respond to items used to measure his or her value for learning mathematics, and confidence in learning and problem solving in mathematics. Then, he or she will be given a mathematics problem (one used in the regular curriculum). Your child will work on the mathematics problem during regular class time and his/her thought processes will be audio-recorded. After completing the mathematics problem, your child will then complete a questionnaire that will measure his or her emotions experienced during problem solving. Performance on the mathematics problem will also be measured. These sessions will occur during regularly scheduled class activities and will take no more than 1 hour.

Moreover, for each year of the study, we will collect:

1. Teachers' ratings of children developing self-regulation: Your child's teacher will respond to questions about how your child approaches learning.
2. Teachers' descriptions of their classroom contexts: Your child's teacher will describe her classroom context by responding to questions about how she provides opportunities for children to develop self-regulated learning in her classrooms.
3. Classroom observations: My research assistants and I will observe your child's classroom two times each year (October and May). These observations help us understand how different teachers implement activities that support self-regulation, and how students take up these opportunities on a day-to-day basis. These observations do not require your child or his/her teacher to do anything they would not normally be doing.

Other Important Information

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

Participation in this study is completely voluntary on the part of your child. We expect that students who participate in this study will benefit given that they will have the opportunity to further develop their numeracy skills through practice. Moreover, to compensate your child for his or her time, your child will receive an iTunes gift card for $10 for each year that he or she participates.

Your child may withdraw from the study at any time for any reason. Moreover, participating (or not participating) in this study will not in any way affect his or her regular classroom activities and will not negatively influence his or her grades. Given that this study will be conducted during regularly scheduled activities, the students who do not consent will be doing the same thing as those who do consent. We will simply not use their information for the study. Risks to your child are minimal and should be no greater than those associated with everyday classroom activities. The students will be informed of all aspects of the study before they participate, as described here in the consent form. We will gladly answer any questions and address any concerns they may have. We plan to publish the results of the study in journals designed for teachers and researchers. No reference will be made to the school or to your child in written or oral materials that could link them to this study. All information will be stored in a locked facility at McGill University for at least five years after the completion of the study. After this time, all information gathered will be destroyed.

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

To ensure the study is being conducted properly, authorized individuals such as a member of the Research Ethics board, may have access to your child's information. By signing this consent form, you are allowing such access. Please sign below if you have read the above information and consent to participate in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. A copy of this consent form will be given to you and the researcher will keep a copy.

Thank you for your co-operation,

Krista R. Muis, PhD
Associate Professor and Canada Research Chair
Faculty of Education
McGill University

Yes. I, ________________________________ (Parent/ Legal Tutor), give permission for my

child ________________________ (name of child) to participate in all research aspects as

described above.

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

Signature of Parent/Legal Tutor: ____________________________

Date: _____/_________/_________
Day Month Year

Birth date of child: _____/_________/_________
Day Month Year

No. I, ___________________________________ (Parent/ Legal Tutor), do NOT give my child

_________________________ (name of child) permission to participate in this research.

INFORMED ASSENT

Dear Student,

I am a professor at McGill University and am doing a project with your teacher. We would like to learn more about how you solve math problems, the feelings you have about math, and how those change over the school year. We will continue this project at Dorset from October 2017 until June 2019. During the time you are at Dorset, you may participate each year until the end of the study (or until you leave Dorset).

What will you do?

For each school year, you will work on two math problems – one in October and another one in May. We will ask you to talk out loud to tell us what you are thinking as you solve the problem. The problem will take about 20 minutes to solve, and we will record your voice as you try to solve the math problem. We will also ask you about your feelings about math after solving these problems. Your teacher will also fill out questionnaires about classroom activities, and the kinds of things you do when you learn. We will also visit your classroom a few times to see what kinds of activities happen in your class.

Other Important Information

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

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

If you take part, you will receive an iTunes gift card for $10 for each year that you participate. If you have questions you can call Dr. Krista Muis at (514) 398-3445. Thank you for reading this letter and for your help,

Krista R. Muis, PhD
Associate Professor and Canada Research Chair
Faculty of Education
McGill University

Yes. I _________________________ (name of child) agree to take part in this study.

