Situating Emotions in the Context of Mathematics: A Multi-Method Approach to Investigate the Functions of Emotions in the Process of Learning

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Summary

Recently, emotions have entered the spotlight of cognitive and educational research, as provocative calls insist that “We feel, therefore We Learn” (Immordino-Yang & Damasio, 2007, p. 3) and thus claiming a central function of emotions for learning and instruction. While the instrumentality of emotions for learning is indeed being increasingly acknowledged (Beaty, Benedek, Silvia, & Schacter, 2016; De Corte, Depaepe, Op’t Eynde, & Verschaffel, 2011; Pekrun, 2016; Ranellucci, Hall, & Goetz, 2015), the complexity of emotions’ role in the process of reasoning, learning and cognitive development remains poorly understood. The control-value theory of achievement emotions (CVT; Pekrun, 2006; Pekrun & Perry, 2014) presents a comprehensive theoretic frame explicating the instrumental properties of emotions for students’ learning and performance. Several cognitive and motivational functions are posited to be responsible for emotion effects, including students’ cognitive resources, motivation, strategy use, and regulation of learning (Pekrun, 2006). These mediational mechanisms constitute that student learning is a complex interaction between emotional experiences and cognitive, motivational and behavioral factors that, taken together, determine learning progress and achievement outcomes (Linnenbrink & Pintrich, 2000). While this cognitive-motivational model follows the principle of functional universality, another central assumption in the CVT framework postulates that emotional experiences in achievement related settings are ‘context sensitive’, thus highlighting the situational nature of learning processes not only across, but also within a domain (e.g., mathematics). Based on CVTs’ postulations and employing a variety of different methodological approaches, the functional mechanisms of emotions for adaptive learning in mathematics were investigated relative to momentarily emotional experiences (study 1), with respect to emotions arising when working on a complex mathematical task (study 2), and in relation to recurring emotional experiences during learning and classroom activities in mathematics generally (study 3). Thus, all three studies presented herein elucidate the mediational mechanisms of emotions, as formulated by the cognitive-motivational model as part of CVT, in order to investigate the functional mechanisms of differently ‘situated’ emotions during learning in mathematics.

The first study investigated the effects of emotions experimentally in order to determine their impact on thinking in mathematics. Empirical evidence from neuroscience and cognitive psychology indicates that positive affective states broaden, whereas negative affective states narrow our cognition. This suggests that emotions can trigger qualitatively different cognitive processes, which can both be functional for thinking, if adaptive to the cognitive task. The findings revealed that the experimental emotion induction procedure evoked intense emotional experiences of excitement and anxiety across the experimental emotion groups. These activating emotional states did outperform the deactivating control groups on both mathematical tasks. Further, it was found that enjoyment and anxiety differentially complemented cognitive mechanisms; with enjoyment supporting the generation of mathematical ideas, whereas anxiety help to better identify false mathematical ideas.

This second study examined the function of naturally occurring emotions in their interaction with a complex cognitive mathematical task. Findings revealed that students experience a broad range of different epistemic emotions, such as curiosity, enjoyment, frustration, and boredom while engaging in and reasoning about a mathematical problem. Structural equation modelling found that both, control and value appraisals, served as important antecedents of curiosity, enjoyment, surprise, confusion and boredom experienced during the task. In addition, curiosity, enjoyment, frustration and boredom were found to relate to intrinsic motivation and attention as well as task performance. Indirect effects offer support for the postulated functional properties of epistemic emotions as suggested in CVT, as epistemic emotions mediated relations between appraisals and intrinsic motivation and attention, as well as intrinsic motivation and attention mediated relations between enjoyment and task performance.

The third study examined the developmental trajectories of learning-related emotions and investigated the reciprocal relations between achievement emotions and class participation over one school year. Findings showed that enjoyment of learning is not only an important predictor but also an outcome of cognitive and behavioral learning in classroom activities and instructions in mathematics. Specifically, structural equation modeling indicated that enjoyment reported near the beginning of the school year positively predicted class participation at the end of the year, and that this relation was mediated by the use of learning strategies in the middle of the school year. Additionally, class participation at the beginning of the year positively predicted enjoyment, and negatively predicted boredom, at the end of the year, and these relations were also mediated by cognitive strategies reported in the middle of the year.

The overall findings from these three studies provide further evidence for the central assertion of the instrumentality of emotions for learning (Pekrun, 2006; Pekrun & Perry, 2014); specifically that emotions effect and interlink with cognitive, motivational and behavioral processes which together determine complex thinking, learning, achievement and academic development. Most importantly, however, the findings accumulated empirical

evidence for these mechanisms to function beyond the situational specificity of emotional experiences, indicating that emotions do not only influence cognitive-motivational processes moment-specifically but that their effects carry over to determine habituated learning experiences as well. Here, the most fundamental principle in the CVT concerning emotion-effects, as outlined by mediational principles, thus supports the principle of general universality.

Therefore, emotions do rightfully deserve further empirical attention, especially so in light of the increasing scientific as well as educational interest of functional properties of emotions that can inform educational practice.

1 General Introduction

In the academic context, emotions are recognized as one integral component of learning by initiating, steering, changing or halting processes that constitute learning progress, performance and learners' psychological growth (Op't Eynde & Turner, 2006; Pekrun, 2016; Pekrun & Linnenbrink-Garcia, 2014). For example, findings point in the direction that positive emotions, like enjoyment of learning, open the mind to creative problem solving and lay the groundwork for students to actively monitor and control their learning (Fiedler & Beier, 2014; Fredrickson, 2001; Linnenbrink & Pintrich, 2004; Pekrun, Goetz, Titz, & Perry, 2002a). Negative emotions, such as confusion and frustration, may be functional for a learner by signaling a blocked goal, thereby motivating to change the course of action in pursuing these same goals (Artino, 2009; D'Mello, Lehman, Pekrun, & Graesser, 2014; Macklem, 2015). Problematically, such adaptive functions, however, may not always be beneficial for learning and can contribute to maladaptive learning behaviors (Izard & Ackerman, 2000). For example, if enjoyment is interpreted in an "all is well" manner it may prompt a learner to lean back and refrain from investing any more effort in the learning endeavor (J. Gruber, Mauss, & Tamir, 2011; N. Schwarz, 1990; N. Schwarz & Clore, 1996). Similarly, negative emotions, like excessive anxiety or frustration may impair engagement and may not only prompt to 'give up' but even commit students to drop out of school and impact negatively on their psychological and physical well-being (Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010; Tze, Daniels, & Klassen, 2016; Zeidner, 2014).

The control-value theory of achievement emotions (CVT; Pekrun, 2006; Pekrun & Perry, 2014) provides an integrative theoretic frame allowing to systematically investigate functional properties of positive and negative emotions with respect to their adaptive as well as maladaptive effects on learning and achievement. More specifically, the theory takes a 'situated' perspective by describing the functions of academic emotions as grounded in their respective contexts. In contrast to the perspective of emotions as evolutionary programs (Cosmides & Tooby, 2000) (e.g., curiosity as encouraging exploration or fear for ensuring withdrawal in light of danger), academic or achievement-related situations are more complex in that specific emotion-effects on learning must be investigated relative to the socio-cultural contexts in which they occur (Pekrun, 2006; Pekrun & Perry, 2014). That is, while the basic structures and causal mechanisms describing the effects of emotions should generalize across achievement settings (i.e. the proposed cognitive-motivational model as part of CVT), such a 'situated' perspective of academic emotions is critical to better account for contextual variation that activate specific control and value appraisals forming specific emotional experiences and thus consequences for learning (J. C. Turner & Trucano, 2014).

The present dissertation seeks to investigate functions of discrete emotions for learning in ‘situated’ achievement contexts relative to their adaptive and maladaptive mechanisms, that operate during and form on-going learning endeavors (Pekrun, 2016; Pekrun & Linnenbrink-Garcia, 2014). The first study (chapter 2) investigates the cognitive mechanisms that accompany and are automatically elicited by intense emotional experiences. To untangle these reciprocal mechanisms, an experimental design aimed to show that different discrete emotions induce differential cognitive processes that might each be adaptive for performance, if contingent upon the cognitive processes required by the task (Baumann & Kuhl, 2005; Fiedler & Beier, 2014). While empirical studies have systematically addressed the effects of discrete emotions on several mechanisms that operate during information processing (e.g., mode of attention, cognitive control mechanisms, access to semantic memory, retrieval-induced forgetting, etc.; Bolte, Goschke, & Kuhl, 2003; Goschke & Bolte, 2014; Kuhbandner, Bäuml, & Stiedl, 2009; Wegbreit, Franconeri, & Beeman, 2015), no study has systematically considered these processes, as affected by emotions, and investigated how they might be adaptive for performance. The CVT provided an important theoretic frame helping to systematize recent empirical findings of emotion effects and to arrive at specific hypotheses, describing how emotions modulate cognitions in a specific moment.

The second study (chapter 3) situates emotions task-specifically and examines if emotions, that arise in interaction of dealing with a complex cognitive task, can be assigned a knowledge generating – an epistemic – role during complex problem solving. However, this group of naturally arising epistemic emotions has only recently attracted empirical attention (D’Mello & Graesser, 2012; Meier, 2014; Muis, Pekrun, et al., 2015; Pekrun, Vogl, Muis, & Sinatra, 2016) and therefore comprehensive frameworks for investigating these emotions are only starting to be developed. The integrative frame of the CVT, however, allows for incorporating this group of epistemic emotions and, as will be outlined below, makes specific assumptions of the instrumentality of these emotions for learning processes operating during task-specific performance.

Finally, the third study (chapter 4) situated emotions at the class-level and investigates how achievement emotions develop in the context of learning and instruction over time. In this process, reciprocal links of emotions with learning might be of particular importance and constitute emotions not only as important predictors but also as outcomes of learning, respectively. Problematically, fully-articulated models that integrate emotions as instrumental components of self-regulated learning are still lacking, despite the critical importance of describing how these mechanisms enhance each other and develop over time (Boekaerts & Pekrun, 2015; B. J. Zimmerman, 2000). The basic proposition of self-enhancing feedback loops, as part of the CVT, allows to systematically describe how emotions influence learners' abilities to regulate their own achievement striving and learning progress.

Prior to situating the present set of studies in the achievement context of mathematics and formulating specific aims and research questions respectively, the following sections outline basic propositions of the CVTs' situational specificity assumption. First, the importance of conceptualizing emotions as discrete constructs will be discussed relative to their specific functions for learning. Second, theoretical and methodological considerations are summarized with respect to investigating emotions context-specifically in order to arrive at the overarching framework (summarized in Table 1.2) of the present dissertation.

1.1 Situational Specificity of Emotions in Academic Settings: Components, Consequences and Contexts

1.1.1 Component Structure of Discrete Emotions

Academic emotions specifically describe students' emotions tied directly to academic learning, achievement activities and outcomes therein (e.g., in mathematics) (Pekrun & Stephens, 2012). Academic achievements typically entail evaluations of performance based on some competence-based standard of excellence (Pekrun & Perry, 2014). Therefore, CVT describes academic emotions as the outcome of consciously or subconsciously activated personal *evaluative* cognitions or appraisals during learning, that emerge relative to the self (and/ or others; i.e., based on control and value appraisals) and the specific learning situations (Pekrun, 2006; Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011; Pekrun & Perry, 2014).

Therefore, one of the most important 'situativity' principles is the notion that emotions are generated by person-environment relations that are specific to time and circumstance. Based on such situation-specific appraisal mechanisms, component system theories (Scherer, 1982, 2005; Shuman & Scherer, 2014) define emotions as multi-component entities comprising and coordinating psychological subsystems. Beyond the cognitive component (i.e., made up from appraisal mechanisms), additionally affective, motivational, expressive, and peripheral physiological processes contribute to an emotional episode (Kleinginna & Kleinginna, 1981; Pekrun, 2006; Pekrun et al., 2011; Scherer, 2009). These interrelated components can be exemplified by the emotional experience of anger, which is typically coupled with fury (e.g., change in the subjective experience), outrage (e.g., cognitive processing and evaluation), impulses to approach the cause of the emotion (e.g., motivational action tendencies), an increase in heart rate and blood pressure (e.g., characteristic body changes) and can be accompanied by certain facial and vocal expression (e.g., to communicate a reaction as well as the behavioral intention). In line with this example, it is important to note that these components do not function independently but instead are closely interrelated and synchronized (Pekrun, 2016). Hence, all components regulate each other and together describe the quality of an emotional experience or episode (Scherer, 2004, 2009). These cognitive-motivational-behavioral facets of emotions are critical for discerning emotional functions. Accordingly, the respective impulses of emotion-components will be more closely examined in the three herein presented empirical studies, as they are further posited to influence more complex achievement-related cognitions, motivations and behaviors (e.g., information processing, motivation and volition, self-regulation), and ultimately effect achievement outcomes. In sum, component definitions of discrete emotions acknowledge a 'fluid principle of reciprocal determinism' (Bandura, 1978, 1983) that describe cognitive, motivational and behavioral processes not only as an integral part of an emotional episode, but that these components in turn constitute the effects of emotions respectively (see study 1, chapter 2).

1.1.2 Consequences of Academic Emotions for Learning

The basic functions of emotions have broadly been summarized by an emotions' capacity to motivate actions, to organize perception and cognitions, and to activate behaviors for coping, in order to preserve and restore psychological as well as physiological well-being (for such a functionalist perspective see Izard & Ackerman, 2000). A useful model, explicating the instrumental properties of emotions for student's learning and performance, is the cognitive-motivational explanation of the mechanisms initiated by emotions, as part of the CVT framework (Pekrun, 2006; Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011; Pekrun & Perry, 2014). Several mediating mechanisms are posited to be responsible for emotion-effects, including students' cognitive resources, motivation, strategy use, and regulation of learning (Pekrun, 2006). These mediational mechanisms constitute that student learning is a complex interaction between learning related emotions and motivational, cognitive and behavioral factors that, taken together, determine learning progress and achievement outcomes (Linnenbrink & Pintrich, 2000). By grouping discrete emotions, with respect to their underlying dimensions[1], the effects on learning can be determined. According to the CVT, the minimally required categorization should occur based on levels of valence and arousal (see Figure 1.1) in order to determine effects of emotions for learning. The model assumes that emotions effect learning and achievement through several mediating mechanisms: (1) by facilitating different modes of information processing, (2) by steering cognitive resources, (3) interest and the motivation to achieve as well as (4) self-regulation as influenced by learning strategies and learning related behaviors.

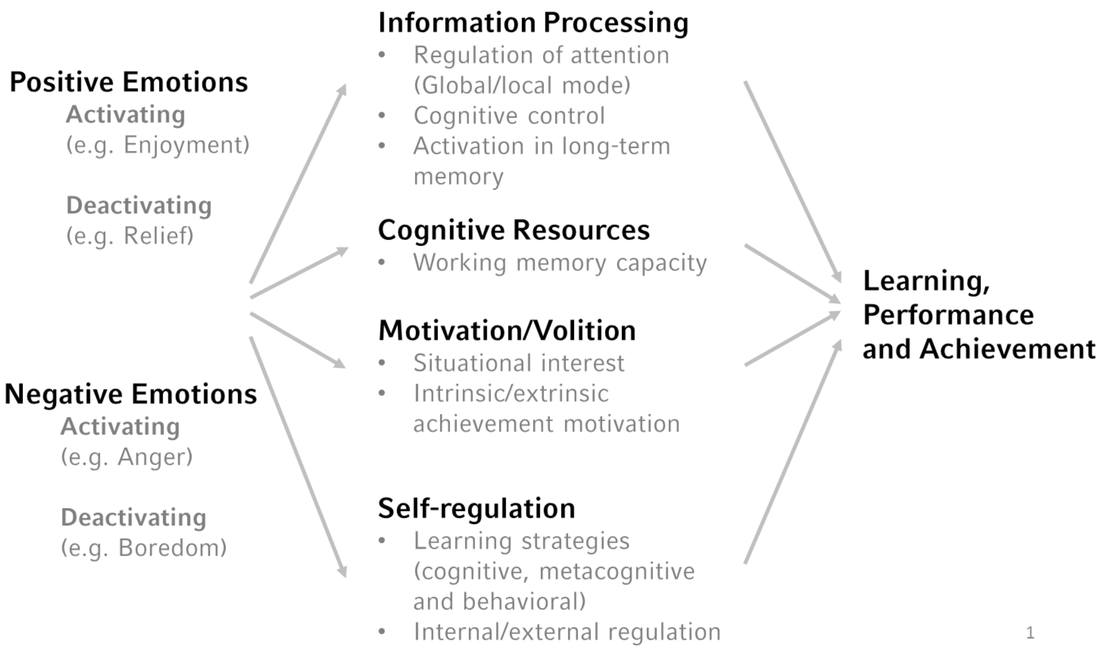

Figure 1.1: Adapted model for the effects of emotions on cognitive, motivational and behavioral mechanisms during learning (Pekrun, 2006; Pekrun & Perry, 2014).

Empirical findings concerning information processing have found that positive-activating states (e.g., when feeling excited) promote a global focus of attention (Fredrickson & Branigan, 2005; Gasper & Clore, 2002; K. J. Johnson, Waugh, & Fredrickson, 2010a) and stimulate the right temporal cortex helping to access more remotely associated items in memory (Bolte et al., 2003; Goschke & Bolte, 2014). Negative-activating states (e.g., when

[1] As a framework for defining emotions, the CVT is grounded in the notion that every academic emotion can be classified according to their valence, their activating nature, their object focus (see Pekrun and Stephens (2012) for a differentiation of specific groups of academic emotions, namely incidental emotions, achievement emotions, epistemic emotions, social emotions, and topic emotions), their duration and intensity (described as states or traits), the reference as focused relative to oneself or another agent, as well as their situational specificity. These dimensions together describe a categorizing taxonomy of academic emotions that is instrumental for explaining the functions of emotions in the process of learning and subsequent achievement.

feeling anxious), on the other hand, tune bottom-up cognitive control (Bishop, Duncan, Brett, & Lawrence, 2004; van Steenbergen, Band, & Hommel, 2010), activate only immediately relevant information in memory and thus provide stable maintenance of action (Goschke & Bolte, 2014). To more closely investigate if these mechanism translate into performance effects, study 1 was designed to examine how emotions differentially impact the quality of cognitive performance (Fiedler & Beier, 2014).

Further, emotions have been found to influence cognitive resources and the motivation to achieve. Specifically, emotions arising from a cognitive task (i.e., when the object focus is directed on learning) –which will be the critical focus of study 2 (chapter 3)– have been found to direct attention towards the tasks, whereas emotions experienced unrelated to a cognitive task (i.e., when the object focus is directed at an external event) reduce cognitive resources for learning as consumed by the external trigger of the emotion (Pekrun & Perry, 2014). These emotions have been found to elicit, sustain, or reduce academic motivation and related volitional processes. Positive activating emotions such as enjoyment of learning were consistently found to enhance academic motivation, whereas deactivating emotions (e.g., hopelessness or boredom) lead to uniformly lower total motivation to learn (Pekrun et al., 2010, 2002a; Titz, 2001; Tze et al., 2016). Interestingly, effects of negative activating emotions seem to be more ambivalent. Shame, for example, may exert a strong motivational force in order to avoid failure (J. E. Turner & Schallert, 2001). Similarly, other negative activating emotions, such as anxiety or anger, may induce strong extrinsically motivated processes in order to cope with a negative event (e.g., failure feedback) (Bandura & Cervone, 1983; Pekrun et al., 2002a). Differential effects have also been reported for positive deactivating emotions (e.g., relief or relaxation). While they may disband any immediate motivation to continue academic work, they may have long-term motivational benefits for engagement (Pekrun, 2011).

Last, the empirical link between students' emotions and self-regulated learning will be addressed in study 3 (chapter 4). The few findings available to date indicate that enjoyment relates positively to elaboration and self-regulated learning (Chatzistamatiou, Dermitzaki, Efklides, & Leondari, 2015a; Ranellucci et al., 2015), whereas anxiety negatively predicts meta-cognitive regulatory strategies (Ahmed, van der Werf, Kuyper, & Minnaert, 2013; Mega, Ronconi, & De Beni, 2014; Villavicencio & Bernardo, 2013). By contrast, deactivating emotions such as boredom, were found to undermine any strategic efforts like time management, elaboration and self-regulated learning (Pekrun et al., 2010, 2002a; Ranellucci et al., 2015).

Notably, the overall effects of emotions on achievement are inevitably complex, and more research is clearly needed to systematically disentangle the impact of different emotional categories on cognitive, motivational and behavioral processes during learning. One critical component that might help extricate these mechanisms more specifically is the situated context in which learning occurs (J. C. Turner & Trucano, 2014).

1.1.3 Contextual Specificity: Domain Specific and Domain General Conceptions of Academic Emotions

A proposition at the core of the CVT is that emotional experiences during learning are considered to be context sensitive (Goetz, Frenzel, Pekrun, & Hall, 2006; Op't Eynde & Turner, 2006; J. C. Turner & Trucano, 2014). Accordingly, CVT suggests to differentiate levels of granularity of a context along a hierarchical organization of an emotional experience (Goetz, Hall, Frenzel, & Pekrun, 2006; Pekrun et al., 2011). This means that all academic emotions can be "differentiated according to the generality of the situation they refer to" (Goetz, Hall, et al., 2006, p. 325) (see Table 1.1, Figure 1.1). The highest level of the hierarchy is the most general level (see Table 1.1.; L4), for example, describing the situational or dispositional emotional experience while thinking about school or academia in general (e.g., the level of the educational institution). Next, emotional experiences may further be distinguished with respect to more specific situations within an educational setting, such as specific academic domains (e.g., such as mathematics classes or seminars (see study 3, chapter 4)). One level further down, more specific areas within a given subdomain (e.g., in mathematics: geometry, algebra, or statistics) may be prone to different emotional experiences. At this level, it is not just important to consider the given subdomain but also the specific setting which it refers to (e.g., during specific tasks, homework, tests, or classroom activities; see study 2, chapter 3) (Pekrun et al., 2011). The lowest and most specific level refers to a particular momentary emotional experience in the individual mind relative to a specific situation within an academic context (see study 1, chapter 2) (Goetz, Frenzel, et al., 2006; Goetz, Hall, et al., 2006; Nett, Goetz, & Hall, 2011; Pekrun et al., 2011).