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

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

____
(child's signature)

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

____
(child's signature)

APPENDIX B: REB RENEWAL REQUEST

McGill University
Research Ethics Board Office (REB-1, 2, 3, 4)
RENEWAL REQUEST/STUDY CLOSURE FORM

This form must be completed to request **ethics renewal approval** or to **close a study**. A current ethics approval is required for ongoing research. To avoid expired approvals and, in the case of funded projects, the suspension of funds, this form should be returned 1-2 weeks before the current approval expires. **No research activities including recruitment and data collection may take place after ethics approval has expired.**

REB File #: 291-0113 Principal Investigator: Dr. Krista R. Muis
Project Title: Self-regulatory processes, emotions, and motivation during mathematics problem solving
Email: krista.muis@mcgill.ca
Faculty Supervisor (if PI is a student):

1. Any modifications to the study or forms must be approved by the REB **prior** to implementation. **Are there any modifications to be made that have not already been approved by the REB?** ____YES __X__NO
If yes, complete an amendment form indicating these changes and attach to this form.

2. The REB must be notified of any findings that may have ethical implications or may affect the decision of the REB. The REB must be promptly notified of any new information that may affect the welfare or consent of participants.
Are there any ethical concerns that arose during the course of this research? ___ YES _X__ NO
If yes, please describe.

3**.** Unanticipated issues that may increase the risk level to participants or that may have other ethical implications must be promptly reported to the REB. **Have any participants experienced any unanticipated issues or adverse events in connection with this research project that have not already been reported to the REB?** ___ YES _X__ NO
If yes, please describe.

4. Is this a funded study? ___ NO
__X__YES. If yes, **indicate the agency name and project title** and the Principal Investigator of the award if not yourself. This information is necessary to ensure compliance with agency requirements and avoid interruption of funding.

SSHRC – Investigation elementary age children's development of self-regulation for learning

Principal Investigator Signature: _____________ Date: ___Sept 23, 2019______

Faculty Supervisor Signature: ____________________________________ Date:______________
(if PI is a student)

____ Check here if the **study is to be closed** and continuing ethics approval is no longer required. A study can be closed when all data collection has been completed and there will be no further contact with participants. Studies involving secondary use of data no longer need ethics approval when all secondary data has been received.

_X__ Check here if this is a **request for renewal** of ethics approval.

For Administrative Use

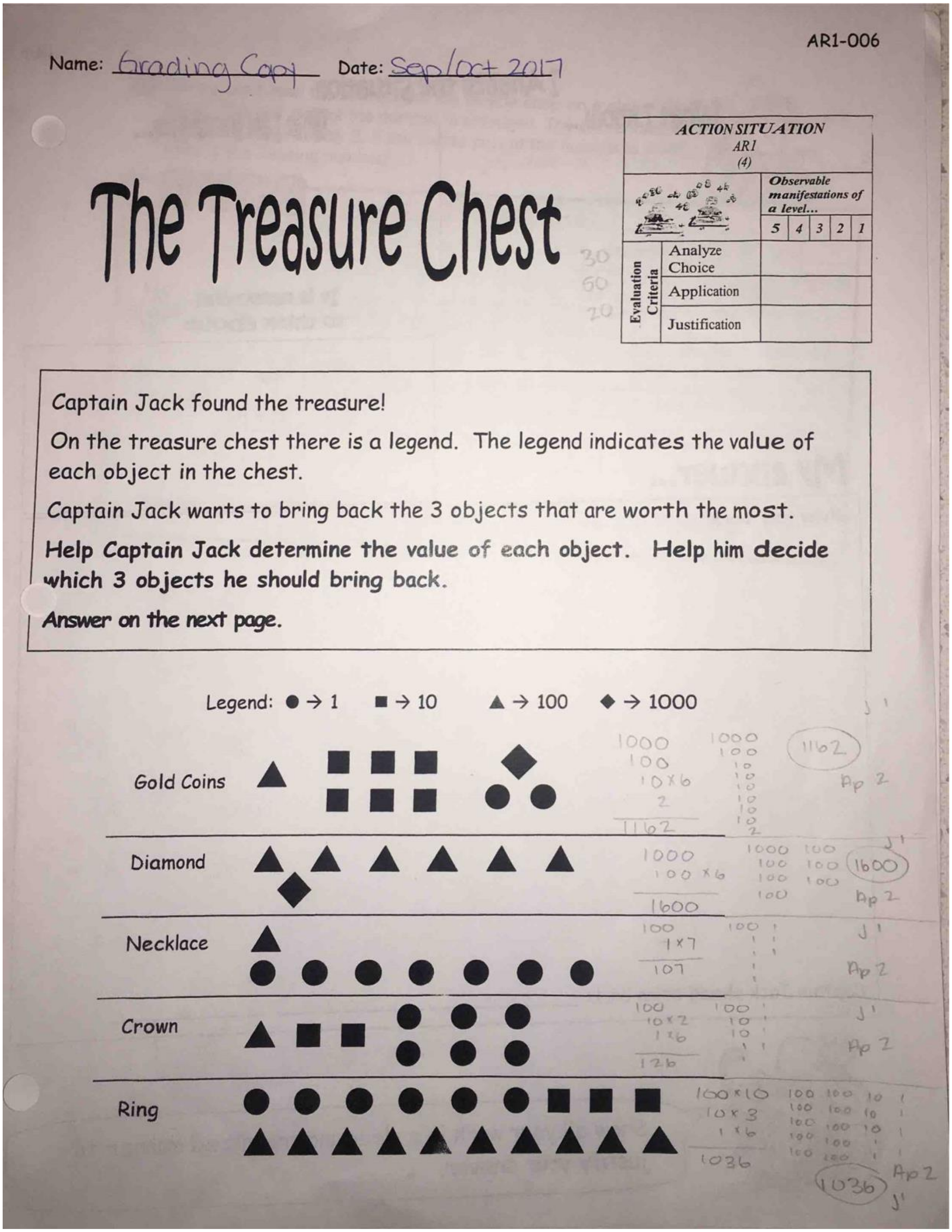
Signature of REB Chair or designate: lynda.mcneil@mcgill.ca Digitally signed by lynda.mcneil@mcgill.ca DN: cn=lynda.mcneil@mcgill.ca Date: 2019.09.23 19:56:33 -04'00' Date: __________________