This classification[2] highlights that specific learning situations are always grounded in a broader social context in which knowledge and beliefs are formed and shared (Cobb & Bowers, 1999; Op’t Eynde & Turner, 2006). For example, students’ emotions related to a specific situation during mathematical learning (e.g., a specific complex task) are not only influenced by the immediate class context (e.g., the mathematics classroom), but also by all previous mathematics classes and activities, home cultures (e.g., beliefs about mathematics held by parents), and the ideas about mathematics and learning generally held in the broader socio-cultural society (i.e., school system, ministry of education) (Goetz, Hall, et al., 2006; Goetz, Zirngibl, Pekrun, & Hall, 2003; Op’t Eynde & Turner, 2006).

Studies directly examining the situational specificity assumption have not only demonstrated that the experience of academic emotions is clearly organized in domain specific ways (e.g., as indicated by weak correlations of mean level emotional experiences across mathematics, and languages such as Latin, English and German) (Goetz et al., 2014; Goetz, Frenzel, et al., 2006), but even more importantly, suggest that hierarchical gradations within an academic domain must also be differentiated. More specifically, empirical findings indicate that predominantly top-down mechanisms determine emotional reactions to specific situations within an academic domain (Dinkelmann & Buff, 2016; Goetz, Hall, et al., 2006; Marsh & Yeung, 1998). In other words, more general emotional schemas formed at higher levels within the hierarchy predispose students to respond to specific learning situations with specific emotional patterns (Goetz, Hall, et al., 2006; Pekrun & Schutz, 2007). Additionally, it has also been suggested that the causal flow might also involve generalization (bottom-up processes) through which the perceived sum of emotional experiences at lower levels influences more general emotional reactions (Goetz, Hall, et al., 2006). Here, empirical findings are however scarce. Taking a different approach, Hattie (2004) discussed relationships of such hierarchies, in light of the academic self-concept, and suggested that it

[2] Critically, the hierarchical levels aiming to describe the amplitude of emotional experiences must not be equated with the state-trait conception of emotions (Pekrun & Bühner, 2014; Spielberger, 1972). State emotions are momentarily or ‘real-time’ occurrences and describe transient emotional experiences (brief period of time) (Eid, Schneider, & Schwenkmezger, 1999). Consequently, state emotions are by definition moment-specific and have been described to be more strongly influenced by contextual variables (Eid et al., 1999). Trait conceptions of emotions, on the other hand, may either describe individuals’ tendencies to frequently experience specific moods or emotions across contexts (e.g. general tendency to be anxious) (L. A. Clark, Watson, & Mineka, 1994; Titz, 2001), or refer to habituated emotional experiences within specific contexts (e.g. test anxiety; being anxious of mathematics classes) (Goetz, Hall, Frenzel, & Pekrun, 2006). As a consequence, either trait conception of emotional experiences will, over time, describe relatively stable dispositional tendencies that reinforce themselves with respect to the frequency and the intensity of the experience of the corresponding state emotions (Bieg, 2013). As a consequence, it is crucial to carefully differentiate trait conceptions of emotions relative to the specific academic context they refer to.

might not be either bottom-up nor top down-effects, but instead emphasized the processes operating at each level of learning might be responsible for intertwining the hierarchical levels respectively. This is certainly a suggestion worthwhile considering for investigating functional properties of emotions for learning, especially in light of the interaction with cognitive, motivational and behavioral processes that together determine learning progress and achievement (for a more detailed discussion see chapter 5).

In sum, distinctions between domain general and domain specific conceptions of learning situations are characterized by different functions and socio-cultural structures, implying that emotions arising within or relating to these contexts may differ and most importantly, must be distinguished accordingly in empirical research (Pekrun et al., 2002a).

Table 1.1: Multi-level model of the experience of enjoyment in the academic context.

Level	Contextual specificity	Level of Learning	Emotional Experience
L4	Context specific (e.g. educational institution)	School/University	Enjoyment of school (“in general, in school”)
L3	Domain specific (e.g. educational setting)	Academic subdomain (mathematics)	Enjoyment of mathematics (“in general, in the classroom”)
L2	Situation specific (e.g. individual student)	Task, problem (in the context of homework, exams, or instruction)	Enjoyment of the task (“relative to the task”)
L1	Moment specific (e.g. individual mind)	Decision making, thinking	Enjoyment in the moment

Note. Adapted from multi-levels models describing a hierarchy of academic emotions (Goetz, Hall, et al., 2006; Goetz et al., 2003; Pekrun & Schutz, 2007). L1 represents the lowest and L4 represents the highest level of generalization of enjoyment experienced in the academic context.

1.2 Situational Specificity of Emotions in Empirical Research: Theoretical and Methodological Considerations

In order to measure students’ subjective experience of an emotional episode, researchers most often rely on self-reports (Pekrun & Linnenbrink-Garcia, 2014). It has been argued that self-reports are appropriate tools, as "it is not reality that determines one's thoughts and behavior but one's perception of that reality" (Goetz et al., 2003, p. 22). Additionally, observers might misinterpret facial expressions, body language and posture as well as physiological data (Skinner, Kindermann, & Furrer, 2008). Indeed, to date, subjective self-reports are still the only available method to assess the content of the subjective experience (i.e., 'the feeling') component of an emotion (Quigley, Lindquist, & Barrett, 2014). An additional advantage is that self-reports are not limited to measuring emotions but can provide insight into other factors determining learning such as cognitive, motivational and behavioral variables (Pekrun & Bühner, 2014). Problematically, more often than not, emotions are investigated through the use of general self-reports only (e.g., indicating trait emotions) and fail to situate the self-reported ratings in specific contexts (Efklides & Volet, 2005; J. C. Turner & Trucano, 2014). For advancing understanding of the functions of emotions at different specificity levels of learning, it is important to additionally investigate momentary or activity specific emotional episodes within specific learning contexts (Goetz, Hall, et al., 2006; e.g. Tulis & Fulmer, 2013).

1.2.1 Self-reporting Situation Specific versus General Emotional Experiences

To better qualify the emotional experiences reported in respect to different levels of generality and specificity during learning, the 'accessibility model of emotional self-report' (Robinson & Clore, 2002) suggests that different memory systems operate when students report emotions from different hierarchical levels. Broadly speaking, the model assumes that emotions reported at more general levels require absolute frequency estimations derived from averaging particular emotional episodes over a specified time frame (Robinson & Clore, 2002). Since this is a difficult cognitive estimation to make, the authors describe that students may abandon such efforts and instead derive the required *emotional* information from semantic memory. This, however, entails that memory-related biases (e.g., beliefs about the mathematics classroom) and more general heuristics (e.g. of mathematics competence or prior performance) will shape the reported emotion response, rather than episodic details from specific learning situations (Robinson & Clore, 2002; N. Schwarz, 1994, 1999; Tversky & Kahneman, 1973). The closer assessments target emotion ratings in specific situations (the most specific is the experience in the moment or "online"), the more experiential knowledge will overwhelm prior beliefs (Robinson & Clore, 2002).

Aligning this model with the hierarchical levels of emotional specificity and generality (see Table 1.2), it suggests that students might refer to different knowledge sources when reporting their emotions concerning different levels (e.g., thus accentuating qualitative differences of emotion ratings as reported relative to experiences during a mathematics tasks versus mathematics classes in general). Relative to moment specific emotional experiences, as investigated in study 1 (see Table 1.2; L1), the model proposes that students should be able to directly access experiential information qualifying the subjective experience in a given moment. Importantly, experiential knowledge is more differentiated when assessed ‘online’ and harder to access retrospectively (Robinson & Clore, 2002). Problematically, it has been suggested that reporting about experiences of concurrent emotions may predominantly change how someone is feeling (Quigley et al., 2014; J. C. Turner & Trucano, 2014). In essence, the act of reporting an emotion will make the subjective feeling component salient and thismight unintentionally interfere with or interrupt accompanying components (e.g., appraisal processes) (J. C. Turner & Trucano, 2014). As the consequence of directing attention to the emotional components to the learner, may not only dissolve an emotional episode but also the respective emotion-effects (personal communication with Prof. Dr. Christof Kuhbandner on June 1st, 2015; Quigley et al., 2014), study 1 refrained from having students report these moment-specific experiences.

This issue, however, stresses advantages of retrospective reports as employed in study 2 and 3, while additionally allowing for an estimate of the overall emotional experience during a certain task or during class in general (J. C. Turner & Trucano, 2014). Here, however, it is important to consider that memory for contextual details (as contained in episodic memories) fades quickly and, with elapsing time, becomes inaccessible (Robinson & Clore, 2002). Yet, it has been shown that students are able to report which specific emotion was experienced relatively more intensely than others, for example in respect to reporting if one was more frustrated than bored during a task. This was the most essential methodological consideration for conducting study 2 (chapter 3) (Schimmack, 2003). In fact, intense emotional experiences are more salient in memory and can be reported (Scollon, Prieto, & Diener, 2003) (see Table 1.2; L2). The broader and more “time-inclusive” the emotion assessment (e.g., “in general”, see Table 1.2; L3), the more will students tend to adapt estimations and consequently deviate to report on knowledge derived from semantic memory (containing beliefs). Generally, it is important to note that any-self report measure (as assessed online or being more general) is subject to a number of measurement problems such as social desirability, cognitive biases and cultural norms (Pekrun & Bühner, 2014; N. Schwarz, 1999; Scollon et al., 2003).

1.2.2 Functionally different Emotions: States and Traits.

Over the years, typically weak to moderate relations between trait and state measures have been observed (Bieg, Goetz, & Lipnevich, 2014; Roos et al., 2015; Schwartz, Neale, Marco, Shiffman, & Stone, 1999). The accessibility model provides one approach for explaining the discrepancy in associations between state and trait assessments of emotions (Bieg et al., 2014; Roos et al., 2015; Wilson & Gilbert, 2005). While it has been questioned whether trait emotions reflect *actual* emotions (i.e., due to the strong influence of and overlap with beliefs in the emotion ratings) (Roos et al., 2015), it might be more expedient to contrast the respective functional relevance of state and trait emotions and thereby reveal differential functions and research objectives for each conception of emotion (Scollon et al., 2003). For example, individual emotional experiences 'in situ'provide a more fine-grained, detailed picture of emotional experiences and can better account for dynamic mechanisms (i.e., the automatic pull of changes in other components of an emotional experience) of emotions in a specific situation (Nett et al., 2011; Scollon et al., 2003). Hence, study 1 investigates state emotions assessed in a specific context in order to better account for situational factors of learning mechanisms and adaptive behaviors (D'Mello et al., 2014; Goetz, Sticca, Pekrun, Murayama, & Elliot, 2016; Muis, Psaradellis, Lajoie, Di Leo, & Chevrier, 2015). More general self-report assessments of emotions can cover longer time frames, making them better trait indicators, as opposed to aggregates of moment-specific emotions reports (such as experience sampling; see Bieg, Goetz & Lipnevich, 2014; Zelenski & Larsen, 2000). Accordingly, this between-person level allows to examine the long-term structure of emotional experiences (e.g. Diener, Emmons, Larsen, & Griffin, 1985), as employed in study 3 (chapter 4). In that respect, empirical studies found that trait measures of emotions have predictive value in determining general future behavior (Hsee & Hastie, 2006; Levine, Lench, & Safer, 2009; Wirtz, Kruger, Scollon, & Diener, 2003). Therefore, trait emotions might be critical for investigating students general learning behaviors and outcomes, for example self-regulatory abilities or determining future choices, such as taking a mathematics course or pursuing a career requiring mathematical knowledge (Brown, Brown, & Bibby, 2008; Chipman, Krantz, & Silver, 1992; e.g. Kyttälä & Björn, 2010). On a concluding note, relative to the state-trait controversy, it has been suggested that state and trait measures are each predictive of different behaviors and learning outcomes in their own right (Schwartz et al., 1999).

In sum, the different 'grain sizes' of the methodological approaches employed in this dissertation allow for investigating emotions determined by different time frames and levels of specificity. Therefore, all studies and research questions presented herein refer to these different levels in order to "contribute in a mutually consilient way" to better and more thoroughly understanding the function of emotions during learning (Goldin, 2014, p. 396).

1.2.3 Aligning the Construct of Emotions with Cognitive, Motivational and Behavioral Variables.

With respect to investigating the effects of emotions assessed at different hierarchical levels of learning, it is important to note that motivational, cognitive and behavioral processes play an important role during learning at each level of situativity. Closely investigating these processes helps to better describe, for example, how emotions modulate perception and information processing or regulate action and learning behaviors (Hirt, Melton, McDonald, & Harackiewicz, 1996). Consequently, when analyzing relations with, or effects of emotions on, cognitive, motivational or behavioral variables, it is important to equate the level of generalization for each construct assessed (Bandura, 1986, 1997; Goetz, Hall, et al., 2006). Bandura (1986; 1997) described this "matching principle" by explaining that the predictive power of a measure depends on the match between the specificity of a predictor and that of a criterion variable. This suggests that variables measured at a more general level (e.g., general mathematics anxiety) will be most strongly related to general outcomes (e.g., general mathematics achievement). Conversely, more specific predictor variables (e.g., being anxious towards a specific task) will have more explicatory power in accounting for the variance related to a corresponding outcome (e.g., performance on the respective task) (see Bong, 2001 for motivation; Goetz, Hall, et al., 2006; see Marsh & Yeung, 1996 for self-concept). Critically, this alignment of constructs should not only be relevant for the relation between emotions and performance (or achievement) measures, but should also be important for investigating cognitive, motivational and behavioral mechanisms that are critical in discerning the processes that operate during learning (Goetz et al., 2003; Pekrun, 2006) (see Table 1.2).

In that respect, it might be reasonable to speculate that reporting on cognitive, motivational and behavioral processes that operate during learning may be prone to the same "accessibility principles" as emotional self-reports (Robinson & Clore, 2002). That is, taken the example of the cognitive processes that accompany an emotional experience in a given moment, componential theorists' of emotions argue, that these must not always be conscious, but instead are rather automatically elicited and prone to change and dissolve immediately with altered appraisal constellation (Shuman & Scherer, 2014). Here, empirical findings have shown that momentarily experienced emotions might influence the breaths of visual attention, the ability to process peripheral information, as well as the inhibition or spread of associations in semantic memory (K. J. Johnson et al., 2010a; Rowe, Hirsh, & Anderson, 2007; Wegbreit et al., 2015). Therefore, study 1 investigates these processes which may be elicited by emotional experiences, even outside of our conscious control, and takes into account that these subjective experiences are especially moment-sensitive (see Table 1.2; L1). However, the cognitive processes operating while a learner solves a complex mathematical task, may rely more on and may be more prone to the learners' control. For example, a learner noticing ones' thoughts drifting off and steering attention back to the task, does not only exemplify that at this 'level' cognition and motivation are ought to closely interact, as will be more closely examined in study 2, but also that these cognitive-motivational actions may be accessible as 'contextual details' relative to the task in episodic memory and thus, can be reported immediately after a task (see Table 1.2; L2). The last 'level', which will be addressed in this dissertation in study 3, is classroom-specific and concerns learning activities and instructions in mathematics classes (see Table 1.2; L3). This 'level' assumes that certain learning behaviors do become habituated over time and therefore lends itself to understand how emotional experiences, felt over and over again, link with cognitive and behavioral learning that perpetuate in semantic memory.

Table 1.2: Multi-level model of the Experience of Enjoyment in Conjunction with Cognitive, Motivational and Behavioral Mechanisms that together modulate Learning in the Academic Context.

					Mechanisms during learning			Methodological considerations	
Level	**Contextual specificity**	**Level of learning**	**Emotion (e.g. enjoyment)**	**Type of memory**	**Motivational**	**Cognitive**	**Behavioral**	**Time frame**	**Type of self-report**
L4	Context specific (e.g., educational institution)	School/University	Enjoyment of school ("in general, in school")	Semantic memory (normative and idiosyncratic beliefs)	goals	General learning strategies	Attending school/university	Years, decades and centuries	State/Trait, Time-inclusive/ retrospective ("in general, in the [context]")
					Self-regulation				
L3	Domain specific (e.g., educational setting)	Academic subdomain (mathematics)	Enjoyment of mathematics ("in general, in the classroom")	Semantic memory (prone to domain specific belief)	Goals	General mathematics learning strategies	Participating in class (attending class, raising hand, asking questions)	Hours to years	State/Trait, Time-inclusive/ retrospective ("in general, in the [domain]")
					Cognitive Resources, Motivation & Volition				
L2	Situation specific (e.g., individual student)	Task, problem (in the context of homework, exams, or instruction)	Enjoyment of the task ("relative to the task")	Episodic memory	Situational interest, motivation, Effort	Task-focused attention, task specific strategies	Working on the task	Minutes to hours	State/Trait, situation-specific retrospective ("relative to the [situation]")
					Information Processing				
L1	Moment specific (e.g., emotion-components)	Reaction times, decision making, thinking	Enjoyment in the moment	Experiential information (reactive/automatic)	Approach/Avoidance tendencies	Activation in memory, global/local control	Directing gaze	Fractions of seconds to minutes	Concurrent (cannot be accessed retrospectively, may not be accessible at all)

Note. Adapted from the model from Goetz, Hall, Frenzel, Pekrun, 2006, Pekrun & Schutz, 2007 and Robinson & Clore, 2002. L1 represents the lowest and L4 represents the highest level of generalization of enjoyment experienced in the academic context.

1.3 Previous Research on Emotions in Mathematics

Investigating the functions of emotions for learning in mathematics is especially intriguing since mathematical thinking is typically conceived as being a “rational, analytical, and non-emotive area” of learning (Blanco, Guerrero, Caballero, Brígido, & Mellado, 2010, p. 266). Today, it is not only widely accepted that cognitive and emotional processes together modulate such ‘cold’ reasoning (Lazarus, 1984; Zajonc, 1984) but that, in fact, mathematical thinking is a highly emotionally-charged endeavor (Goldin, 2014; Hannula, 2012).

Generally, research investigating the influence of affective variables on mathematics learning and teaching has mainly focused on broader affective constructs such as attitudes, beliefs and values towards mathematics (DeBellis & Goldin, 2006a; Fennema & Sherman, 1976; McLeod, 1989, 1992). Additionally, mathematics anxiety is likely one of the most thoroughly researched topics in the emotion literature (Beilock & Willingham, 2014; Dowker, Sarkar, & Looi, 2016; Wigfield & Meece, 1988; Zeidner, 2014); especially with regard to the influence on performance and respective reciprocal functions (Carey, Hill, Devine, & Szücs, 2015; Hembree, 1990; Ma, 1999).

Despite this evident progress in the notion that affective variables are critical for mathematics learning, more fine-grained investigations of emotions, for example as they occur in academic settings of mathematics learning and instruction, have been slow to emerge so far. In this respect, an important turning point were two – now historic – articles (Mc Leod, 1989; Schoenefeld, 1985) describing not only the cognitive processes during mathematical problem solving but also linking affective dimensions to cognitions in mathematical activities. Since then, a host of qualitative studies have examined students’ fluctuations of emotional experiences while solving mathematical problems (Ahmed, van der Werf, & Minnaert, 2010; Gómez-Chacón, 2000; Hannula, 2002, 2012; Op’t Eynde, De Corte, & Verschaffel, 2006). DeBellis and Goldin (2006), for example described affective pathways during problem solving in an attempt to better account for arising sequences of emotions and to point out how they interact with cognitive representations during problem solving. Similarly, Op't Eynde and colleagues (Op’t Eynde et al., 2006, 2007; Op’t Eynde & Hannula, 2006) observed that students experience different emotions while solving a problem and ascribed functional properties inherent to these emotions, such as redirecting behavior or looking for alternative cognitive strategies to find a solution to the problem. These descriptions closely mirror what is now quantitatively investigated as *epistemic emotions* and *impasse driven theories* (D’Mello & Graesser, 2012; Muis, Psaradellis, et al., 2015; Pekrun et al., 2016) and highlight the urge to connect emotional experiences to the cognitive, motivational and behavioral variables during learning, as suggested in CVT.

Today, few quantitative studies have investigated students' emotions in mathematical problem solving (e.g. Muis, Psaradellis, et al., 2015; Tornare, Czajkowski, & Pons, 2015) and even less research exists distinguishing other activities related to mathematics, for example, emotions in specific activities (e.g., such as test taking, doing homework (as rare examples see Dettmers et al., 2011; Goetz et al., 2012). Possibly, the gap of empirical findings investigating the functional properties of emotions situated in the mathematics context so far, may be a failure of interdisciplinary integration of applicable psychological theories accounting for the emotional, cognitive, motivational and behavioral mechanisms during learning (e.g. Op't Eynde & Hannula, 2006). For example, integrative theories, such as the CVT which incorporates emotions as part of cognitive-motivational models for learning, would allow for systematic and theoretically grounded emotion investigations (Goldin, 2014). To accentuate this point, a literature search[3] for peer-reviewed studies on emotions in academic contexts of mathematics examining or referring to the control-value theory (from 1980 to 2016 using the PsycINFO, ERIC and PsyINDEX as a database) revealed only 22 hits (see Appendix A for Coding Scheme with all studies included). Notably, the most prominent research question investigated antecedents of academic emotions; with 18 out of the total 22 studies examining control and value appraisals. Based on this literature search (which is acknowledged to be a convenience sample only), studies concerning the effects of emotions on learning in mathematics are scare. Even more so, only a total of six studies, as part of the pulled sample, have investigated the impact of emotions on self-regulation and only two of those had investigated these learning-related mechanisms task specifically. In that respect, the present dissertation aims to extent the research on learning related mechanisms and sets out to investigate the effects of emotions on cognitive, motivational and behavioral learning related variables during achievement activities in mathematics. Importantly, it seems crucial to consider the function of emotions moment-specifically, and to additionally investigate emotion-mechanisms during learning endeavors task-specifically as well as those that are pursued over a longer period of time.

[3] The literature search was conducted with the EBSCOhost and searched the database PsychInfo, ERIC and PsychIndex for peer-reviewed articles based on a strategy combining three sets of terms covering (1) emotion*s, feel*ings, or affect* (2) math*ematics and (3) 'control'and 'value' including publications from 1980 to 2016. By using the truncation search option of an asterisk, the search terms 'emotion*', 'feel*', 'affect*' and 'math*'also included longer versions of each term (e.g., such as mathematics or mathematical).

1.4 Overview of the Present Dissertation

The aim of the present dissertation was to investigate the functional importance of emotions in the process of learning in achievement contexts in mathematics. Specifically in light of the aim of investigating functions of emotions relative to different levels of specificity, the applicability and requirement of different methodological approaches becomes apparent. Therefore, a multi-method approach was employed and empirically investigated emotions with an experimental (see study 1, in chapter 2), a quasi-experimental (see study 2, in chapter 3) and a non-experimental (see study 3, in chapter 4) study design that were either conducted as laboratory or field studies, in order to account for their respective complementary advantages. As postulated in CVT, the present dissertation investigated the modulating function of emotions on information processing, motivation, cognitive resources and students' self-regulated learning. Importantly, learning is investigated as a situated process composed of interactions of emotions with cognitive, motivational and behavioral variables within the academic domain of mathematics (Op't Eynde et al., 2006).

1.4.1 Aims and Research Questions of the Three Studies Presented

The series of studies of this dissertation aim to investigate the precise mechanisms through which learning is shaped by emotions. To reach this goal, the first study (chapter 2) examined momentarily experienced emotions by means of a rigorous experimental laboratory-based design. Here, two experimental tasks were created in an attempt to reflect the mechanisms that have empirically been shown to be modulated by emotions. Therefore, the experiment thought to address the following research questions (RQ):

RQ1: Does the employed emotion induction method elicit the intended emotional experiences?

RQ2: Do activating emotions enhance cognitive performance more than deactivating affective states?

RQ3: Do positive and negative activating emotions effect performance in differential ways?

Turning to naturally experienced emotions during an even more complex mathematical task, the second study (chapter 3) examined if emotions, that arise in interaction of dealing with a mathematical task, can be assigned a knowledge generating – an epistemic – role during complex problem solving. As epistemic emotions are assumed to not only be a natural part of, but also to be critically important for steering cognitive and motivational mechanisms during complex learning, Study 2 examined these mechanisms in jointly determining task performance. The main research questions were:

RQ4: Do students experience epistemic emotions while solving a complex mathematical task?

RQ5: Do control and value appraisals systematically influence the rise of epistemic emotions?

RQ6: How do epistemic emotions impact motivational and cognitive processes operating during task completion and do these mechanisms together determine task performance?

Study 3 (chapter 4) presents a field study that investigated achievement emotions in the course of a full school year relative to the learning and instruction in mathematics classrooms. Self-regulatory learning was conceptualized by cognitive and behavioral variables during learning and instruction in mathematics activities in the classrooms. Therefore, the study thought to inquire on achievement emotions:

RQ7: Are achievement emotions predictors as well as outcomes during self-regulated learning?

RQ8: How do achievement emotions in mathematics relate to cognitive and behavioral variables in mathematics classes?

RQ9: Do learning strategies function as mediators between achievement emotions and behavioral participation in mathematics over a school term?

This dissertation concludes (chapter 5) by summarizing the findings of the three empirical studies. Strengths and weaknesses as well as implications for research and practice are discussed. Last, the findings will be revisited in light of the postulated multi-level model (see Table 1.2) situating not only emotional experiences but their respective cognitive, motivational and behavioral functions in specific contexts of mathematics, which together determine learning.

2 Study 1 – Emotions color Cognition: Adaptive Functions of Positive and Negative Emotions for Thinking in Mathematics

2.1 Abstract[4]

This psychological experiment tested the effects of emotions on rational, logic thinking in a STEM discipline. Empirical evidence from neuroscience and cognitive psychology indicate that positive affective states broaden, whereas negative affective states narrow our cognition. This suggests that emotions can trigger qualitatively different cognitive processes, which can both be functional for thinking, if adaptive to the cognitive task. Previous research, however, investigating effects of emotions has yielded contradictory results based on severe methodological limitations in the studies of the field. With this experimental study, we demonstrate that positive-activating emotions, such as enjoyment, support the generation of ideas. Negative-activating emotions, such as anxiety, help to better identify false ideas. These findings suggest that emotions and cognition are intimately linked, illustrate how the subtle modulation of cognition, instigated by emotions, changes our thinking and importantly highlights the adaptive functions of both, positive as well as negative emotions for complex thought.

2.2 Introduction

It is well documented that we do not process or encode incoming information 'objectively' (Dai & Sternberg, 2004; Lewis, Haviland-Jones, & Barrett, 2008). Rather, our perception, cognition, and memory are colored with emotional overtones (Bolte & Goschke, 2010; Fiedler & Beier, 2014; Fredrickson, 2013; Kuhbandner, Lichtenfeld, & Pekrun, 2011). Indeed, empirical evidence from neuroscience and cognitive psychology indicates that emotions may influence all 'stages' of information processing, by influencing attentional mechanisms (e.g., focus of attention), working memory processes (e.g., mode of cognitive control) as well as long-term memory (e.g., storage and retrieval). Specifically, positive affective states have been found to broaden the attentional focus, whereas negative affective states narrow our attention, thereby revealing rather distinct cognitive functions of different emotions (Bolte & Goschke, 2010; Fiedler & Beier, 2014; Fredrickson, 2013; Gasper &

[4] This study was conducted in collaboration with Prof. Reinhard Pekrun and Prof.Stefan Ufer. Together, it was decided to write up this study as a ~2500 word manuscript.

Clore, 2002; K. J. Johnson et al., 2010a; Topolinski & Deutsch, 2013). For example, it has further been found that enjoyment “loosens” cognitive control (Fiedler, 1988; Goschke & Bolte, 2014), while anxiety not only leads to “zoom in” on a problem, but also provides “stable maintenance” in light of a critical situation demanding immediate action (Fiedler & Beier, 2014; Goschke & Bolte, 2014; Wegbreit et al., 2015) (see Figure 2.1).

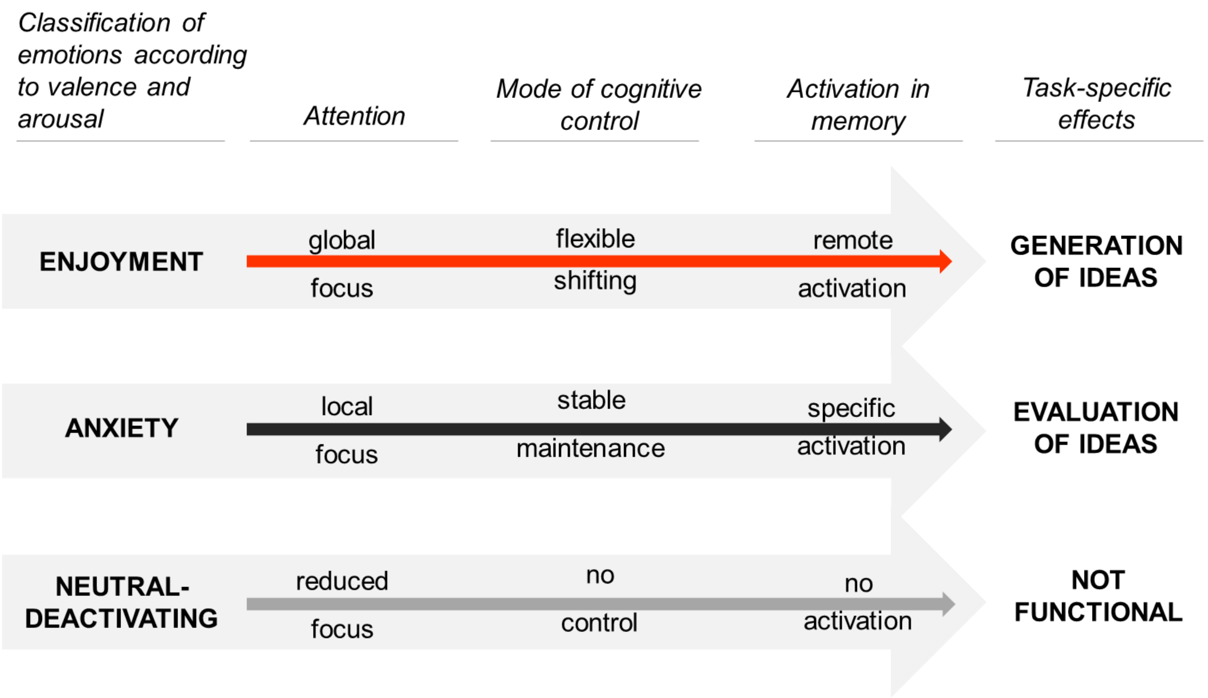

Figure 2.1: Model showing effects of emotions on different stages of basal information processing which might overall be adaptive to different kinds of cognitive tasks (e.g., the generation or the evaluation of scientific ideas).

While the fact that emotions are tightly integrated with cognition is rather well established, the notion that emotions should also be an integral aspect of scientific thinking is new and provocative (Fischer et al., 2014; Jaber & Hammer, 2016; Sinatra, Broughton, & Lombardi, 2014). Indeed, previous research so far was not successful in systematically demonstrating the effects emotions have on thinking, let alone of scientific nature, and, to complicate matters even further, has yielded utterly contradictory results (Jeffrey R Huntsinger, Isbell, & Clore, 2014; Jefferies, Smilek, Eich, & Enns, 2008; Jung, Wranke, Hamburger, & Knauff, 2014). One major point of critique has been the neglect of carefully controlling the type of valence (positive vs. negative) and arousal (low activation vs. high activation) of emotions (Baas, De Dreu, & Nijstad, 2008) as well as the emotionality of tone in the problem content (Hirt, Devers, & McCrea, 2008; Kuhbandner et al., 2009). In addition, we argue that many of the cognitive tasks employed to examine emotion-effects, may not adequately capture the cognitive processes that they claim to represent[5], which might contribute to contradictory findings (Lin, Tsai, Lin, & Chen, 2014). Accordingly, we designed two experimental tasks, aiming to correspond to these differential cognitive functions, in order to show that positive and negative emotions can each complement thinking, if the respective cognitive processes are adaptive to the cognitive task.

Based on theories describing the nature of two different processes required for scientific thinking (Fischer et al., 2014; Klahr & Dunbar, 1988; Klahr, Zimmerman, & Jirout, 2011; Popper, 2002), our two experimental tasks aim to reflect the following two components: (i) the generation of ideas based on available theoretical frames or empirical evidence, which (ii) must then be subjected to critical tests or evaluation by validating or refuting these ideas. This dichotomy between generation and evaluation also mirrors the psychological underpinnings of creative reasoning (Ellamil, Dobson, Beeman, & Christoff, 2012; Finke, Ward, & Smith, 1992; Guilford, 1967) and the functions of different brain networks (Beaty et al., 2016; Ellamil et al., 2012). In sum, we are suggesting that these two components inherent in complex scientific problems (such as formulating a mathematical proof) might benefit from emotional influences in differential ways: positive affect may enhance heuristic processing, whereas negative affect facilitates more detailed, systematic processing (Fiedler & Beier, 2014; Hirt et al., 1996).

[5] For example, so-labeled 'divergent thinking' tests are ought to test the amount of divergent material they bring to mind (thus calling for cognitive processes that support a spread of associations in semantic memory). However, one of the most frequently used tests of this sort, namely the Remote Association Test (Mednick, Mednick, & Mednick, 1964), additionally requires the participants to *constrain* thinking to successfully identify the common core of the three presented words (the test demands to identify the (semantic) relations between three words, which at first seem not to share a common denominator, but will be related on some (more or less) abstract level). Another frequently employed 'divergent thinking' test is ought to test the production of ideas that are both novel and of value (Unusual Uses Task; Guilford, 1967) but this test has exclusively been used to test ideas that might help navigate through daily life (i.e., the test asks to generate different uses of a daily object, such as a tin can) and thus does not reflect the processes nor the knowledge that it takes to advance technology or scientific understanding. In turn, tests intended to measure 'convergent thinking' are often called 'insight problems', such as Dunkers' Candle Problem (Duncker & Lees, 1945) or Maier's Two String Problem (Maier, 1931), and do not only require analytical thinking but also a certain amount of creativity and flexibility. While it is true that these problems lead to a clear and well-defined solution, which must be identified, the designated 'insight' does not arrive upon algorithmic testing of the problem space only but also, almost by definition, necessitates conceptual or representational change, for example by relaxing self-imposed constraints (Haager, Kuhbandner, & Pekrun, 2014; Sternberg & Davidson, 1995). In sum, the cognitive processes operating in these tests are inevitably complex and must be carefully controlled.

2.3 Hypotheses

By considering the above stated effects of emotions on cognitive processes (Pekrun & Linnenbrink-Garcia, 2014), we derived the prediction that persons experiencing positive-activating emotions (e.g., enjoyment), profit from more cognitive flexibility and activation of widespread associations in memory, and should therefore better *generate ideas* — as this requires divergent thinking and the ability to retrieve remotely associated ideas. Persons experiencing negative-activating emotions (e.g., anxiety), however, might have a more restricted focus and rely more heavily on specific information in memory, and should therefore better *evaluate ideas* — as this requires a careful examination of presented information in a sequential-analytical manner (Fiedler & Beier, 2014). People in neutral-deactivating affective states[6] will not benefit from cognitive processes that might support either task format (see Figure 2.1).

Apart from the cognitive processes, also motivational processes have been suggested as serving a mediational function which can explain how emotions might affect task performance (Pekrun, 2006; Pekrun et al., 2002a; Pekrun & Linnenbrink-Garcia, 2014). In essence, it was proposed that emotions serve a functional value by informing whether a situation warrants action (N. Schwarz, 1990). In this view, positive emotions might be misattributed that ‘all is well’ thus refraining from investing effort in the task (Pekrun & Stephens, 2012). Conversely, positive emotions might also be interpreted in assigning greater value to a task, thus perceiving the task as fun and enjoyable, which in turn leads to greater concentration, effort, or motivation (Murray, Sujan, Hirt, & Sujan, 1990; Pretty & Seligman, 1984; Sansone, Sachau, & Weir, 1989). In the same view, negative emotions might indicate a problem and thus induce motivation to examine the situation carefully and search for solution, thus instigating greater effort, concentration and motivation. These mechanisms, in turn, have been found to influence performance (Bless & Schwarz, 1999; M. S. Clark & Isen, 1982; Isen, 1987; Pekrun & Linnenbrink-Garcia, 2014). To rule out that such motivational mechanisms were responsible for the effects of emotions in our experiment, intrinsic and extrinsic motivation, as well as effort and concentration were accounted for and controlled in

[6] This assumption is also often labeled the ‘activation hypothesis’. It argues that merely the level of emotional activation influences the engagement with cognitive tasks and suggests that, in particular, complex thinking processes are enhanced by moderately high levels of arousal (Feldman Barrett & Russell, 1998; Pekrun & Linnenbrink-Garcia, 2012, 2014). Based on the activation hypothesis, it was postulated that the two experimental emotions groups combined, should outperform the control group on either task format.

all analyses (see Appendix B.1. for Measures of Motivational Variables and Prior Knowledge).

2.4 Method

We tested our hypotheses in a 3 (emotions) x 2 (task types) computer-based experimental study. Mathematic university students (n = 246) were randomly assigned to one of three emotion conditions (enjoyment vs. anxious vs. deactivating control condition) and solved either a generation (n = 124) or an evaluation task (n = 122)[7]. The six experimental groups did not differ in terms of students' gender or task-relevant knowledge (see Table 2.1). To address the main research question using analyses of variances, a minimum of 120 participants for each task was determined a priori with power analysis (G*$_{power}$; (Faul, Erdfelder, Lang, & Buchner, 2007) based on α = .05, power (1-β) = .8 and a large effect size (Hedges' g = .50) for the emotion elicitation method (Lench, Flores, & Bench, 2011). In the beginning of the experiment an informed consent form (see Appendix B.2.) was signed by each participant.

The experimental sessions were conducted by trained investigators who were oblivious of specific hypotheses throughout the data collection process[8]. An established emotion induction procedure (Eich, Ng, Macaulay, Percy, & Grebneva, 2007) was successful in

[7] The overall sample consisted of 246 university students from the mathematics department at a university in the south of Germany. Students were around 22 years of age (M_{age} = 21.9 years, SD_{age} = 3.1 years) and attended on average their 5th semester (M = 5.16 semester, SD = 6.3). 49.7% of those students were enrolled in a bachelor or master program with a special focus on mathematics, physics or computer science, 39.1% were teacher students for mathematics and 11.4% reported "other" special foci within their mathematics study program. All participations reported proficient levels of the German language (32 students reported that German was not their mother tongue but foreign students had to verify their language skills with a C2-certificate as a requirement for matriculation) and did not report psychiatric problems on the consent form (see Appendix B.2. for consent form). Both, the students as well as the investigators were blind to the experimental hypotheses and conditions. The investigators were aware that emotions played a role in the experiment, but they remained oblivious of specific hypotheses throughout the data collection process. Chi-square tests for independence showed that women were evenly represented across all six cells, in emotion groups $\chi 2$ (1, n = 246) = .47, p = .79, phi = .04, as well as in the types of tasks, $\chi 2$ (1, n = 246) = .08, p = .77, phi = –.02) (see Table 2.1).

[8] After signing the consent form, participants were tested for about 40 min. in a private work cubicle. Students participated in the study in exchange for 10, 00€ and completed this computer based study at their own pace. First, baseline measures of affective states were assessed. Next, students were provided a practice task to familiarize themselves with the format of the task. Then, students received the emotion induction and started to work on the experimental task immediately afterwards. An audio signal announced after three minutes via headphones (that students wore as part of the emotion induction procedure) that time had expired while a visual signal indicated the investigator to remove the worksheet. Then, participants completed the affect measures for a second time and reported retrospectively their subjective affective experiences during the emotion induction (Fabrigar, Wegener, Reis, & Judd, 2014). Last, they reported retrospectively about their motivation while working on the task. In this and all comparable experiments in the literature the knowledge test was completed by participants at the end of the study to avoid interference with the experimental manipulation (Elliot, Maier, Moller, Friedman, & Meinhardt, 2007). Before leaving the laboratory, all students were debriefed.

generating different intensities of enjoyment, and anxiety across the three emotion groups and was found to keep high levels of arousal for the experimental groups, while levels of arousal dropped significantly for the control group (see Figure 2.2 and Appendix B.2. for Emotion Induction and Manipulation Check).

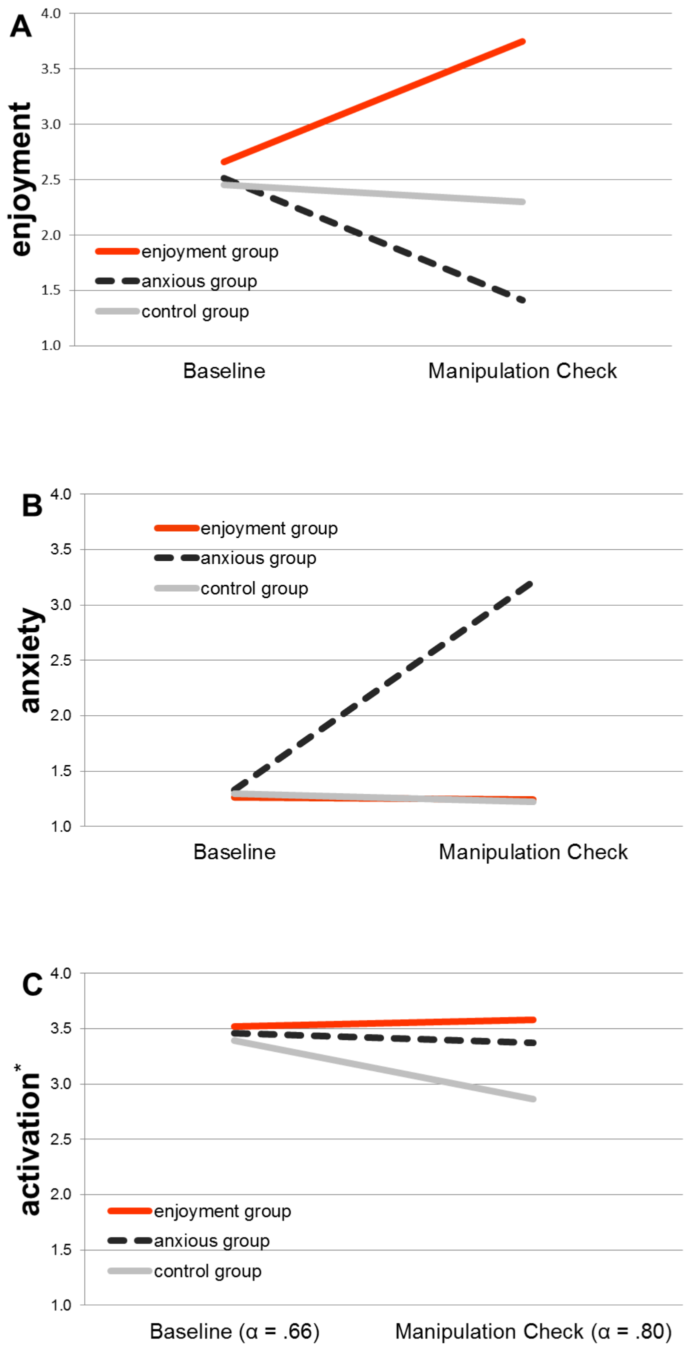

Figure 2.2: Students' emotional states before (Baseline) and after the emotion induction phase (Manipulation Check) by differentiating intensities of discrete emotions words (A = enjoyment; B = anxiety) as well as levels of activation (C = combined from three discrete emotion words: active, awake, and attentive) across all three experimental groups.