Approval Renewal Period: October 15, 2019 to October 14, 2020

The researcher is responsible for ensuring that all other applicable approvals/renewals from other organizations are obtained before continuing the research.

Submit by email to deanna.collin@mcgill.ca. tel: 514-398-6831/6193; www.mcgill.ca/research/research/compliance/human
(UpdatedApril-17-2019)

APPENDIX C: GRADE 3 COMPLEX MATHEMATICS PROBLEM



AR1-006

Name: Grading Copy Date: Sep/Oct 2017

ACTION SITUATION AR1 (4)						
	Observable manifestations of a level…					
		5	4	3	2	1
Evaluation Criteria	Analyze Choice					
	Application					
	Justification					

The Treasure Chest

Captain Jack found the treasure!

On the treasure chest there is a legend. The legend indicates the value of each object in the chest.

Captain Jack wants to bring back the 3 objects that are worth the most.

Help Captain Jack determine the value of each object. Help him decide which 3 objects he should bring back.

Answer on the next page.

Legend: ● → 1 ■ → 10 ▲ → 100 ◆ → 1000

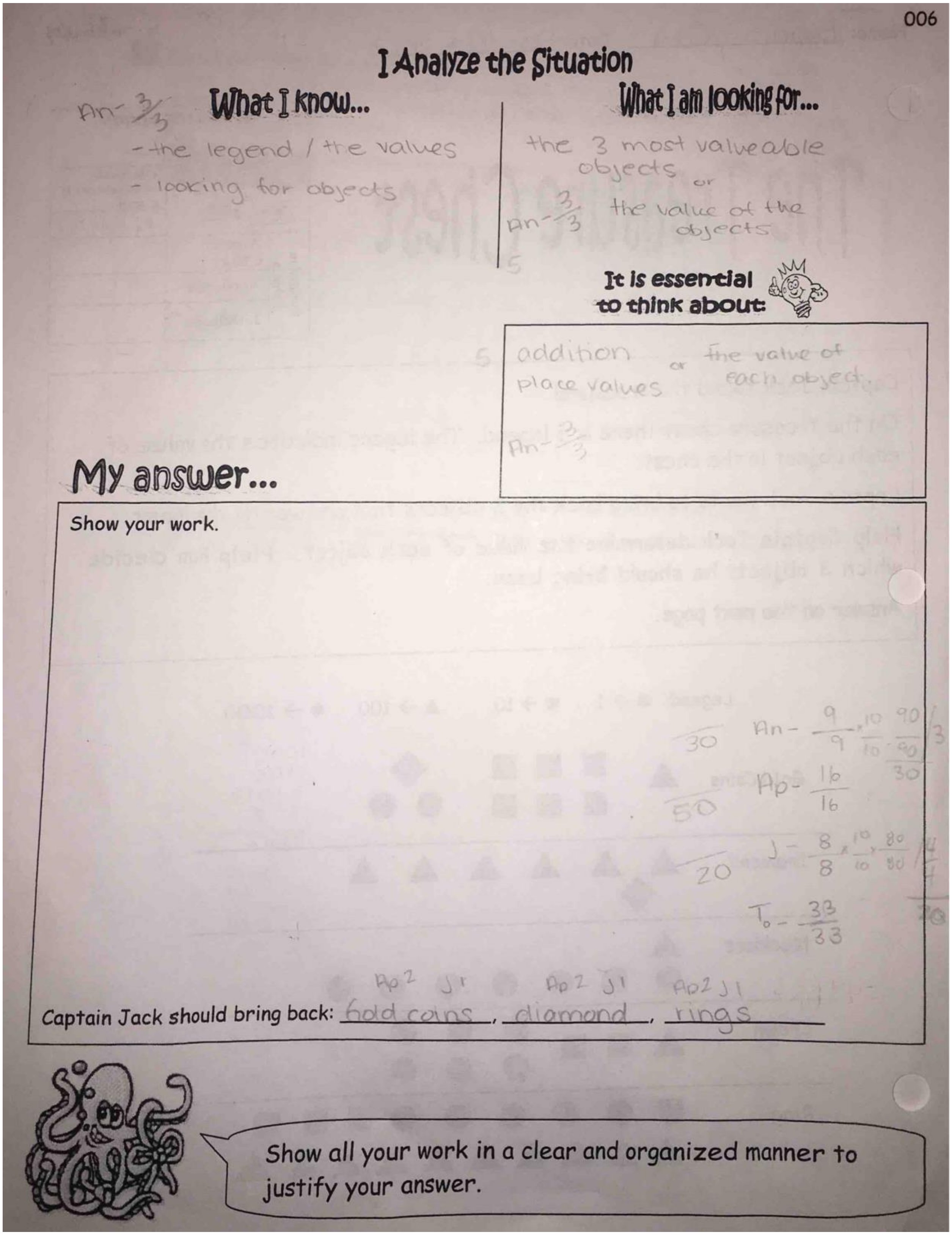
Gold Coins 1162

Diamond 1600

Necklace 107

Crown 126

Ring 1036


006

I Analyze the Situation

What I know...

An- 3/3

- the legend / the values
- looking for objects

What I am looking for...

the 3 most valueable objects or the value of the objects

An- 3/3

5

It is essential to think about:

5

addition or the value of each object

place values

An- 3/3

My answer...

Show your work.

30 An - 9/9 x 10/10 90/90 /3 30

50 Ap - 16/16

20 J - 8/8 x 10/10 x 80/80 /4 /4 20

To - 33/33

Ap 2 J 1 Ap 2 J 1 Ap2 J 1