Immediately after the emotion induction, students worked on the experimental tasks (see Appendix B.4. for piloting and coding of experimental tasks). Importantly, both tasks were based on identical mathematical content (see Figure 2.3) for the common problem space of both tasks (Klahr & Dunbar, 1988)) making the effects of positive as well as negative emotions directly comparable.

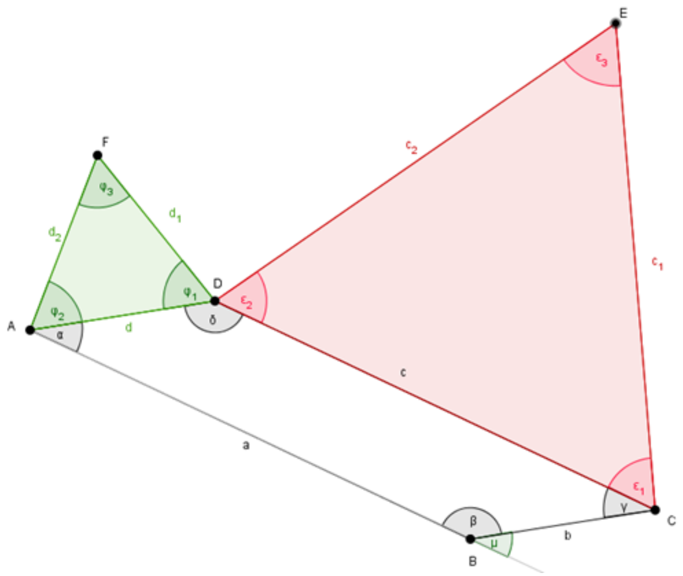

Figure 2.3: Both tasks showed the figure representing a parallelogram with two equilateral triangles built on adjacent sides on the parallelogram.

The *generation task* asked students to generate valid mathematical ideas about the geometric figure. The *evaluation task* presented ideas about to the mathematical figure and students were asked to validate or refute ideas, by identifying them as “true” or “false”. Maximum time for each task was three minutes (see Appendix B.5. for experimental task instructions and coding schemes). To measure performance on the *generation task*, we used three indicators of idea generation (DeHaan, 2011; Guilford, 1967; Torrance, 1966): *Fluency* was operationalized as the number of unique ideas generated by each student. *Originality* of an idea was measured by its frequency relative to the total number of ideas generated in the sample. *Cognitive flexibility* was measured by the number of distinct theoretical categories which would support the different ideas (e.g., “properties of parallelograms/equilateral triangles” or “properties of angles at transversals of two parallel lines”). Performance on the *evaluation task* was defined as the number of ideas correctly identified as “true” (correct validation of an idea) or “false” (correct refutation of an idea).

2.5 Results

To investigate the effects of emotion on performance in the generation task, a multivariate analysis of variance (MANCOVA; 3 emotion conditions, 3 performance measures as dependent variables) was conducted (including all motivation variables as covariates[9]). To account for the confounding effects between all performance indicators (Cole, Maxwell, Arvey, & Salas, 1994; Hirt et al., 2008), all three were included as dependent variables. There was a multivariate effect indicating that the emotion groups differed significantly above controlling for the influence of motivational variables, using Pillai´s trace: $V = 0.13$, $F(6,228) = 2.73$, $p = .014$, $\eta^2 = .067$ (Levene's Fs [2,119] < 1.59, ps > .21). Subsequent univariate analyses revealed significant differences between the emotion groups in all performance indicators: fluency, $F(2,122) = 4.25$, $p = .017$, $\eta^2 = .07$; originality, $F(2,122) = 3.83$, $p = .025$, $\eta^2 = .06$; cognitive flexibility, $F(2,122) = 3.01$, $p = .053$, $\eta^2 = .05$[10] (see Figure 2.4).

As predicted, pairwise comparisons revealed that students in the enjoyment group (ENJ) generated significantly more ideas than the control group (CON; ENJ-CON: $\Delta M = 1.94$, $p = 0.004$, $CI_{95\%}$ [.615, 3.259]). These ideas also showed significantly higher originality (ENJ-CON: $\Delta M = .12$, $p = 0.007$, $CI_{95\%}$ [.033, .203]) and flexibility (ENJ-CON: $\Delta M = .39$, $p = .048$, $CI_{95\%}$ [.003, .782]). The differences between the enjoyment and anxious group (ANX) were only marginally significant for fluency (ENJ-ANX: $\Delta M = 1.18$, $p = 0.088$, $CI_{95\%}$ [-.178, 2.531] but differed substantially for flexibility (ENJ-ANX: $\Delta M = .45$, $p = 0.027$, $CI_{95\%}$ [.053, .851]. The magnitude of this difference was a substantial medium effect ($\eta^2 = .06$).

However, differences between the enjoyment and the anxious group with regard to originality were not statistically significant (ENJ-ANX: $\Delta M = .057$, $p = 0.196$, $CI_{95\%}$ [-.030, .144]), nor were any of the differences between the anxious and the control group (see Figure 2.4).

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[9] In all following analyses, the variables intrinsic and extrinsic motivation, effort and concentration were controlled. Therefore, the reported means for all performance measures refer to estimates of models including these covariates. For values not including covariates (simple univariate analyses for performance measures on either task format) please see Table 2.1.

[10] As all main analyses presented in this Study are based on one-way analyses of general linear modeling, thus describing the proportion of the total variability attributable to one factor only (Levine & Hullett, 2002), all effect sizes will be based on eta-squared values (η^2) and interpreted along the suggested benchmarks: η^2 of .0099 constitutes a small effect, η^2 of .0588 describes a medium effect, and η^2 of .1379 depicts a large effect (Cohen, 1988; Maher, Markey, & Ebert-May, 2013). A medium effect is considered to be of great magnitude for research conducted in educational research (Richardson, 2011a).

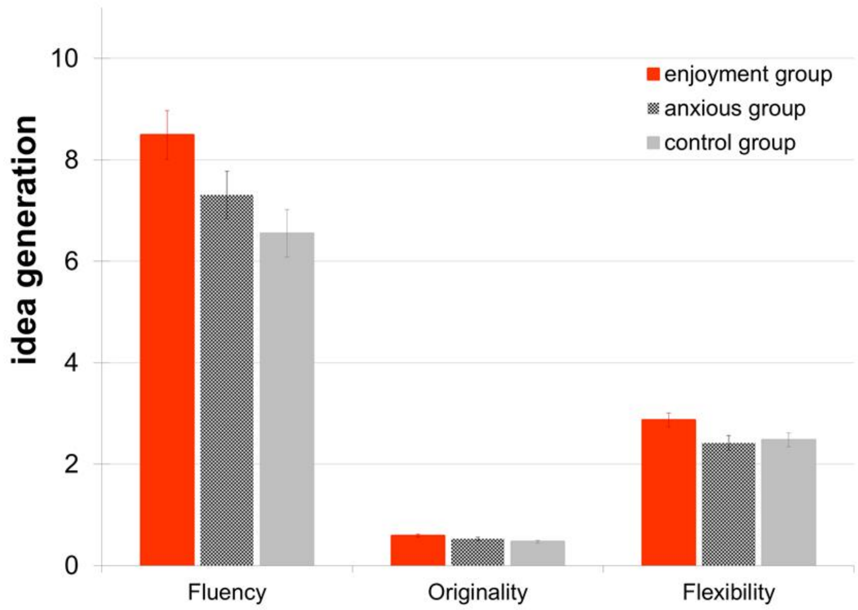


Figure 2.4: Differences of emotion groups in generating ideas. Means and standard errors are shown for the total amount of ideas (fluency), the uniqueness of those ideas (originality) and the amount of distinct theoretic categories from which ideas were pulled (flexibility). Differences were computed using multivariate analyses of variance (MANCOVA). Error bars represent ±1 SEM (0.47 for fluency, 0.03 for originality and 0.14 for flexibility).

A unifactorial (emotion groups: enjoyment vs. anxious vs. control group) analysis of covariance was conducted on the validation of mathematical ideas (M = 3.53, SD = 1.81), while accounting the influence of all motivational variables as covariates in the analysis. Unexpectedly, the analysis revealed no significant effect of emotion groups on correctly identifying “true” ideas, F(2,122) = 2.15, p = .12, η^2 = .04 (Levene’s F [2,119] = 1.33, p = .27). Nonetheless, the descriptive statistics emerged in the hypothesized direction with students in the anxious group (M = 3.93, SD = 1.98) identifying more ideas correctly than the students in the enjoyment (M = 3.49, SD = 1.75, ANX-ENJ: ΔM = .66, p = 0.12, $CI_{95\%}$[-.182, 1.509]) or the control group (M = 3.15, SD = 1.64, ANX-CON: ΔM = .80, p = 0.053, $CI_{95\%}$[-.011, 1.617]) (see Figure 2.5). A second unifactorial (emotion groups: enjoyment vs. anxious vs. control group) analysis of covariance was conducted on the refutation of mathematical ideas (M = 3.12, SD = 1.36), while accounting the influence of all four motivational factors as covariates in the analysis. The analysis revealed a significant effect of emotion groups on the ability to correctly identify presented ideas as false, F(2,122) = 3.82, p = .023, η^2 = .06 (Levene’s Fs [2,119] = 2.09, p = .13). As expected, students in the anxious group correctly refuted more ideas correctly than the control group (ANX-CON: ΔM = .80, p = 0.009,

$CI_{95\%}$[.203, 1.394]), while additionally differences with the enjoyment group were marginally significant (ANX-ENJ: $\Delta M = .61$, $p = 0.052$, $CI_{95\%}$[-.007, 1.231]) with a notable medium effect size ($\eta^2 = .06$) (see Figure 2.5).

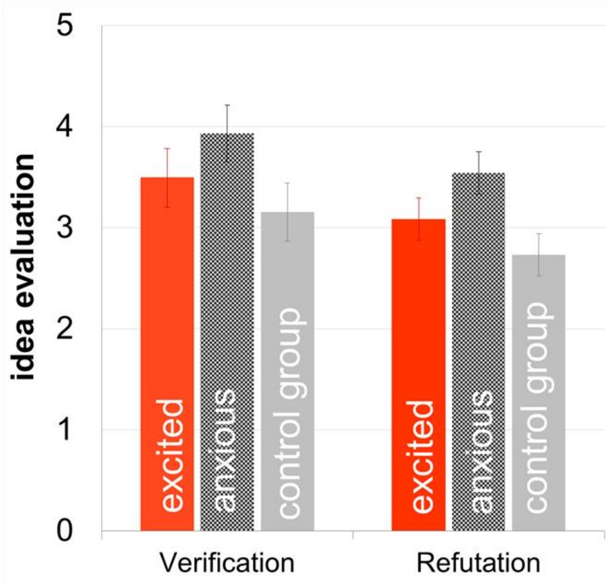


Figure 2.5: Differences in emotions groups in evaluating ideas. Means and standard errors are shown for correctly evaluated mathematical ideas by identifying them as “true” (verification) or “false” (refutation). Differences in variances were computed using analyses of covariance. Error bars represent ±1 SEM (0.28 for validating and 0.21 for refuting ideas).

Last, in order to test the activation-hypothesis, both experimental emotion groups (i.e., the enjoyment and the anxious group) were combined and contrasted against the control group (which was found to show significantly lower levels of emotional activation (see Figure 2.2)). In order to account for motivational covariates, an ANCOVA compared the performance on the idea generation task for activated versus deactivated emotion groups. The three performance indicators of idea generation (fluency, originality and flexibility) were standardized, by transforming them into z-scores, in order to compute an overall performance measure of idea generation (range: $-2.25 < z_{\text{idea generation}} < 2.08$). This unifactorial (emotion groups: activated vs. deactivated) analysis of covariance revealed that both groups significantly differed in the overall performance of the idea generation task, $F(1,122) = 5.44$, $p = .021$, (Levene’s Fs [1,120] = .40, $p = .53$). As expected, students that had been randomized to activated-emotion groups (ACT, $M = .13$, $SD = .86$) performed significantly better than the deactivated control group (DEACT; $M = -.24$, $SD = .95$). The magnitude of the difference (ACT-DEACT: Δ*M* = .38 (*SE* = .16), *p* = 0.02, $CI_{95\%}$ [.064, .778]) was a substantial medium-sized effect (*η²* = .05) (see Figure 2.6).

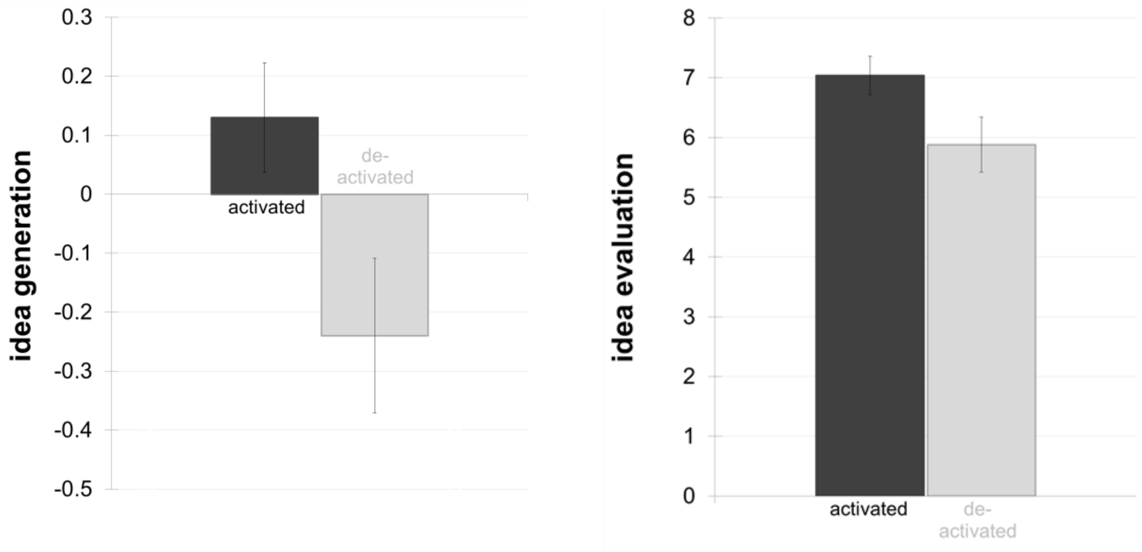


Figure 2.6: Differences between activated and deactivated emotions groups for overall performance on idea generation and idea evaluation tasks. Means and standard errors are shown for performance measures. Performance measure for idea generation represents a composite score of the standardized performance indicators (fluency, originality and flexibility). Performance measure for idea evaluation represents the overall composite score (i.e., total sum) of correct verifications and refutations.

For testing the activation-hypothesis relative to the idea evaluation task respectively, both performance measures (number of correct verifications and refutations) were added to form one overall composite score indicating the total amount of ideas that were correctly identified and analyzed. Again, all motivational covariates were included in the model, such that an ANCOVA compared the total scores on the idea evaluation task for activated versus deactivated emotion groups. This unifactorial (emotion groups: activated vs. deactivated) analysis of covariance revealed that differences between the groups approached statistical significant differences in the overall performance of the idea evaluation task, F(1,122) = 3.13, p = .079, η² = .03 (Levene's Fs [1,120] = 2.61, p = .11). According to the hypothesis, students that had been randomized to activated-emotion groups (ACT, *M* = 7.04, *SD* = 2.93) solved more items correctly than the deactivated control group (DEACT; *M* = 5.88, *SD* = 2.67). The magnitude of the difference (ACT-DEACT: Δ*M* = 1.01 (*SE* = .57), *p* = 0.079, $CI_{95\%}$ [-.120, .2.132]) was a small effect (*η²* = .03) (see Figure 2.6).

Table 2.1: Descriptive Statistics (Means and Standard Deviation) for Performance Measures on Generation and Evaluation Task (excluding motivational covariates), gender, Motivational Variables and prior knowledge across emotion groups and tasks and F-Statistics of one/two-way ANOVAs for Effects of Emotion Groups across task types.

Variables	Generation Task M (SD)			Evaluation Task M (SD)					Emotion Group x Task Type Interaction
	Enjoyment (N_{total} = 40)	Anxious (N_{total} = 42)	Control (N_{total} = 42)	Enjoyment (N_{total} = 39)	Anxious (N_{total} = 43)	Control (N_{total} = 40)	Task Type $F(1,240)^a$	Emotion Group $F(2,119)^a$	$F(2,240)^a$
N females	18	16	17	16	17	19			
Performance Measures									
Fluency	8.77 (2.91)	7.07 (3.17)	6.54 (3.18)	-	-	-	-	5.66** (.09)	-
Originality	.61 (.20)	.51 (.21)	.47 (.20)	-	-	-	-	4.94** (.08)	-
Cognitive Flexibility	2.92 (.77)	2.33 (.87)	2.51 (1.05)	-	-	-	-	4.44*(.07)	-
Verification	-	-	-	3.49 (1.75)	3.93 (1.98)	3.15 (1.64)	-	1.97	-
Refutation	-	-	-	3.08 (1.29)	3.54 (1.42)	2.73 (1.26)	-	3.90*(.06)	-
Motivational Mechanisms									
Intrinsic Motivation	2.82 (.81)	2.79 (.80)	2.75 (.88)	2.84 (.80)	2.70 (.65)	2.58 (.85)	.61	.84	.29
Extrinsic Motivation	2.86 (.90)	2.74 (.71)	2.88 (.84)	2.42 (.79)	2.71 (.71)	2.98 (.80)	1.43	2.94°(.02)	2.49°(.02)
Effort	4.15 (.69)	3.93 (.71)	3.93 (.82)	4.07 (.72)	3.82 (.73)	3.98 (.72)	.28	2.11	.27
Concentration	3.98 (1.27)	3.24 (1.12)	3.73 (1.06)	3.71 (1.05)	2.80 (1.13)	3.44 (1.15)	5.28*(.02)	11.49**(.09)	.04
Trait									
Prior Knowledge [max.49]	39.95 (5.32)	40.76 (5.20)	40.60 (4.25)	40.15 (4.75)	40.84 (3.99)	40.60 (4.60)	.03	.55	.01

Note. Measures of motivational mechanisms were obtained using a five-point rating scale assessing the agreement: 1 = not true of me at all to 5 = very of me), aEffect Sizes (η2s) given in parentheses for (marginally) significant results. °p < .085. *p <.023. **p < .009. No homogeneity of variances assumption were violated (all ps > .29).

2.6 Conclusion

The present findings show the significance of positive as well as negative emotions[11] for thinking. Enjoyment reliably improved performance on an idea generation task, while anxiety leads to better selection of false ideas in need of rejection. The present findings suggest that emotions are functional in coordinating cognitive processes that contribute to reasoning and thus offer a reconciliation of the conflicting results reported in the extant literature. More specifically, the findings suggest that subjective emotional experiences significantly influence both, quantitative (number of generated and evaluated ideas) and qualitative (originality and flexibility) aspects of scientific performance. Most importantly, however, our findings have critical implications from a scientific, practical and educational point of view. Results from this research suggest that if a task calls for creativity and imagination, then experiencing positive-activating emotions is more beneficial. On the other hand, negative-activating emotions might counteract cognitive biases (Kahneman, 2013), which is not only critical for scientific theory revision, but might additionally help to reduce diagnostic errors (e.g., essential for all professions involving decision making or risk-taking). For educators, the findings points to the importance of awareness of emotions (e.g., their implications for open-ended questions vs. multiple-choice testing) and their regulation respectively, as potential leverage for increasing cognitive performance (Gross, 2015). In sum, these findings suggest that emotions and cognition are intimately linked, illustrate how the subtle modulation of cognition, instigated by emotions, changes our thinking and importantly highlights the adaptive functions of both, positive as well as negative emotions for complex scientific thought.

[11] In light of interpreting the present findings, it is critical to attend to the object focus of the investigated emotions as these were unrelated to the context of the learning tasks. Thus, the functional properties and consequently effects of emotions may be different for emotions directly relating to the object focus of an experimental task. For instance, anxiety arising with respect to fear of failure relative to an achievement situation may elicit fundamentally different cognitive and motivational processes likely to produce different effects of learning. Thus, the object focus of emotions is one critical dimension for determining effects of emotions for learning and achievement (Pekrun & Perry, 2014).

3 Study 2 – Hot Reasoning in Mathematics: How Epistemic Emotions arise and drive Motivation and Attention during a complex reasoning task

3.1 Abstract[12]

This study examined antecedents and effects of epistemic emotions, typically defined by their object focus relating to reasoning and knowledge generation (Pekrun et al., 2016). The control-value theory (CVT; Pekrun, 2006) offers an integrative theoretic frame including a cognitive-motivational explanation of the antecedents and outcomes of epistemic emotions. Data were collected from mathematics university students (*N* = 80) before and after working on a complex reasoning task. Before the task, participants were asked to report on their control- and value- appraisals relative to a practice task. Immediately upon completion of the task, students reported their epistemic emotions as well as their motivation and attention as experienced during the task. Mathematical performance was assessed by three indicators of quantity and quality of proof formulation. Structural equation modelling revealed that both control and value appraisals served as important antecedents of curiosity, enjoyment, surprise, confusion and boredom experienced during the task, and were also related to intrinsic motivation and attention. In addition, curiosity, enjoyment, frustration and boredom were found to relate to intrinsic motivation and attention as well as task performance. Indirect effects offer support for the postulated functions as suggested in CVT, with epistemic emotions mediating relations between appraisals and intrinsic motivation and attention, as well as intrinsic motivation and attention mediating relations between enjoyment and task performance. The assessment of task and situation specific epistemic emotions is crucial for understanding their interplay with cognitive and motivational processes driving epistemic activities. The findings suggest that the role of epistemic emotions for complex reasoning should be considered in future research and can guide educational practice.

3.2 Introduction

While it has become increasingly clear that emotion, cognition, and motivation are intricately intertwined during complex reasoning (Azevedo, 2015; Dai & Sternberg, 2004;

[12] This study was conducted in collaboration with Dr. Elisabeth Vogl, Prof. Reinhard Pekrun and Prof. Stefan Ufer. The manuscript length was not specified for this study.

DeBellis & Goldin, 2006b; McLeod, 1992; Mega et al., 2014; Op't Eynde et al., 2006; Pekrun & Perry, 2014), their joint functions and interplay in the process of learning and problem solving are only starting to be addressed (D'Mello & Graesser, 2011, 2012; Duffy & Azevedo, 2015; Tulis & Fulmer, 2013). Specifically, recent findings from experimental psychology and neuroscience stress that epistemic emotions tightly interact with cognitive and motivational systems during reasoning, which in turn determine performance (Gottlieb, Lopes, & Oudeyer, 2016; Pekrun & Linnenbrink-Garcia, 2014). Therefore, the aim of this study was to examine the functions of epistemic emotions, namely curiosity, enjoyment, surprise, confusion, anxiety, frustration and boredom (Pekrun et al., 2016), in directing attention and activating motivational resources during a complex reasoning task in mathematics. Whereas research on some epistemic emotions such as curiosity and surprise has a long tradition (Berlyne, 1954; Foster & Keane, 2015; Grossnickle, 2016; White, 1959), epistemic enjoyment, anxiety and boredom have only recently received educators' attention (Eren & Coskun, 2016), and empirical evidence on other epistemic emotions, such as confusion or frustration, is scarce and not yet conclusive. Precisely, it has been suggested that all epistemic emotions should be considered simultaneously, in order to investigate their joint impact on task-specific attentional processes and motivational tendencies in order to better understand their relations with performance (Gottlieb et al., 2016; M. J. Gruber, Gelman, & Ranganath, 2014).

The control-value theory (CVT; Pekrun, 2006) offers an integrative theoretic frame of emotions typically experienced in competence and achievement-based settings, with a cognitive-motivational explanation of the antecedents and outcomes of those emotions (Pekrun, 2006; Pekrun et al., 2002a; Pekrun & Perry, 2014). The theory is designed to encompass functional mechanisms pertaining to emotions relating to learning and achievement (Pekrun & Stephens, 2012). Therefore, these postulated functions should be universally applicable to all groups of academic emotions, thus including epistemic emotions. Specifically, CVT describes cognitive appraisal dimensions of control and value as critical determinants of emotions relating to learning and achievement. The effects of emotions on reasoning and performance, in turn, are thought to be mediated by their impact on attention and motivation, through which consequences on reasoning and performance are modulated (Pekrun et al., 2002a, 2016; Pekrun & Perry, 2014). Critically, the theory makes sequential assumptions on the functional chain of these cognitive, emotional and motivational variables for reasoning: while epistemic emotions are thought to mediate relationships between cognitive appraisals and attentional and motivational processes during a complex reasoning task, attentional and motivational processes, in turn, are thought to mediate relations between epistemic emotions and performance outcome.

Thus far, only a handful of studies have integrated on-task measures of students' discrete epistemic emotions, as well as task-related cognitive and motivational processes relative to a complex reasoning task (Muis, Psaradellis, et al., 2015; Tulis & Fulmer, 2013). Additionally, research is lacking with regard to exploring both antecedents and effects of epistemic emotions simultaneously (Muis, Psaradellis, et al., 2015). The current study addressed this gap in research by investigating the origins and effects of epistemic emotions, namely surprise, curiosity, enjoyment, confusion, anxiety, frustration and boredom (Pekrun & Stephens, 2012), during a complex reasoning task. In particular, we investigated task-specific control and value appraisals as antecedents of epistemic emotions together with their effects on attention and motivation which in turn were investigated relative to the quality of task performance.

3.2.1 Conceptualizing Epistemic Emotions

Epistemic emotions relate to the knowledge-generating aspects of learning and other cognitive activities such as problem solving (Pekrun et al., 2016). For example, the curiosity and/or confusion that can be triggered by contradictory findings, the enjoyment of seeing a hypothesis confirmed, or the frustration of repeatedly encountering new problems with the same problem, provide only few examples of how intricately interwoven epistemic emotions are with complex reasoning and problem solving (Ainley & Ainley, 2011; Jaber & Hammer, 2016). As such, the critical defining feature pertaining to this specific group of academic emotions (see further, Pekrun & Stephens, 2012) is that the respective object focus must be on epistemic aspects of reasoning. Since epistemic emotions occur during thinking or ongoing knowledge-generating activities, they can always be considered activity emotions and mark dynamic, arousing and in-the-moment affective states. Epistemic emotions include, but are not limited to (e.g., for the epistemic emotion "awe" see Valdesolo, Shtulman, & Baron, 2016), curiosity, enjoyment, surprise, confusion, anxiety, frustration and boredom[13] (D'Mello, Lehman, & Person, 2010; Pekrun et al., 2016). While the importance of epistemic emotions for epistemic activities is being increasingly acknowledged, systematic research examining

[13] Boredom marks the great exception in this list of epistemic emotions as typically the object focus, under the experience of boredom, diverts away from epistemic aspects of a cognitive activity and typically boredom is defined as a deactivating emotion not directly contributing to cognitive stimulation (Pekrun, Vogl, Muis, & Sinatra, 2016).

the specific functions of emotions for learning and reasoning, however, is largely lacking (Fischer et al., 2014; Sinatra et al., 2014).

3.2.2 Antecedents of Epistemic Emotions

Given that the specific functions of epistemic emotional states are tightly coupled with the production of knowledge, it is imperative to understand their respective antecedents to describe how discrete epistemic emotions arise. It that respect, it is important to consider the situational characteristics of a learning situation (e.g., complexity of a problem) as well as the students' appraisals of that situation.

Cognitive Discrepancy/ Incongruity. Generally, epistemic emotions have been described to arise when cognitive discrepancies or cognitive *gaps* in one's existing knowledge are made salient (Grossnickle, 2016; Loewenstein, 1994), for example as caused by a "mismatch between stimulus input and preexisting cognitive dispositions" (Frijda, 1986, p. 346). Therefore, the "cognitive gap" or the schema discrepancy refers to the demands of the immediate situation relative the student's knowledge or goal. For example, cognitive discrepancies occur when learners are confronted with deviations from expectations or beliefs, impasses or obstacles to goals, as well as from complex tasks, such as a mathematical proof. Such schema-discrepancies have been found to trigger cognitive-affective processes until equilibrium is restored, disequilibrium is dampened, or the student disengages from the task (D'Mello & Graesser, 2012; Graesser & D'Mello, 2012).

More specifically, the trajectories of such impasses have been linked with specific emotional experiences (Pekrun & Stephens, 2012). For example, curiosity has been described to arise relative to knowledge gaps (Grossnickle, 2016), enjoyment is experienced when recombining information helps to solve the problem (Pekrun & Stephens, 2012) and surprise is experienced upon encountering novelty or unexpected events (Berlyne, 1954, 1960; Scherer, Schorr, & Johnstone, 2001). Further, confusion arises when the incongruity cannot be immediately resolved (D'Mello & Graesser, 2012; D'Mello et al., 2014), anxiety may be experienced when severe incongruity deeply disturbs existing beliefs (Muis, Pekrun, et al., 2015; Pekrun & Stephens, 2012) and frustration occurs if a student gets stuck, if important goals are blocked or if plans to resolve such impasses are unavailable (D'Mello & Graesser, 2012). The last instance of these affective dynamics is boredom, as this self-disruptive emotion (Eren & Coşkun, 2015) has been hypothesized to cause students to disengage from and to give up on epistemic endeavors (D'Mello & Graesser, 2012; Pekrun et al., 2010).

Control and Value Appraisal of the Cognitive Activities. According to the CVT, achievement emotions are elicited via cognitive appraisals of control and value in relation to an achievement situation. Value refers to one's appraisal of the significance or importance of the an achievement activity or its outcome and includes both intrinsic (interest) and extrinsic (utility and attainment) values (Pekrun et al., 2011). The perception of cognitive control refers to the appraisal of the possibility to personally influence the cognitive activity (relative to ongoing actions as well as outcomes) and may be influenced by competence beliefs (e.g., through constructs such as self-efficacy, the academic-self-concept of a given domain or the internal locus of control), task demands or the perceived probability of success or failure. As there is no fully formulated theory as of yet, describing the specific appraisal mechanisms pertained to be most relevant for the rise of epistemic emotions, we started to investigate the antecedents of epistemic emotions relative to those appraisals deemed to be especially important in the academic context generally, namely control and value.

Applying these theoretical considerations to the category of epistemic emotions, the intensity of the experience of epistemic emotions might be determined by the extent to which the respective information or task is perceived to be valuable. In line with reasoning from CVT, the more epistemic value is assigned to a complex cognitive task or its outcome, the more intensely will – positive as well as negative – epistemic emotions be experienced. The exception is boredom. Here, the intensity of the experience of this negative emotion should diminish with greater value (Pekrun et al., 2010).

The few empirical findings available to date are in line with these postulations. Curiosity and enjoyment have been found to be positively associated with greater value, the relationships between value and negative activating emotions have been found to be either negative or unrelated and findings for surprise have largely been inconsistent (Ainley & Ainley, 2011; Muis, Psaradellis, et al., 2015; Pekrun et al., 2016).

Beyond these independent effects of value, CVT proposes that control interacts with the experienced value and that their combined effects predict the rise of epistemic emotions relative to the specific learning situation (see further for expectancy - value interaction; Trautwein et al., 2012). This means that if the value of a cognitive activity is sufficiently high and personal control is perceived as high, curiosity and/or enjoyment are experienced (Loewenstein, 1994). If, on the other hand, perceived control over the cognitive activity is only low or moderate, anxiety or confusion may be experienced, however, confusion may also be experienced under feelings of high control (Pekrun et al., 2016; Silvia, 2010, 2013). Frustration occurs if cognitive activity is highly valued but cognitive incongruity is persistent and control is perceived as low (Pekrun, 2006). Recent empirical findings support the proposed appraisal interaction as predictors for activity specific learning emotions (Bieg, Goetz, & Hubbard, 2013; Goetz, Frenzel, Stoeger, & Hall, 2010). For example, it has been found that enjoyment is experienced if the mathematical problem to which it relates is positively valued and if it is perceived as sufficiently controllable, however, if the task is not adequately controllable, frustration can occur (Baker, D'Mello, Rodrigo, & Graesser, 2010). This means that a lack of control and high value of a failure outcome may produce negative-activating emotions (e.g., anxiety, frustration) (Bieg et al., 2013). Moreover, low perceived controllability and low subjective value of a task, may yield negative-deactivating emotions like boredom (Pekrun et al., 2010). In conclusion, the different combinations of the antecedents of epistemic emotions (i.e., the extent and persistence of cognitive incongruity, control and value appraisals as well as their interactive effect) can explain why the same cognitive task can trigger different epistemic emotions in different individuals.

3.2.3 Outcomes of Epistemic Emotions

As suggested by philosophers, the activating qualities of epistemic emotions determine epistemic ends which consequently are functionally important for initiating, directing, or terminating the search for reason and evidence during epistemic activities (Brun, Doğuoğlu, & Kuenzle, 2008; Morton, 2010). Particularly, epistemic emotions have been found to regulate attention during cognitive problem solving (Fiedler & Beier, 2014) and are functionally important for motivational processes (Tuan, Chin, & Shieh, 2005). The overall effects of any given emotion on performance will likely depend on the nature of the mechanisms facilitated by the emotion, the interplay of these mechanisms, and their interactions with task demands (Pekrun & Stephens, 2009).

In order to discern functional differences of academic emotions, Pekrun (2006) classified three particularly critical dimensions describing emotions, namely the object focus, valence and activation dimension. Critically, the object focus for all epistemic emotions is always the cognitive task at hand. In terms of valence and activation, epistemic emotions can be both, positive and negative, and in terms of activation, epistemic emotions can be activating as well as deactivating. Through combining the valence and activation dimensions, epistemic emotions enclose positive activating emotions (curiosity, enjoyment), negative activating emotions (confusion, anxiety, frustration), and negative deactivating emotions (boredom). In addition, the activating emotion surprise can be experienced as positive or negative (Pekrun et al., 2016).

Effects of Epistemic Emotions on Attention. Epistemic emotions are conceptualized as arousing emotional states that serve functions of directing attention and activating cognitive resources toward the object of the emotion, in terms of epistemic emotions the epistemic activity or task (Ellis & Ashbrook, 1988). These attentional mechanisms, in turn, are assumed to facilitate or hinder epistemic activities (Pekrun & Perry, 2014). For example, curiosity is thought to stem from situations revealing gaps in one's knowledge (Loewenstein, 1994) ultimately directing attention toward the problematic gap, thus allowing for the full use of cognitive resources in order to reduce this feeling of knowledge deprivation (Grossnickle, 2016). In line with this, a recent eye tracking study showed that epistemic curiosity steers eye movements towards the incongruent or unexpected information (Baranes, Oudeyer, & Gottlieb, 2015). Enjoyment of learning has been found to stimulate cognitive activation and use of cognitive resources, for example by directing attention on the object of learning (Buff, Reusser, Rakoczy, & Pauli, 2011; Fredrickson, 1998; Pekrun et al., 2002a). Similarly to curiosity, surprise can be elicited by novelty or deviations from expectations (Scherer, 2001; Stiensmeier-Pelster, Martini, & Reisenzein, 1995) and has been found to focus attention on the unexpected or novel information (Foster & Keane, 2015; Horstmann & Herwig, 2015). However, curiosity and surprise seem to be functionally distinct in that curiosity is a pro-active process that anticipates, or motivates to obtain new information, whereas surprise indicates a reactive process after having processed the information (Baranes et al., 2015).

Confusion and frustration seem to have more complex relationships with learning and thinking; on the one hand they are a natural part of and even necessary for complex learning (D'Mello et al., 2014), while, on the other hand, it has been found that spending a considerable amount of time confused or frustrated is associated with worse performance (Graesser & D'Mello, 2012). In more detail, confusion arises when discrepant information is detected (e.g., a conflict with prior knowledge or expectations; Silvia, 2010, 2013). This cognitive gap is believed to trigger regulatory strategies either focusing attention on the discrepancy of information or leading to avoid the cause of the confusion (Jacobs & Gross, 2014). As such, confusion may only be beneficial for learning if the impasse is attended to, actively engaged with and ultimately resolved (D'Mello & Graesser, 2014; D'Mello et al., 2014). Similarly, frustration occurs when students 'get stuck' over an impasse (D'Mello & Graesser, 2011). This negative cognitive loop, if persistent, may transition into boredom (D'Mello & Graesser, 2012). Studies investigating the cognitive consequences of experiencing boredom while working on a task, typically report attention impairments (Pekrun et al., 2010; Titz, 2001; Tze et al., 2016). That is, students have problems concentrating when they are bored and are therefore more prone to be distracted by task irrelevant information (Craig, Graesser, Sullins, & Gholson, 2004; D'Mello & Graesser, 2012; Pardos, Baker, San Pedro, Gowda, & Gowda, 2014). Similarly, a rather well documented cognitive consequence of test anxiety is the interruption of information processing, which, as a result, impairs the attention that can be allocated on the academic task (Clarke, MacLeod, & Guastella, 2013; Fiedler & Beier, 2014; Zeidner, 2007).

Effects of Epistemic Emotions on Motivation. Epistemic emotions have been ascribed a motivational function in that they help prioritizing certain goals and thereby mobilize energy and give direction to learning and behavior (Grossnickle, 2016). Such motivational processes are, for example, well documented for epistemic curiosity (M. J. Gruber et al., 2014; Kang et al., 2009). The driving force of curiosity was suggested to stem from the desire to eliminate a knowledge gap by obtaining the missing pieces of information (information-gap theory; Loewenstein, 1994). Accordingly, epistemic curiosity has been found to promote the exploration of new knowledge (Berlyne, 1954; Jirout & Klahr, 2012; Litman, Hutchins, & Russon, 2005). Similarly, the experience of enjoyment of learning is positively associated with intrinsic (i.e., motivation to learn because the material is interesting and learning is enjoyable) as well as extrinsic motivation (i.e., motivation to learn to attain outcomes) (Pekrun et al., 2002a). While most authors agree that surprise is an arousing state triggering attention (Horstmann & Herwig, 2015), and consequently making information more memorable (Fazio & Marsh, 2009; Parzuchowski & Szymkow-Sudziarska, 2008), motivational consequences of this epistemic emotion have not been systematically investigated. Confusion, despite being a negative-activating emotion, has recently been found to motivate learners to actively engage with learning materials (D'Mello & Graesser, 2012; D'Mello et al., 2014). However, this effect only comes into play if confusion triggers mechanisms for resolving this discomforting state (VanLehn, Siler, Murray, Yamauchi, & Baggett, 2003), as it might otherwise impair performance (Muis, Psaradellis, et al., 2015). Similarly, anxiety can induce strong extrinsic motivation to invest effort to avoid failure (Pekrun et al., 2002a). Even frustration may promote exploration and learning, if the frustrated person is able to use it for strengthening motivation and effort by maintaining positive expectancies in their abilities (Baker et al., 2010; Wong, 1979). However, research so far has suggested rather detrimental effects of anxiety and frustration on learning and achievement (Pekrun & Stephens, 2012; Zeidner, 2014). Last, boredom has been described as a "motivational barrier" (Vogel-Walcutt, Fiorella, Carper, & Schatz, 2012, p. 90) leading to uniformly lower total motivation to learn (Baker et al., 2010; Eren & Coskun, 2016; Eren & Coşkun, 2015; Pekrun et al., 2010, 2002a; Tze et al., 2016).

3.2.4 Attention and Motivation as Predictors of Performance

Cognitive activities pursued with full investment of cognitive functions and done out of intrinsic motivation have been found to not only predict the engagement with a cognitive endeavor but also the quality of performance (Pekrun & Linnenbrink-Garcia, 2012). Attention can be defined as the "focusing of the mind" and has long been recognized as a critical prerequisite for learning to occur (Nissen & Bullemer, 1987). Specifically, the amount of attention directed towards a cognitive task has been found to determine the selection of information (J. R. Anderson, 1990, 2013; Gottlieb, Oudeyer, Lopes, & Baranes, 2013) and consequently determines what information will be processed in working memory (Awh, Vogel, & Oh, 2006; Cardoso-Leite & Bavelier, 2014). Intrinsic motivation, a motivation that energizes engagement in activities via the inherent satisfaction derived from effective, freely chosen action, results in high quality learning (Deci, 1992; Eccles & Wigfield, 2002; Harackiewicz, 2000; Ryan & Deci, 2000). Empirical findings indicate that intrinsically motivated learners derive pleasure from the task itself (e.g., enjoyment from problem solving) are more actively involved in tasks (Harter, 1992; Tobias, 1994), and show greater task persistence (Patrick, Skinner, & Connell, 1993; Tulis & Fulmer, 2013).

3.3 Aim, Research Questions and Hypotheses of the Present Research

In the present study, we explore if epistemic emotions serve cognitive and motivational functions during a complex reasoning task in mathematics (Brun et al., 2008; Morton, 2010). Complex problems in mathematics are particularly ripe with epistemic emotions as these naturally entail cognitive incongruity (Hannula, 2012, 2014). Specifically, the formulation of a mathematical proof requires mathematicians to coordinate several mental activities and to bridge cognitive gaps (Boero, 1999; Ufer, Heinze, & Reiss, 2009). For example, evidence has to be searched that might contradict one's own assumptions, reasoning paths have to be altered or at times refuted and induction and deduction must be used as reasoning operators (Reiss & Heinze, 2004). From this perspective, mathematical reasoning is bound to trigger highly emotional responses driving epistemic processes (Fischer et al., 2014; Muis, Pekrun, et al., 2015).

Because epistemic emotions arise and operate in the nexus between the learner and a task, the level of granularity of the measurement of particular emotional, cognitive and motivational processes during task performance is crucial for understanding their respective functions for ongoing cognitive performances (Azevedo, 2015). Accordingly, epistemic emotions must refer to knowledge or the generation of knowledge as experienced during the task (Pekrun et al., 2016). Complementary, measures of attentional and motivational processes must align with what actually occurred during reasoning about the problem (B. J. Zimmerman, 2008). Further, cognitive incongruities give rise to and shape epistemic emotions as appraised relative to task-specific competencies and values (Pekrun, 2006; Pekrun & Perry, 2014).

Accordingly, we aimed to examine the task-specific antecedents and effects of epistemic emotions, namely curiosity, enjoyment, surprise, confusion, anxiety, frustration, and boredom in an attempt to better describe the processes guiding complex reasoning (Pekrun et al., 2016). Pekrun´s (2006) control-value theory suggests that epistemic emotions arise as a function of different appraisal dimensions in relation to the cognitive activity. Therefore, we first investigated if cognitive evaluations of control and value apply are relevant appraisal processes giving rise to epistemic emotions (RQ 1). Further, the theory suggests that learning-related emotions have a modulating function, in that their effects might be mediated by cognitive or motivational mechanisms, which in turn determine the quality of performance. In line with this assumption, we examined the joint impact of epistemic emotions on cognitive and motivational processes, specifically by determining the motivation invested in and attention allocated onto the task, which in turn are thought to relate to performance of a complex reasoning task (RQ 2).