Captain Jack should bring back: gold coins, diamond, rings

APPENDIX D: GRADE 4 COMPLEX MATHEMATICS PROBLEM

Name: ____________________ Date: ____________

Theme 1, Section 6, Activity 2 – To Reason

On Monday morning, Cabossa had 1234 talking cats and 456 evil cats in her store.

On Monday, she sold 787 cats.
On Tuesday, she sold 542 cats.
On Wednesday morning, Professor Potirus ordered 370 cats from her.

Does Cabossa have enough cats to fill Professor Potirus' order?

IWB Interactive Activities
Grade 4

NUMERS
N53510

1

APPENDIX E: GRADE 5 AND 6 COMPLEX MATHEMATICS PROBLEM

TECHNOLOGICAL PROBLEMS – Grade 6

Customers have been complaining to a manufacturer of computer tablets. It seems that there are a number of defects in machines with serial numbers from 24901 to 24926 inclusive.

> Tablets with serial numbers that are divisible by 2 have problems with their screen colour.
>
> Tablets with serial numbers that are divisible by 5 and 10 have faulty keyboards.
>
> Tablets with serial numbers that are divisible by 3, 6 and 9 have trouble with their charging mechanisms.
>
> Tablets with serial numbers that are divisible by 4 and 8 have trouble with their on/off switch.

The manufacturer plans to recall the faulty tablets. In order to plan for repairs, the manufacturer needs to know how many machines will be returned with each defect. The company has hired you to figure it out. The company has informed you that you must show all your work and send a memo to the Repairs Vice President once you have completed your analysis. The blank memo is on the bottom of page 3. Do your work on pages 2 and 3.