Last, the sequential nature of the CVT specifies a number of mediating processes during complex reasoning tasks. Accordingly, we investigated if epistemic emotions would mediate the relations between control and value appraisals and intrinsic motivation and attention and second, if intrinsic motivation and attention would mediate the relations between epistemic emotions and performance outcome on the complex reasoning task (RQ3) (for the full theoretical research model see Figure 3.1).

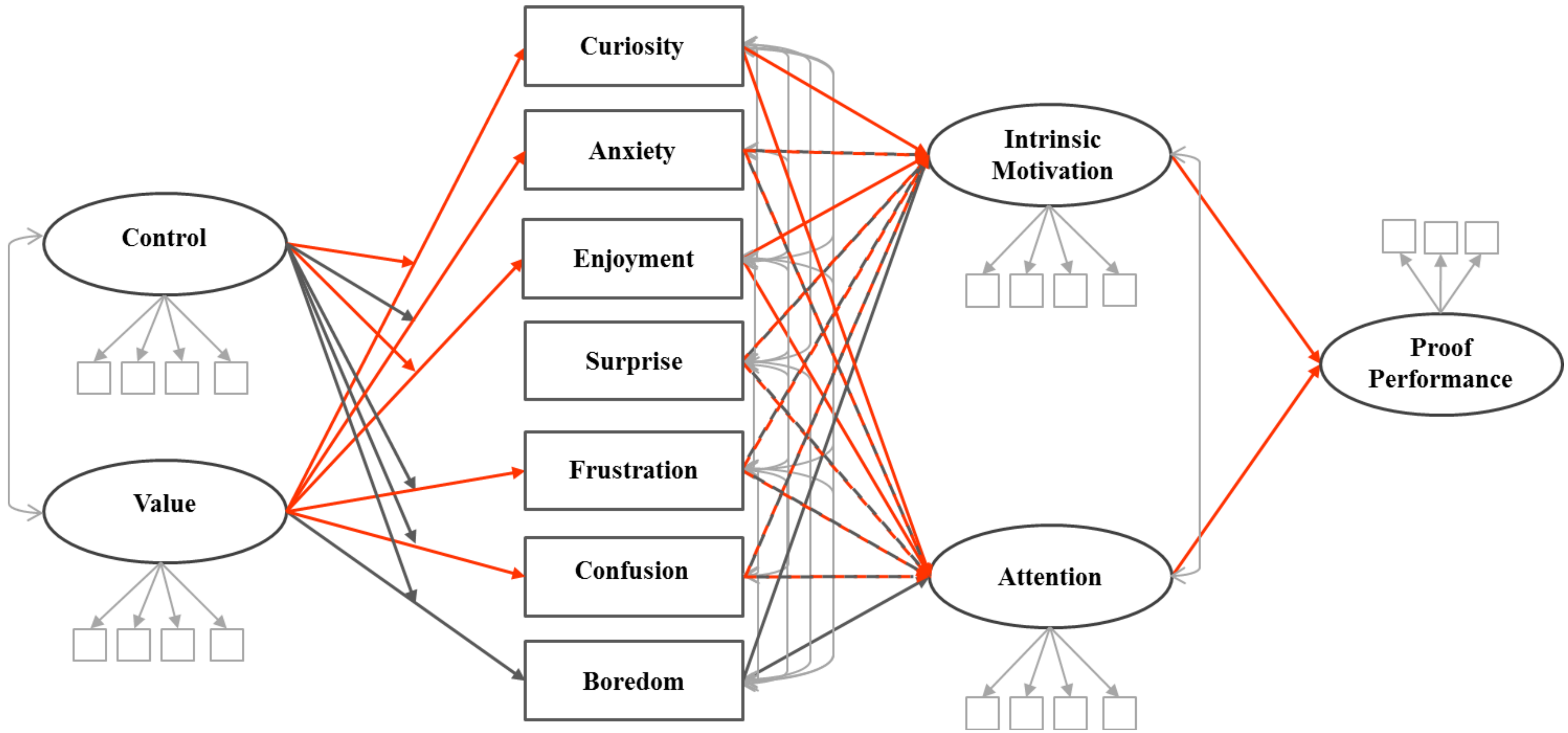


Figure 3.1: Theoretical Research Model (adapted from Pekrun & Perry, 2014; Pekrun, 2006) on the function of epistemic emotions during a complex proof task considering control and value appraisals as antecedents as well as intrinsic motivation and attention and the quality of performance on the proof task. Further, direct paths from appraisals to motivation and attention, as well as direct paths from epistemic emotions to performance were included in the model, but for clarity, excluded from the depiction. Please note that orange lines indicate positive effects, whereas grey lines denote negative effects. Multi-colored lines indirect that positive as well as negative effects might be expected.

Research Question 1. Control and Value Appraisals as Antecedents of Epistemic Emotions. The first aim of our study was to investigate whether appraisals of control and value are related to epistemic emotions experienced during a complex reasoning task in mathematics. Generally, we expected that the more task value is assigned to the complex mathematical problem, the more intensely will epistemic emotions be experienced. An exception to this is surprise which may be experienced without the need of any appraisal of the situation. Consistent with previous studies showing clear relations between discrete emotions and their control and value antecedents (Bieg et al., 2013; Frenzel, Pekrun, & Goetz, 2007; Frenzel, Thrash, Pekrun, & Goetz, 2007; Goetz et al., 2010), we hypothesized that positive appraisals of control and value should determine the intensity of the positive epistemic emotions curiosity and enjoyment elicited during problem solving. Regarding the postulated interaction between appraisals, we suggest that when students believe that the domain of the task they are dealing with has personal relevance and meaning for their lives (greater intrinsic or extrinsic value) while feeling moderate or high levels of control over the domain of the to-be-solved problem, relationships should be positive with positive epistemic emotions (enjoyment and curiosity), whereas relationships would be negative for negative epistemic emotions (confusion, anxiety, frustration, and boredom).

Research Question 2. Epistemic Emotions Effect Attention and Motivation. CVT specifies that epistemic emotions, as they occur during epistemic activities, do not directly affect performance but should modulate cognitive and motivational mechanisms which in turn, determine respective performance effects. While we expect uniformly positive effects of curiosity and enjoyment on attention and intrinsic motivation, negative effects would be expected for boredom. Relationships for negative-activating epistemic emotions have previously been found to be more complex. Epistemic emotions, such as confusion, frustration, or anxiety, are generally considered to be detrimental to student learning and performance since they reduce intrinsic motivation and foster task-irrelevant thinking by directing attention towards the object of emotions (Pekrun, 2006). However, confusion, frustration, or anxiety may also produce the opposite effect by strengthening student extrinsic motivation and getting students' to try harder and invest more effort in order to avoid future failure, therefore having a positive effect on performance (Pekrun et al., 2002). Similarly, surprise might exert positive effects on attentional processes but if a motivational function inheres this epistemic emotions, is unclear. In sum, relations of surprise, confusion, anxiety and frustration may both be positive and negative with attention and intrinsic motivation.

Research Question 3. Mediational Mechanisms of Epistemic Emotions as well as Attention and Motivation. In line with sequential suggestions made in CVT, several mediating mechanisms are postulated. Accordingly, we examined if (i) epistemic emotions mediate relations between control and value and motivational mechanisms, and second, if (ii) motivational and attentional mechanisms mediate relations between epistemic emotions and performance.

3.4 Method

3.4.1 Participants and Procedure

Eighty German university students (n = 80) were recruited from study programs in mathematics (M_{Semester} = 4.28, SD_{Semester} = 3.07). Students were on average 23 years of age (M = 22.91, SD = 4.54) and 33 participants were female (41.3%). In this computer based lab study, students solved a series of multiple choice questions regarding their knowledge in geometry theorems and received an exemplary proof task, with identical instructions to the experimental task, relative to which control and value appraisals were assessed. Immediately afterwards, students worked on the geometric proof task without a time limit. Upon completion of the task, students reported the intensity of epistemic emotions experienced while solving the task, as well as task-specific attention and motivation. Last, demographic information (gender, age, year of study) was assessed.

3.4.2 Materials and Measures

Descriptive statistics and reliabilities of measures are presented in Table 1. For all measures, higher scores reflect a higher endorsement of the corresponding construct.

Gender and Prior Knowledge as Covariates. In addition to the specified hypotheses, we considered that previous studies have consistently shown that female students typically report lower self-concepts in mathematics relative to male students (Hyde et al., 1990; Goetz et al., 2008, 2013). Further, prior knowledge in the domain under consideration has been found to influence performance (Sommerhoff, Ufer, & Kollar, 2015). Accordingly, gender (as assessed as part of the demographic information) and prior knowledge were included as covariates in the research model. Prior knowledge was assessed based on a series of multiple choice questions regarding knowledge of basic geometry theorems. One point for each correct answer was given, which resulted in a range of possible scores from 0 to 35 (M = 30.43, SD = ±3.72, Min. = 15, Max. = 35). All items met satisfactory item parameters with a difficulty index of $0.49 < P < 0.99$ (M (P) = .78; SD (P_i) = .11) as well as a discrimination index of $r_{j(t-j)} > 0.40$.

Value. Four items from Pekrun and Meier's (2014) Task Value Questionnaire (based on Eccles, Wigfield, Harold, & Blumenfeld, 1993) were used to measure student´s value attributed to the presented trial task (Eccles & Wigfield, 2002; Wigfield & Eccles, 1992, 2000). All items were adapted to meet the domain specific context of problem solving in geometry and measured attainment and utility values (extrinsic values). Attainment values pertain to the perceived importance of doing well (e.g., "I feel that, to me, learning more about problem solving in geometry is very important") while utility values relate to the value of academic engagement for obtaining outcomes, such as the usefulness for a future career (e.g., "Learning more about problem solving in geometry is useful for my life"). In order to avoid conceptual overlap with the epistemic emotion enjoyment, intrinsic task value, describing the enjoyment one gains when doing a cognitive task, was excluded from the value measure (e.g., "Generally, I enjoy solving geometric problems").

Control. As an indicator for academic control, we measured students' academic self-concepts. Four items were assessed as indicators for how good a student thinks he or she is in geometry, relative to the trial task, based on the Self-Description Questionnaire (for German version see Kunter et al., 2002; SDQ; Marsh, 1990; Marsh, Byrne, & Shavelson, 1988). The SDQ assesses self-concept as a trait construct involving habitual judgments of one's personal competence in a given domain and accordingly, items were adapted to meet the domain specific context of the task (e.g., "I am quite good in geometry").

Epistemic Emotions. Epistemic emotions that students experienced while solving the complex proof task were measured using the short version of the Epistemic Emotions Scales (EES; Pekrun et al., 2016). Each item consisted of a single word describing one emotion (e.g., curious, surprised, confused, anxious, frustrated, excited, bored) and were assessed as intensity ratings (1 = *not at all* to 5 = *very strong*).

Intrinsic Motivation. In order to measure situational motivation to perform the task, the intrinsic motivation subscale was employed from the Situational Motivation Scale (SIMS; Guay, Vallerand, & Blanchard, 2000). Intrinsic motivation assessed the degree to which a student reported to having solved the task in order to experience pleasure, satisfaction and mastery inherent in the activity (e.g., "Because I thought that this task was interesting"). All items were adjusted to fit the task specific context of geometry (Instruction: "Why [were] you engaged in this [task]?") and collected via self-report on 5-point Likert Scales (1 = *strongly* *disagree* to 5 = *strongly agree*) so that a higher score represents a stronger endorsement of the motivation scales.

Attention. As an indicator for the amount of cognitive resources allocated to the task, student's attention was assessed based on the utilization of internal resources to manage attention (Wild & Schiefele, 1994). In particular, the scale refers to the lack of concentration, distractibility and task-irrelevant thinking during the completion of the task. Participants responded to four items by using 1 (strongly disagree) to 5 (strongly agree) scales (e.g. "It was hard for me to stay focused during the task"). All items were reversed so that a higher score on the scale represent more attention allocated to the task.

Mathematical Proof Performance. Geometry is that part of school mathematics where students usually encounter proofs for the first time and accordingly, learn how to apply knowledge in order to prove mathematical theorems (Heinze, Anderson, & Reiss, 2004). The present proof task was developed based a geometric figure (see Figure 3.2) providing the frame which must be exploited for arguments belonging to a set of defined theorems concerning this problem space (Boero, 1999; Klahr & Dunbar, 1988) and based on which the proof must be formulated [Task: Proof that ∢BEF = ∢BFE is true].

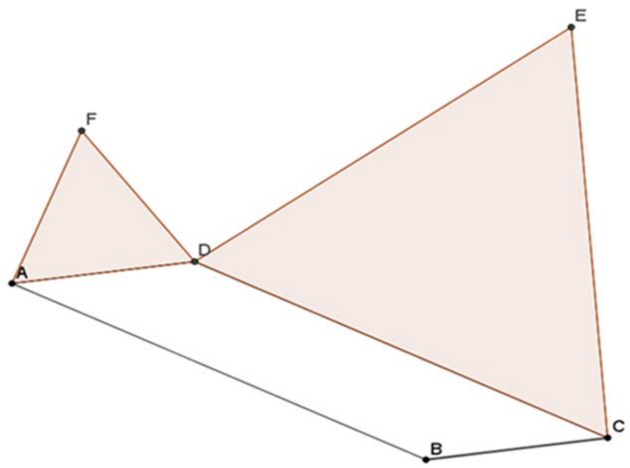


Figure 3.2: Geometric Figure: Parallelogram with two equilateral triangles.

A coding scheme was developed based on which all data were double coded by two independent raters resulting in a high interrater agreement (ICC = 0.83, Cohen's Kappa (*k*) ranged from .74 to 0.96, *M* = .83, *SD* = .11) indicating overall a very good reliability of the coding scheme (see Appendix C for coding scheme). Based on these rated variables the following three measures were computed: 1) the number of arguments logically constructed to formulate the proof (based on premises and conclusions); 2) the number of arguments to which a mathematical justification had been added (i.e., a direct reference to a mathematical theory); and 3) the quality of those arguments (i.e., integration of arguments). Participants took on average 23 minutes ($M = 23.67$, $SD = 11.00$) to solve the proof task.

3.5 Rationale for Analytic Approach

3.5.1 Preliminary Analyses

First, the intensities of frequencies of specific epistemic emotions as experienced during the complex reasoning task were outlined in Figure 3.3. For investigating whether control moderated relations between value and epistemic emotions (Hypothesis 1), multiple linear regression analyses were conducted using SPSS Version 24. Each epistemic emotion served as a dependent variable predicted by control, value and their respective product terms to test interaction effects (Aiken, West, & Reno, 1991). In constructing the product term, the product of individual (z-scored) standardized (i.e., mean-centered) variables was used. A significant C x V interaction would indicate that control and value combine multiplicatively in predicting epistemic emotions. In preparing the main analysis as presented in the theoretical research model (see Figure 3.1), confirmatory factor analysis (CFA), performed with M*plus* (Muthén & Muthén, 2013), were used to test the psychometric properties of, and relationships between, appraisals, epistemic emotions, motivation and attention, as well as performance.

3.5.2 Main Analyses

Structural equation modelling (SEM), performed with M*plus* (Muthén & Muthén, 2013) was used to test the overall model representing a sequential analysis of the mechanisms determining the rise and effects of epistemic emotions consistent with the theoretical considerations from CVT (for a similar sequence of variables, see, e.g. (Muis, Psaradellis, et al., 2015). Specifically, we modeled control and value appraisals as cognitive antecedents to epistemic emotions, while in turn, epistemic emotions predicted intrinsic motivation and attention, which in turn predicted task specific performance. The seven epistemic emotions as well as control variables (gender and prior knowledge) were treated as single indicator latent variables with perfect measurement ($\lambda = 1$, $\varepsilon = 0$). Measurement models were built for appraisals, motivation, attention and performance. Covariates were included in the model by directional paths to all constructs in the model (see Figure 3.1).

To estimate the model parameters, the robust maximum likelihood estimator (MLR) was employed, accounting for non-normality of the observed variables and the ordinal nature of the scales with which all continuous variables were assessed. To evaluate the fit of the models we investigated both absolute and incremental fit indices, including the comparative fit index (CFI), the Tucker–Lewis index (TLI), the root-mean-square error of approximation (RMSEA), and the standardized root-mean-square residual (SRMR). Despite debates on cut-off values (Heene, Hilbert, Draxler, Ziegler, & Bühner, 2011; Lance, Butts, & Michels, 2006; Marsh, Hau, & Wen, 2004), adequate and excellent fit of data, respectively, are typically considered in the following range: (a) CFI and TLI > .90 and ≥ .95, respectively (Marsh, Hau, & Grayson, 2005; Marsh et al., 2004), and (b) RMSEA and SRMR < 0.08 and ≤.06, respectively (Hu & Bentler, 1999; MacCallum, Browne, & Sugawara, 1996). We adopted recommendations by Trautwein and colleagues (2012) that at least two of these criteria should be met to consider a model to have a reasonably good fit to the observed data.

Last, indirect paths were examined based on a percentile bootstrapping method based on 10,000 resamples by creating 95% confidence intervals around the estimate of the indirect effect (Hayes, 2013). Confidence intervals that cross zero indicate a statistically significant indirect effect.

3.6 Results

3.6.1 Preliminary Analyses

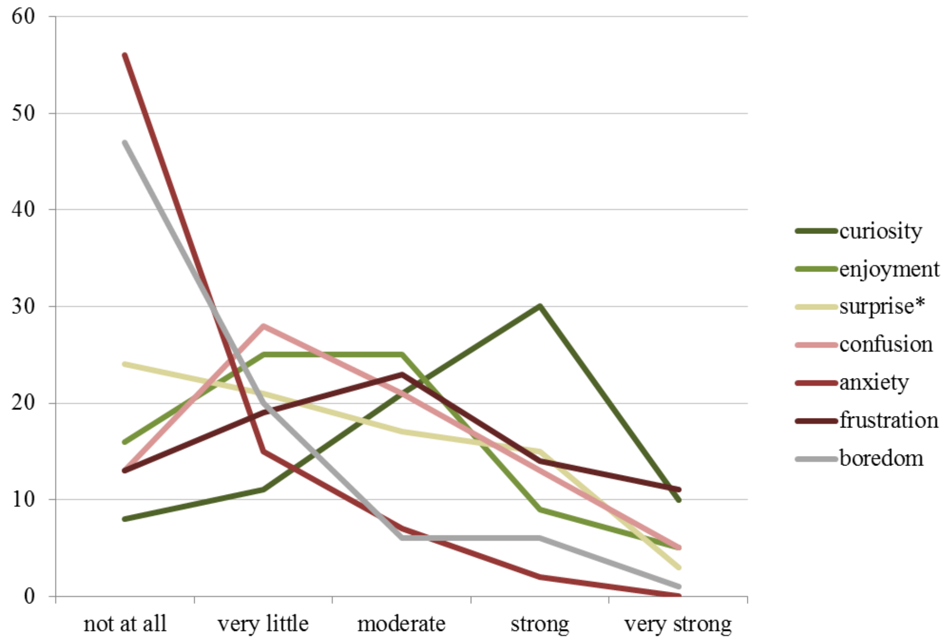
Analyses to determine psychometric properties (see Table 3.1) showed a relatively symmetrical distribution (skewness and kurtosis ranged from -1.00 to 2.25), the exception being anxiety and boredom scale which were positively skewed.

Table 3.1: Psychometric properties of appraisal, epistemic emotion, motivation and attention and performance scales.

	No. items	*M*	*SD*	*α*	*Mean* $r_{j(t-j)}^{a}$	*Possible range*	*Observed range*	*Skewness*	*Kurtosis*	*N (listwise)*
Control	4	3.96	.67	.81	.64	1-5	2.25 - 5	-.46	-.28	80
Value	4	3.14	.89	.88	.75	1-5	1-5	.08	-.63	80
Curiosity	1	3.29	1.16	-	-	1-5	1-5	-.49	-.53	80
Surprise	1	2.40	1.21	-	-	1-5	1-5	.37	-1.00	80
Confusion	1	2.61	1.13	-	-	1-5	1-5	.39	-.59	80
Anxiety	1	1.44	.76	-	-	1-5	1-4	1.72	2.25	80
Frustration	1	2.89	1.27	-	-	1-5	1-5	.14	-.95	80
Enjoyment	1	2.53	1.13	-	-	1-5	1-5	.43	-.39	80
Boredom	1	1.68	.99	-	-	1-5	1-5	1.50	1.50	80
Intrinsic Motivation	4	3.02	.99	.81	.64	1-5	1-5	.05	-.40	80
Attention	4	3.64	1.10	.95	.88	1-5	1-5	-.47	-.83	80
Performance (Z-scores)	3	.00	.92	.94	.85	-	-.96 – 2.36	1.06	-.00	80

Note. [a] Mean of corrected item-total correlations.

Complementary, frequencies of the intensities of epistemic emotions are depicted in Figure 3.3.



Note. *Surprise can be classified as either a positive or a negative activating epistemic emotion.

Figure 3.3: Intensities of epistemic emotions during the complex reasoning task : distribution of intensities of positive activating emotions (curiosity, enjoyment, surprise), negative activating emotions (confusion, anxiety, frustration) and negative deactivating emotion (boredom) during a proof task in mathematics.

Here, the broad range of reported curiosity, enjoyment, surprise, confusion and frustration indicate relatively high levels of variation in the intensities of these emotions across students. Boredom and anxiety were the least intensely experienced emotions (more than 80% of students reported to not have experienced either emotion at all or only very little) and curiosity was the most intensely reported epistemic emotion with more than 75% of students indicating moderate to very intense occurrence of this positive-activating emotion.

We verified the reliability for each scale by calculating Cronbach´s alpha coefficients indicating a very high degree of internal reliability within all measures (Cronbach's α .81 - .95). Further, findings show that scale items had good part whole corrected item total correlations for all scales, with none of the correlations falling short of the .6 threshold. Additionally, confirmatory factor analyses revealed adequate fit for all scales (see Table 3.2) and factor loadings were all satisfactory (λ > .58).

Table 3.2: Component structure of all latent measures by confirmatory factor analysis

Scales	χ^2	*df*	CFI	TLI	RMSEA	90% CI_{RMSEA}	SRMR	Factor Loadings
Control	2.28	2	1.00	1.00	.04	[.000, .230]	.02	.58 – .81
Value	1.91	2	1.00	1.00	.00	[.000, .218]	.01	.72 – .88
Intrinsic Motivation	4.03	2	.98	.95	.11	[.000, .273]	.03	.64 – .96
Attention	.86	2	1.00	1.00	.00	[.000, .173]	.01	.87 – .94
Performance (Z-scores)	.00	0	1.00	1.00	1.00	[.000, .00]	.00	.86 – .99

Note. χ^2= chi-square (Fit of Baseline Model); df = degrees of freedom; CFI = comparative fit index; TLI =; RMSEA = root-mean-square error of approximation, SRMR = the standardized-root-mean residual; CI = confidence interval.

No gender differences were found between value appraisals, epistemic emotions, intrinsic motivation or attention, prior knowledge, nor performance outcome (all $p > .10$). However, females reported to have a lower academic self-concept relative to their male peers (t (76) = -2.89, p =.005, ΔM = -.43, $CI_{95\%}$ [-.721, -.133]) and consequently, gender was included as a covariate on academic self-concept.

3.6.2 Multiple Regression Analysis

The multiple regression findings for each emotion model are presented in Table 3.3. The seven models assessed show the effects of control and value as appraisal antecedents on the emotions of curiosity, enjoyment, surprise, confusion, anxiety, frustration and boredom. Control and value had significant positive effects on curiosity (β = .26/.53 for control/value; $p < .01$). These main effects on curiosity were further qualified by a control x value interaction (β = .20; p = .05). Control and value also showed significant positive effects on enjoyment (β = .36/.26 for control/value; $p < .01$). While surprise was positively predicted by value (β = .27; $p < .01$) boredom was negatively predicted (β = -.27; $p < .01$). Furthermore, control and value showed negative effects on confusion (β = -.25, p = .03/β = -.19, p = .09 for control/value). However, as only one significant moderated effect was found, all appraisal effects were modeled as main effects onto the epistemic emotions in the structural equation model.

Table 3.3: Results of multiple linear regression analyses predicting epistemic emotions by control, value and their interaction

		B	SE_B	β
Curiosity	Control	.30	.12	.26**
	Value	.62	.11	.53***
	Control x Value	.22	.11	.20*
	R^2		.32	
Enjoyment	Control	.41	.12	.36***
	Value	.29	.12	.26*
	Control x Value	.15	.12	.14
	R^2		.18	
Surprise	Control	-.14	.14	-.12
	Value	.32	.14	.27**
	Control x Value	.05	.14	.05
	R^2		.09°	
Confusion	Control	-.28	.13	-.25*
	Value	-.21	.13	-.19°
	Control x Value	.03	.13	.03
	R^2		.10	
Anxiety	Control	-.03	.09	-.04
	Value	.11	.09	.15
	Control x Value	.05	.09	.07
	R^2		-	
Frustration	Control	-.22	.15	-.18
	Value	.03	.15	.03
	Control x Value	.01	.15	.01
	R^2		-	
Boredom	Control	-.07	.11	-.07
	Value	-.27	.11	-.27**
	Control x Value	-.14	.11	-.15
	R^2		.08°	

Note. All outcome and predictor variables were standardized (z scored). In constructing the product term for determining the interaction effect, the product of the individual (z scored) standardized variables was used. The product terms were not re-standardized. B is the unstandardized and β is the standardized coefficient. R^2 is only reported for significant (p <.05) models (ANOVA). *p <.05, **p <.01, ***p <.001, ° p < .09.

3.6.3 Correlating Latent Constructs

As recommended before testing a structural model (Schreiber, 2008), standardized latent bivariate correlations were calculated and are shown in Table 3.4. Academic self-concept and value were unrelated (r = -.05, p = .72) indicating that both constructs seems to exert rather independent effects on epistemic emotions, thus supporting the findings from regression models.

The epistemic emotions were related in the expected directions, for example, positive activating emotions (curiosity and enjoyment) were positively correlated (r = .61, p < .001) while boredom, a negative deactivating emotion, showed a strong negative relationship to curiosity (r = -.48, p < .001) as well as excitement (r = -.40, p < .010). Negative-activating emotions were less consistently, but uniformly negatively, correlated with positive-activating emotions. For example, frustration was negatively related to excitement (r = -.25, p = .020). Additionally, confusion was negatively related to excitement (r = - .26, p = .022) and curiosity (r = - .25, p = .030). Surprise, an activating emotions that can either be positive or negative, was positively related to curiosity (r = .26, p = .012) but also positively related to confusion (r = .29, p = .008). Boredom, the only negative deactivating emotion, was unrelated to all negative-activating emotions (r < .11, p > .268). While frustration was positively related with confusion and anxiety ($r_{confusion}$ = .48, p < .001/ $r_{anxiety}$ = .21, p = .026), confusion and anxiety were unrelated (r = .20, p = .10).

Intrinsic motivation was strongly related to positive activating emotions (r > .74, p < .001) and negatively related to boredom as well as confusion (r < -.35, p > .002). A rather similar pattern emerged for attention, with positive relations with positive activating emotions (r > .34, p < .007) and negative relations with boredom as well as confusion (r < -.33, p < .006) while additionally a strong negatively relationship was found with frustration (r = -.43, p = .001). Intrinsic motivation and attention were positively correlated (r = .47, p < .001) both of which were positively related to task performance (r > .41, p < .001). Prior knowledge was positively related to task performance (r = .31, p = .005) and consequently its influence as a confounding variable was included to account for the variance in the performance outcome.

The time students spent with solving the complex reasoning task was unrelated to task performance (r = .02, p = .894) as well as all other measures except for a marginally negative relation with enjoyment (r = -.19, p = .052).

Table 3.4: Standardized latent bivariate correlations between all Appraisals, Epistemic Emotions, Motivational and Cognitive Mechanisms and Performance.

	1	2	3	4	5	6	7	8	9	10	11	12
Appraisals												
1. Control	-											
2. Value	-.05	-										
Epistemic Emotions												
3. Curiosity	.19	.51***	-									
4. Surprise	-.17	.27**	.26**	-								
5. Confusion	-.28*	-.20	-.25**	.29**	-							
6. Anxiety	-.12	.14	-.02	.15	.20	-						
7. Frustration	-.18	.03	-.12	.21*	.48***	.21*	-					
8. Enjoyment	.31**	.23*	.61***	.12	-.26**	.07	-.25*	-				
9. Boredom	.02	-.26**	-.48***	-.12	.11	-.10	-.02	-.40***	-			
Motivational and Cognitive Mechanisms												
10. Intrinsic Motivation	.20	.44***	.79***	.10	-.35**	.12	-.17	.74***	-.49***	-		
11. Attention	.35**	-.06	.34**	-.03	-.33**	.00	-.43***	.54***	-.36*	.47***	-	
Performance related												
12. Task Performance	.26*	.01	.18	.11	-.20	-.02	-.27**	.30**	-.22*	.41***	.44***	-
13. Prior Knowledge	.13	.14	.17	.18	-.10	.05	-.04	.20	-.04	.26*	.11	.31**
14. Time on Task	.21	.04	-.11	.05	-.16	-.08	-.08	-.19*	.12	-.17	.07	.02

Note. * $p < .05$. ** $p < .01$. *** $p < .001$.

3.6.4 Structural Equation Analysis

By the above mentioned model fit criteria the overall model showed a good fit to the data: $\chi^2(267) = 353.73$, $p <.001$; RMSEA = .06 with 90% Confidence Interval [.044, .081], SRMR = .08; CFI = .93, and TLI = .91. Concerning the direction of the observed relationships, the specific beta coefficients, estimated using the STDYX command in M*plus*, are shown in Table 3.4.

The hypothesized model includes linkages between appraisals and epistemic emotions. For example, curiosity and enjoyment were positively predicted by control ($\beta_{curiosity} = .22$, $p = .052$; $\beta_{enjoyment} = .33$, $p = .004$) and value ($\beta_{curiosity} = .52$, $p < .001$; $\beta_{enjoyment} = .25$, $p = .037$). Further, value was a positive predicator for surprise ($\beta = .26$, $p = .024$) and a negative predictor for boredom ($\beta = -.26$, $p = .015$). Moreover, confusion was negatively predicted by control ($\beta = -.29$, $p < .01$) and approached a significant negative relationship with value ($\beta = -.21$, $p = .072$). Anxiety and frustration were unrelated to both appraisals included in the model.

With regard to outcomes of epistemic emotions, we found significant direct effects of curiosity ($\beta = .49$, $p < .001$) and excitement ($\beta = .38$, $p = .004$) on intrinsic motivation; while, in turn, attention was predicted by frustration ($\beta = -.29$, $p = .007$), excitement ($\beta = .29$, $p = .016$) as well as boredom ($\beta = -.26$, $p = .014$). Surprise, confusion and anxiety did not predict either intrinsic motivation or attention ($r < .12$, $p > .118$). Last, performance was positively predicted by intrinsic motivation ($\beta = .64$, $p =.050$) and attention ($\beta = .28$, $p = .007$).

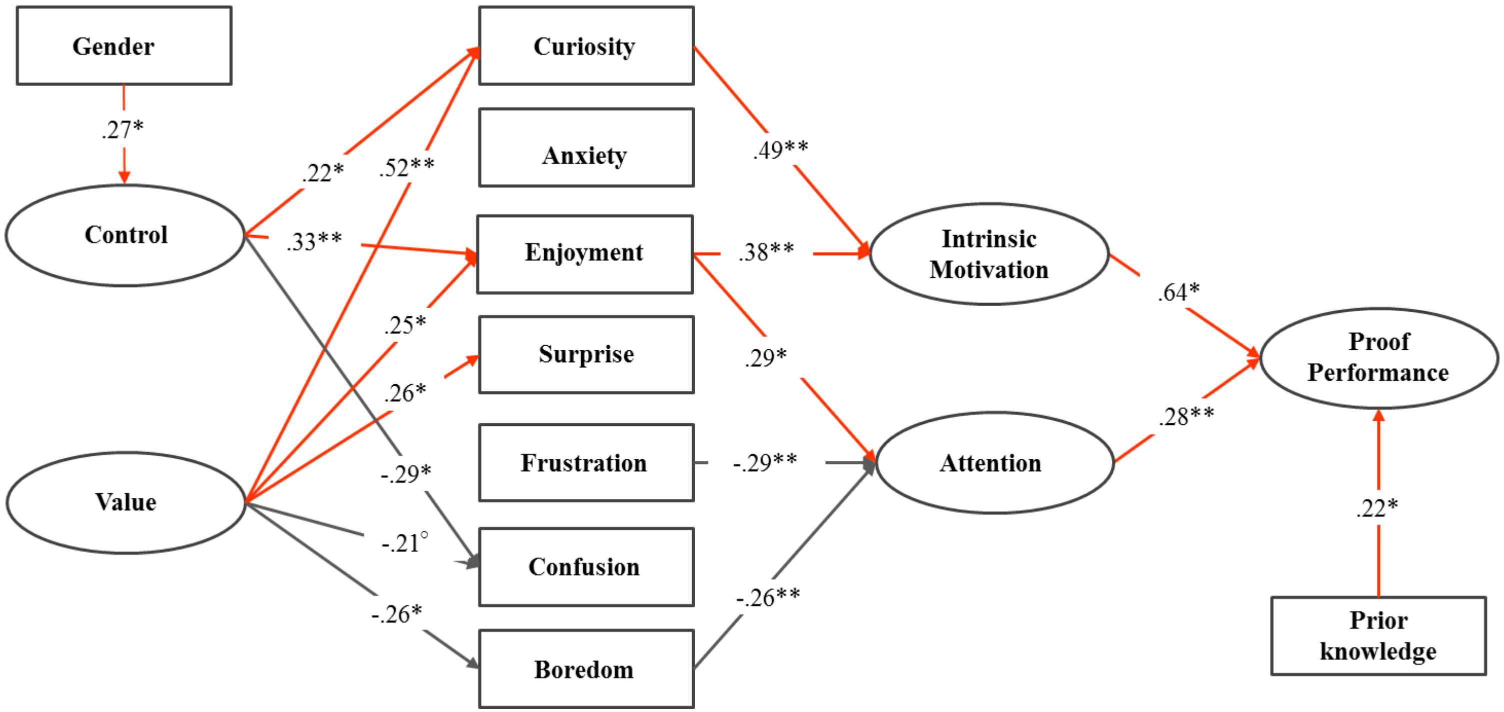


Figure 3.4: Standardized coefficients and statistically significant paths in the SEM (for clarity direct paths from appraisals to motivational and cognitive mechanisms and from epistemic emotions to proof performance were omitted). All coefficients are statistically significant at **p < .01 and *p < .04 except °p = .08.

3.6.5 Estimates of Indirect (Mediated) Paths

Indirect paths were examined at two stages of the model: (i) Appraisals to intrinsic motivation and attention via the mediating role of epistemic emotions, and (ii) from epistemic emotions to performance, via the mediating role intrinsic motivation and attention. The total indirect paths from appraisals to motivational and cognitive mechanisms, revealed that epistemic emotions mediated relations from control to motivation, $\beta = .26$, $SE = .10$, 95% CI [.122, 1.288]. The total indirect effect from value to motivation via the mediating role of epistemic emotions was also significant, $\beta = .40$, $SE = .10$, 95% CI [.205, .859]. Indirect paths from control to attention via the mediating role of epistemic emotions, $\beta = .17$, $SE = .08$, 95% CI [.050, 1.352], and value to attention via the mediating role of epistemic emotions, $\beta = .22$, $SE = .12$, 95% CI [.029, 1.015] were also statistically significant.

Additionally, (ii) indirect effects from epistemic emotions to performance, via the mediation role of attention and motivation, revealed effects only for positive-activating emotions. Specifically, the total standardized indirect effect of enjoyment on performance was mediated by intrinsic motivation and attention ($\beta = .33$, $SE = .18$, $p = .062$, $CI_{95\%}$ [.019, 3.250]), whereas the total standardized indirect effect of curiosity on performance approached significance ($b = .33$, $SE = .18$, $p = .068$, 95% CI [-.028, 4.828]).

Overall, the specified model explained 36.3% of proof performance, 76.7% of intrinsic motivation, and 50.6% of attention during the proof task.

3.7 Discussion

The present research aligns with a recent emphasis on understanding how affective, cognitive and motivational processes interact during reasoning and learning to consequently impact performance (Ainley, Corrigan, & Richardson, 2005; Buff, Reusser, Rakoczy, & Pauli, 2011; Frenzel, Pekrun, & Goetz, 2007; Huk & Ludwigs, 2009; Jarvenoja & Jarvela, 2005; Pekrun, 2006). Therefore, this research addressed a largely unexplored field in empirical educational research, namely antecedents and effects of students' task-specific epistemic emotions while solving a complex reasoning task in mathematics. For the first time, some of the key theoretical propositions outlined in Pekrun's model (2006) were applied to investigate the antecedents and effects of epistemic emotions simultaneously during an epistemic activity. More specifically, the present study explored the interplay between appraisal constellations, epistemic emotions, attention and intrinsic motivation in predicting the quality of proof performance.

3.7.1 Control and Value as Antecedents of Epistemic Emotions

The first research question was based on CVTs' assumptions that control and value are antecedents to epistemic emotions. These cognitions are thought to play a decisive role in appraising the cognitive incongruities as elicited during complex tasks. Findings were most in line with our theoretical assumptions regarding the experience of curiosity. We found that the interaction between control and value was a strong predictor for the experience of this positive activating epistemic emotion while working on the complex mathematical task. Here, we want to highlight that this appraisal interaction predicted curiosity above and beyond controlling for the respective conditional effects of control and value. This result indicates an added multiplicative impact of appraisals on curiosity consistent with classical appraisal theories (Ellsworth & Scherer, 2003; Shuman & Scherer, 2014).

While an interaction of control and value in predicting curiosity has been suggested in the literature numerous times (Brun et al., 2008; Grossnickle, 2016), it has, to our knowledge, never been presented (see for insignificant interaction effect Muis, Psaradellis, et al., 2015). A recent study providing similar findings of everyday positive emotions suggested that such an interaction effect might be interpreted in two ways (Goetz et al., 2010). First, a students' perceived control over the mathematical task may have contributed to the experience of curiosity, if the cognitive activity was of rather high importance. Alternatively, this interaction could also suggest that students' perceived value over the mathematical activity may have a larger impact on the experience of curiosity when students felt competent (high control) as compared to unqualified in solving the task (low control). These interpretations are in line with the theoretical assumptions that postulate moderating effects of control on value appraisals in the experience of epistemic emotions (Pekrun & Perry, 2014).

In addition to this interaction effect, our results suggest that the relation between appraisals and emotional experiences, in relation to a complex mathematical task, can be understood in terms of the relative unique contributions of appraisal mechanisms in explaining the rise of epistemic emotions. With respect to the unique contribution of perceived control appraisals, we found, in line with our hypotheses, positive relations with enjoyment (in addition to curiosity) and a negative relation with confusion. This means that the more students perceived the task as controllable, the more curiosity and enjoyment was experienced and the less likely students experienced confusion while working on the task. These results do not only support theoretical assumptions from CVT for the under-researched group of epistemic emotions, but are also consistent with previous research investigating antecedents of epistemic confusion (Muis, Psaradellis, et al., 2015) as well as enjoyment (Ahmed, Werf, Minnaert, & Kuyper, 2010; Artino & Jones, 2012; Buff, 2014; Buff et al., 2011). These results provide empirical support for perceived control as a critical antecedent of epistemic emotions during a complex reasoning task. This further implies that enhancing perceptions of personal control during complex reasoning and problem solving may be an effective way in which adaptive emotional experiences can be fostered (Bieg et al., 2013; Goetz et al., 2010).

Additionally, all positive emotions, namely enjoyment and surprise (in addition to curiosity) were positively related to perceptions of value. Further, boredom was negatively related to greater value. These results suggest that students tended to experience more positive activating emotions and less boredom while working on the complex mathematical task when they considered the task to be important. Thus, our findings have critical implications from an educational perspective as adaptive emotional experiences during complex tasks can be modulated by making the personal relevance of such tasks, or learning activities more generally, salient to students. This might be of most critical importance to scientific practices in STEM disciplines as here cognitive incongruity is prevailing by definition, while at the same time scientific knowledge and understanding have been described as one of the most important educational outcome in the 21st century (Ibrahim, Aulls, & Shore, 2016; Trilling & Fadel, 2009).

3.7.2 Consequences of Epistemic Emotions on Attention and Intrinsic Motivation

Our second research question addressed the consequences of epistemic emotions during the complex mathematical task, and whether emotions were predictive of attentional and motivational processes during task completion. The findings corroborate that different discrete epistemic emotions relate to different mechanisms determining the process of complex reasoning. When controlling for the influence of control and value appraisals, curiosity and enjoyment were related to intrinsic motivation, and additionally enjoyment, frustration and boredom correlated with attention directed towards the task while solving the problem.

In line with our predictions and previous research suggesting that curiosity is an emotional-motivational state (Kashdan & Roberts, 2004; Litman et al., 2005), curiosity was found to be a positive predictor of intrinsic motivation. We interpret these results to suggest that, in the face of a complex task, students experiencing curiosity will more likely be intrinsically motivated to resolve discrepancies in their cognitive incongruities. This finding is of great importance for fundamental research as it might stimulate experimental research to untangle the feeling component of the epistemic emotion from “the intrinsic desire to seek out and acquire new information” (Litman, 2010, p. 397). The present findings indicate that curiosity and motivational drives might not be a unitary construct per se (Grossnickle, 2016). Instead, our findings allow the suggestion that curiosity might be an indicator of intrinsic motivation (Hidi & Harackiewicz, 2000; Schiefele, 2009; S. A. Turner & Silvia, 2006). However, this finding must be interpreted with caution as the correlational nature of our data does not allow detecting causal effects. Moreover, reciprocal mechanisms between curiosity and intrinsic motivation are also plausible by means of regulatory functions between curiosity and intrinsic motivation (Hidi & Renninger, 2006).

Similarly, enjoyment and intrinsic motivation were also closely associated, however less strongly than curiosity and intrinsic motivation. Hence, this finding suggests that students, who experienced enjoyment, while working on the complex mathematical task, were also likely to experience intrinsic motivation. This result mirrors findings from a recent study that, based on PISA data, reports strong positive relations between enjoyment and interest in learning about science across several countries (Ainley 2011). Importantly, the present findings additionally suggest a cognitive function of enjoyment in focusing attention to the object of learning, namely the cognitive task. This closely mirrors definitions of enjoyment of learning as this positive activating emotion is ought to involve thoughts and cognitions concerning the process of working on the concurrent achievement activity (Pekrun et al., 2002a). Respectively, positive emotions have been found to stimulate learners to invest more mental effort in a learning task (Efklides, Kourkoulou, Mitsiou, & Ziliaskopoulou, 2006). This dual relation of enjoyment with cognitive as well as motivational mechanisms during complex reasoning does not only set this epistemic emotion apart from curiosity, but explains the indirect effect of enjoyment on task specific performance as mediated by intrinsic motivation and attention. This finding in particular suggests that an important aspect of students’ engagement with complex mathematical problems is the mix of enjoyment, intrinsic motivation in addition to the focused attention on the task (Ainley & Hidi, 2014). Therefore, these results point to the importance of both, motivational and cognitive components of learning and problem solving and the maintenance of enjoyment during complex cognitive endeavors.

Unexpectedly, surprise was unrelated to neither attention nor intrinsic motivation. However, our findings indicate that the quality of surprise may be most important with respect to its function as a prototypical epistemic emotion (Brun et al., 2008; Morton, 2010).

Indeed, surprise was most strongly and positively correlated with the only other prototypical epistemic emotions, namely curiosity and confusion. In terms of temporal dynamics, it has been suggested that the first emotional reaction to an unexpected event is surprise (Scherer, 2001). This is in line with neuropsychological evidence (Baranes et al., 2015), describing surprise as a reactive process only. Possibly, surprise may act as a gateway which, upon encountering novelty, elicits more epistemic emotions that have functions of further "dealing with" the detected information depending on appraisal constellations, such as curiosity or confusion.

For confusion, the null effects on attention and intrinsic motivation found in our study may indicate that some students successfully resolved their confusion, while others may have been unsuccessful in the attempt. This is consistent with the notion that confusion may only be beneficial to complex problem solving if the confusion is resolved (D'Mello et al., 2014). Otherwise, confusion has been found to have harmful consequences for the quality of learning (Muis, Psaradellis, et al., 2015). Consequently, it may be important to distinguish adaptive from maladaptive confusion (D'Mello et al., 2014).

Consistent with predictions, frustration was a negative predictor of attentional processes. This is a novel finding as studies have generally neglected investigating negative activating emotions beyond anxiety (Pekrun & Stephens, 2012). Frustration has been described to arise when goals are repeatedly blocked and therefore it does not seem possible to overcome the respective obstacle (D'Mello & Graesser, 2012). In line with this, the present finding might suggest that students who experienced frustration, supposedly upon repeatedly running into impasses, produced goal-irrelevant thinking, thus reducing the cognitive resources available for the task (Pekrun & Stephens, 2012). Our finding might help to better explain the underlying cognitive mechanisms from a previous study that has found frustration to be a negative predictor for meta-cognition and self-regulated learning (Artino & Stephens, 2009). In sum, our finding is in line with previous suggestions indicating that frustration must be overcome in order to result in learning gains (Graesser & D'Mello, 2012).

For anxiety, we had hypothesized similarly negative consequences as for frustration. However, anxiety was found to be unrelated to both attention and intrinsic motivation. Possibly, the little variance in the intensity of the experience of anxiety may explain this null finding. Upon speculation, it is possible that the little variance in anxiety stems from students' misinterpreting anxiety as an achievement emotion, rather than describing the experience of severe cognitive incongruities during task completion (Pekrun & Stephens, 2012). Students were aware that solving the complex task was part of an empirical investigation, and as such knew that achievement evaluations, addressing their competence, were not to be expected, thus explaining the little variance.

Last, and consistent with our prediction, previous research (Eren & Coskun, 2016; Pekrun, Hall, Goetz, & Perry, 2014; Tze et al., 2016), and suggestions from CVT, boredom was a negative predictor of attention. Our finding closely mirrors the observation that the experience of boredom hinders efforts “to maintain or return attention to the activity” (Fisherl, 1993, p. 3). Especially since attention was found to be a positive predictor of students’ performance on the complex mathematical task, boredom is clearly detrimental to performance, particularly in light of complex learning activities.

3.7.3 Mediational Mechanism in the Process of Solving the Complex Task

Beyond investigating these separate paths, the purpose of this study was to test a theoretical model linking appraisals, emotions, attention, and intrinsic motivation to performance. According to the CVT, students’ epistemic emotions are thought to arise based on task specific control and value appraisals, and in turn posited to influence their attention and their motivation, which in turn affect performance. Therefore, we examined these mediational mechanisms and investigated if epistemic emotions mediated the relations between control and value appraisals and intrinsic motivation and attention and second, if intrinsic motivation and attention mediated the relations between epistemic emotions and performance outcome on the complex reasoning task. Our findings supported these theoretical suggestions and revealed epistemic emotions as critical mediators between appraisal mechanisms and attention and intrinsic motivation. Further, attention and intrinsic motivation mediated the effects of enjoyment on performance. Therefore, enjoyment is not sufficient for high quality performance by itself, since attention and intrinsic motivation are also necessary. This implies that the influence of emotions on the process of learning and ultimately performance is inevitably complex and requires more research to provide greater understanding of how emotions shape students’ learning. Generally, however, the CVT seems to provide a research framework applicable for further investigating epistemic emotions.

3.7.4 Limitations and Directions for Future Research

The present study contributes to better understanding of the process by which emotion, cognition and motivation together shape and contribute to the quality of task performance. Nonetheless, research findings need to be interpreted in light of study limitations. Although the research model of the antecedents and effects of epistemic emotions was derived from theory and supported by previous research, causal conclusions cannot be confirmed from cross-sectional data. While appraisals indeed where assessed in line with suggested temporal dynamics during learning, namely as antecedents to epistemic emotions relative to an example task, it is nonetheless important to note that a causal interpretation explaining of the antecedents and effects of surprise, curiosity, enjoyment, surprise, confusion, anxiety, frustration and boredom is not possible due to the correlational nature of path analyses. The findings of the present study do, however, suggest that specific appraisal constellations might cause discrete epistemic emotions, which in turn may have causal effects on cognitive and motivational mechanisms during learning. Therefore, future studies should manipulate this sequential order as part of experimental manipulations to more closely examine the causal directions connecting epistemic emotions with cognitive, motivational or behavioral variables during learning.

Second, the results show the influence of emotions on facets of possible processes that influence learning and reasoning. In particular, our findings highlight functions of positive and negative epistemic emotions on attention and intrinsic motivation. However, as suggested by the CVT, a number of other variables might also operate while working on complex tasks, such as goal settings and metacognitive-regulation (Azevedo et al., 2013; Järvenoja, Järvelä, & Malmberg, 2015), activity or domain specific learning strategies (Malmberg, Järvelä, & Kirschner, 2014), as well as effort and task engagement (Azevedo, 2015; Wang, Fredricks, Ye, Hofkens, & Linn, 2016). Assessing such productive mechanisms might provide an even more fine-grained picture on the function of discrete emotions during complex reasoning. In addition, it might be equally important to simultaneously assess potentially maladaptive processes that occur during complex reasoning such as amotivation, disruptive strategies or approaches to the problem that were rendered to be unsuccessful. For such purposes, think aloud methods might be a means to capture such fluid-mechanisms (see for examples A. M. Johnson, Azevedo, & D'Mello, 2011; Muis, Psaradellis, et al., 2015).

Third, for the purpose of parsimony, the current study examined how appraisals predicted emotions and how emotions, in turn, predicted attention and intrinsic motivation. However, consistent with the theoretical assumption of reciprocal causation (Pekrun, 2016; Pekrun et al., 2002a; Pekrun & Perry, 2014), emotions are conceived to be dynamically emerging and dissolving over time with recurring appraisals of unique characteristics of learning situations (for a more detailed discussion see chapter 5). While a cross-sectional snapshot of the functional importance of epistemic emotions during a complex reasoning task is a critical first step, future studies may want to acknowledge the continuous and quick changes in appraisals which constantly fluctuate throughout task completion, which might better account for emotional dynamics during learning (D'Mello & Graesser, 2012; Graesser & D'Mello, 2012). Here, an important aspect to consider might be to assess appraisals specific to situational difficulties encountered during reasoning (e.g. impasses or cognitive incongruities). Just as self-regulatory processes vary as learning progresses (A. M. Johnson et al., 2011) discrete emotions might have different functions in specific periods of learning (Pekrun & Stephens, 2012).

3.7.5 Conclusions and Implication

To conclude, the findings of the present study confirm the assumption that discrete epistemic emotions have specific functions and can act to energize, direct, or undermine learning. Specifically, a better understanding of the processes that operate while students reason over complex problems hinges on the dynamic interplay between the emotions, cognitions and motivation. In sum, findings from this study indicate that positive epistemic emotions, such as curiosity and enjoyment, are associated with more adaptive cognitive and motivational mechanisms, whereas, negative epistemic emotions – activating and deactivating alike – have been found to be impede adaptive mechanisms. Therefore, evoking curiosity and fostering enjoyment of learning is a means of promoting adaptive learning-related mechanisms that will ultimately benefit the quality of learning and performance.

4 Study 3 – Enjoyment sparks learning and learning fuels enjoyment: Dynamics of achievement emotions, learning strategies, and class participation over time

4.1 Abstract[14]

Based on the control-value theory of achievement emotions (CVT; Pekrun, 2006; Pekrun & Perry, 2014) and models of self-regulation (Cleary & Zimmerman, 2012), we hypothesized that students' achievement emotions during learning and their participation in classroom activities are linked by reciprocal causation over time. We expected that these relations are mediated by students' use of cognitive learning strategies. The present longitudinal study (n = 1,014 year 5 and 6 primary school students) tested the proposed reciprocal relations linking achievement emotions and class participation over one school year. We also investigated the mediating role of cognitive learning strategies (memorization and elaboration) which can help to explain how emotions and participation mutually reinforce each other over time. Structural equation modeling indicated that enjoyment reported near the beginning of the school year positively predicted class participation at the end of the year, and that this relation was mediated by the use of learning strategies in the middle of the school year. Additionally, class participation at the beginning of the year positively predicted enjoyment, and negatively predicted boredom, at the end of the year, and these relations were also mediated by cognitive strategies reported in the middle of the year.

Results provide support for the reciprocal relations between emotions, use of learning strategies, and participation in class activities as proposed by the control-value theory of achievement emotions. This highlights the role of emotions for students' cognitive and behavioural engagement as well as students' engagement as an important antecedent of their emotions.

4.2 Introduction

The aim of this study was to examine the reciprocal relations between emotion and classroom participation over one school year. We also investigated the mediating role of cognitive strategies in the relations between emotions and participation as well as

[14] This study was conducted together with Prof. David Putwain, Dr. Wendy Symes and Prof. Reinhard Pekrun. Prior to writing up this study, we decided on a ~5000 word manuscript.

participation and emotions (Boekaerts, 2016; Goetz, Hall, et al., 2006; Ranellucci et al., 2015). Such dynamics may be relevant to better understand the energizing or undermining functions of emotions for cognitions and behaviors during learning and classroom activities.

It has been suggested that the emotions students experience during learning and classroom instruction and their participation in classroom activities are tightly coupled, in that emotions are proposed to influence class participation, and that class participation, in turn, influences emotions (Reschly, Huebner, Appleton, & Antaramian, 2008; Skinner, Furrer, Marchand, & Kindermann, 2008). However, it is important to also examine the processes through which such dynamics are created and maintained in the classroom. Herein, we focus on the use of cognitive strategies as possible mediators. Emotions have been found to affect the strategic use of learning strategies (Pekrun, 2006; Pekrun, Goetz, Titz, & Perry, 2002), such as memorization or elaboration, and use of these strategies should provide students with a sense of being able to master the demands of academic tasks (Borkowski, Chan, & Muthukrishna, 2000; Zusho, Pintrich, & Coppola, 2003), thus positively influencing their participation in class activities. In other words, the effects of these emotions may be mediated by cognitive strategies, which in turn facilitate or inhibit active classroom participation. Such mediational mechanisms have received little empirical attention (Pekrun & Linnenbrink-Garcia, 2012), especially from a longitudinal perspective (Pekrun, Hall, Goetz, & Perry, 2014; Pekrun & Schutz, 2007) and using younger-aged students (Wang & Degol, 2014).

In turn, class participation, referring to the active and agentic role of the student, may influence the emotions students experience in the classroom (Pekrun & Linnenbrink-Garcia, 2012). Specifically, active class participation might instigate enjoyment, while withdrawal from class participation may trigger boredom. In terms of mediating processes, active participation is thought to influence students' use of strategic approaches to learning, which in turn influences their emotional responses (Wang & Degol, 2014; Wang, Willett, & Eccles, 2011). Accordingly, we also investigated how achievement emotions were influenced by students' active participation as mediated by cognitive strategies (Pekrun, 2006).

In sum this study addresses the reciprocal relations between achievement emotions and class participation to better understand how emotions and participation mutually reinforce each other over the period of a school year in a group of primary school students. We investigated these relations in the context of learning in mathematics (Skinner & Pitzer, 2012). In the following sections, we first define the key constructs used in this research and describe how they can be linked in terms of reciprocal effects over time.

4.2.1 Achievement Emotions

Achievement emotions are emotions that are tied directly to achievement activities and outcomes (Pekrun et al., 2002). Enjoyment and boredom are the most frequently occurring emotions during classroom learning and activities and likely to exert a strong influence on cognition and classroom participation (Frenzel, Thrash, et al., 2007; Pekrun, Goetz, Titz, & Perry, 2002b; Pekrun & Schutz, 2007). CVT differentiates between discrete learning-related emotions along dimensions of valence (pleasant vs. non-pleasant), activation (activing vs. deactivating), and object focus (activity vs. outcome) (Pekrun et al., 2002; Pekrun & Perry, 2014). Enjoyment is defined as a positive, activating emotion, whereas boredom has been conceptualized as a negative and deactivating emotion triggered by over- or under-stimulation during an activity (Vogel-Walcutt et al., 2012).

4.2.2 Classroom Participation

Classroom participation is the core component of behavioral engagement describing involvement in classroom activities and learning (Fredricks, Blumenfeld, & Paris, 2004; Skinner, Kindermann, & Furrer, 2008). The original definition from Finn (1989) characterized involvement in classroom activities by active student behavior at the class level (Skinner, Furrer, Marchand, & Kindermann, 2008), and is now typically operationalized through tangible and observable classroom behaviours such as putting energy into action, persistence, attention and effort, for example by asking questions or contributing to class discussion (Appleton, Christenson, & Furlong, 2008; Fredricks et al., 2004). Active participation in classroom learning and activities has been found to be a strong predictor for positive educational outcomes (Finn & Rock, 1997; Wang & Holcombe, 2010), including student learning, grades, achievement and academic skills, and even school completion (Reschly & Christenson, 2012).

4.2.3 Cognitive Strategies

Cognitive strategies contribute to the process through which students become cognitively and strategically immersed in learning (Cleary & Zimmerman, 2012; Eccles & Wigfield, 2002; Pintrich & De Groot, 1990). In essence, strategies assist learners in carrying out cognitive operations and determine how learners actively encode, process and store information (Krapp, 1993; Pressley, Forrest-Pressley, Elliott-Faust, & Miller, 1985). Two primary cognitive strategies are memorization and elaboration (Artelt, 2006). Memorization is characterized by repetitive rehearsal and rote learning of to-be-learned materials and information (N. J. Entwistle & Ramsden, 2015), whereas elaboration refers to strategies such as paraphrasing, summarizing, or using analogies that build deep connections between prior knowledge and content to be learned (Dole & Sinatra, 1998; N. Entwistle, 2000). Students who use a greater variety of different strategies can better cope with numerous sets of different problems they encounter during learning activities, rather than just a specific set of problems (Siegler, 2003).

4.2.4 Effects of Achievement Emotions on Class Participation

Positive activating emotions, such as enjoyment during learning, have been found to have an energizing function in directing adaptive learning behaviors, such as active class participation (Pekrun & Linnenbrink-Garcia, 2014). Conversely, when students experience boredom during learning and classroom activities, they are unable to sustain behavioral participation over time (Skinner, Furrer, et al., 2008). Importantly, when such emotions reoccur frequently during classroom learning and activities, they become linked to those learning experiences and behaviors (Meyer, 2014). These dynamics have been suggested to be mediated by students thought-action repertoire, including the use of cognitive learning strategies (Pekrun & Linnenbrink-Garcia, 2012; Pekrun & Perry, 2014).

4.2.5 Emotions influence Cognitive Strategies.

Emotions in educational contexts can enhance or impede learning by shaping the cognitive strategies that students use when faced with a new challenge (Pekrun et al., 2002b). Specifically, learning-related enjoyment should promote cognitive flexibility and consequently facilitate use of sophisticated learning strategies such as elaboration (Pekrun et al., 2002a). In contrast, negative-deactivating emotions, such as boredom, have been found to induce superficial information processing and reduce the use of any cognitive learning strategy (Pekrun et al., 2002). Recent empirical findings have shown that enjoyment relates positively, whereas boredom is unrelated or relates negatively, to cognitive strategies (Chatzistamatiou, Dermitzaki, Efklides, & Leondari, 2015b; Goetz, Hall, et al., 2006; King & Areepattamannil, 2014; King, McInerney, Ganotice, & Villarosa, 2015; Pekrun et al., 2011, 2002a; Reschly et al., 2008; Villavicencio & Bernardo, 2013).

A recent meta-analysis (Tze et al., 2016) reports that investigations regarding the impact of boredom on student learning behaviors among primary school students have received insufficient attention and that most studies were cross-sectional. In a notable exception, Ahmed, van der Werf, Kuyper and Minnaert (2013) examined the impact of emotions on students' (aged 12 to 13 years) use of cognitive learning strategies over time and found that an increase in students' boredom was negatively related to shallow and unrelated to deep strategies, while the steeper the rate of decline in students' enjoyment, the steeper the rate of decline in deep as well as shallow strategy use.

4.2.6 Cognitive Strategies influence Class Participation.

It has been suggested that strategic approaches to learning result in energized learning behaviors in the classroom (Pressley & Woloshyn, 1995; B. J. Zimmerman, 2000). This assumption builds on self-system motivation theories (Skinner, Wellborn, & Connell, 1990) explicating that individuals are born with the need to experience themselves as effective in their interactions with the environment (Elliot & Dweck, 2005), and that the extent to which they feel a sense of mastery influences the quality of their engagement in a given domain. Specifically, this suggests that the usage of cognitive strategies during learning provides students with information about themselves: as being competent in effectively enacting and mastering demands of tasks and activities, and as being autonomous learners during activities in the classroom (Deci & Ryan, 2000). It has been found that students capacities to enact cognitive strategies influences students participation in class (Skinner, Wellborn, & Connell, 1990).

4.2.7 Cognitive Strategies Mediate the Effects of Achievement Emotions on Class Participation.

The experience of positive-activating emotions, such as enjoyment, has generally been found to broaden thoughts and behaviors and to facilitate more flexible responses to environments, thus allowing to better attune thought and action to a given learning situation (Baumann & Kuhl, 2005; Dreisbach & Goschke, 2004; Fredrickson, 2001; K. J. Johnson, Waugh, & Fredrickson, 2010b). As such, enjoyment of learning may support students to adopt the most appropriate strategy relative to task demands, phase of learning, or the students' abilities. In contrast, negative-deactivating states (e.g., boredom) reduce the motivation to engage further with tasks or activities, which will consequently undermine the use of cognitive strategies (Pekrun, 2006; 2016) (see Figure 4.1). These modulating functions are theorized to ultimately affect classroom participation. As noted above, more usage of cognitive strategies would be expected to reinforce, and less use to undermine, active participation in mathematics activities and tasks (Hall et al., 2007; Ranellucci et al., 2015).

4.2.8 Effects of Class Participation on Achievement Emotions

A critical feature of the CVT is the proposed feedback loop that explains how achievement emotions arise or are undermined during classroom learning and activities.

Specifically, students have the potential to proactively participate in activities and learning in mathematics classes, which, over time, increases the array of cognitive strategies. That is, the self-enacted cognitive strategies should increase students perceived competence in effectively enacting and mastering demands of tasks and activities (Niemiec & Ryan, 2009; Skinner, Wellborn, & Connell, 1990). Accordingly, it can be suggested that students who actively participate in the learning and activities of their mathematics classes, will, over time, have a broader variety of strategies available to cognitively engage with mathematics lessons and activities. This, in turn, will provide greater feelings of control but also value of their learning and activities in mathematics classes and consequently lead to an increase in enjoyment, while feelings of boredom should decrease (Goetz, Pekrun, Hall, & Haag, 2006) (see Figure 4.1).

Taken together, all study variables influence each other cyclically in that they form feedback loops over time (Skinner, Furrer, et al., 2008). Specifically, the relations of emotions with strategy use and participation, and the relations of participation with strategy use and emotions imply that emotions and participation are expected to be linked reciprocally over time. For both directions, students' use of cognitive learning strategies is expected to act as a mediator.

4.3 Aim and Summary of Hypotheses of the Present Research

In the present study we investigate the reciprocal relations between achievement emotions and class participation near the beginning and at the end of the school year, while additionally considering the mediating role of cognitive strategies as assessed in the middle of the school year (see Figure 4.1 for theoretical research model). The following hypotheses were tested:

H1: Enjoyment positively relates to class participation and boredom negatively links with class participation.

H2: The relations of emotions with subsequent participation are mediated by use of cognitive strategies (elaboration and memorization). (a) Enjoyment positively predicts use of cognitive strategies; boredom negatively predicts strategy use. (b) Strategy use positively predicts class participation.

H3: Class participation positively relates to enjoyment and negatively links with boredom.

H4: The relations of class participation with subsequent emotions are mediated by strategy use. (a) Class participation positively predicts strategy use. (b) Strategy use positively predicts enjoyment and negatively predicts boredom.

As pronounced differences of girls' and boys' emotional experiences in mathematics have been identified (Frenzel, Pekrun, et al., 2007), gender was included as a covariate. Furthermore, as the sample included pupils from the final two years of primary schooling in England (Years 5 and 6), and as knowledge and control of cognitive strategies develop during this time (Annevirta, Laakkonen, Kinnunen, & Vauras, 2007), age was also included as a covariate.

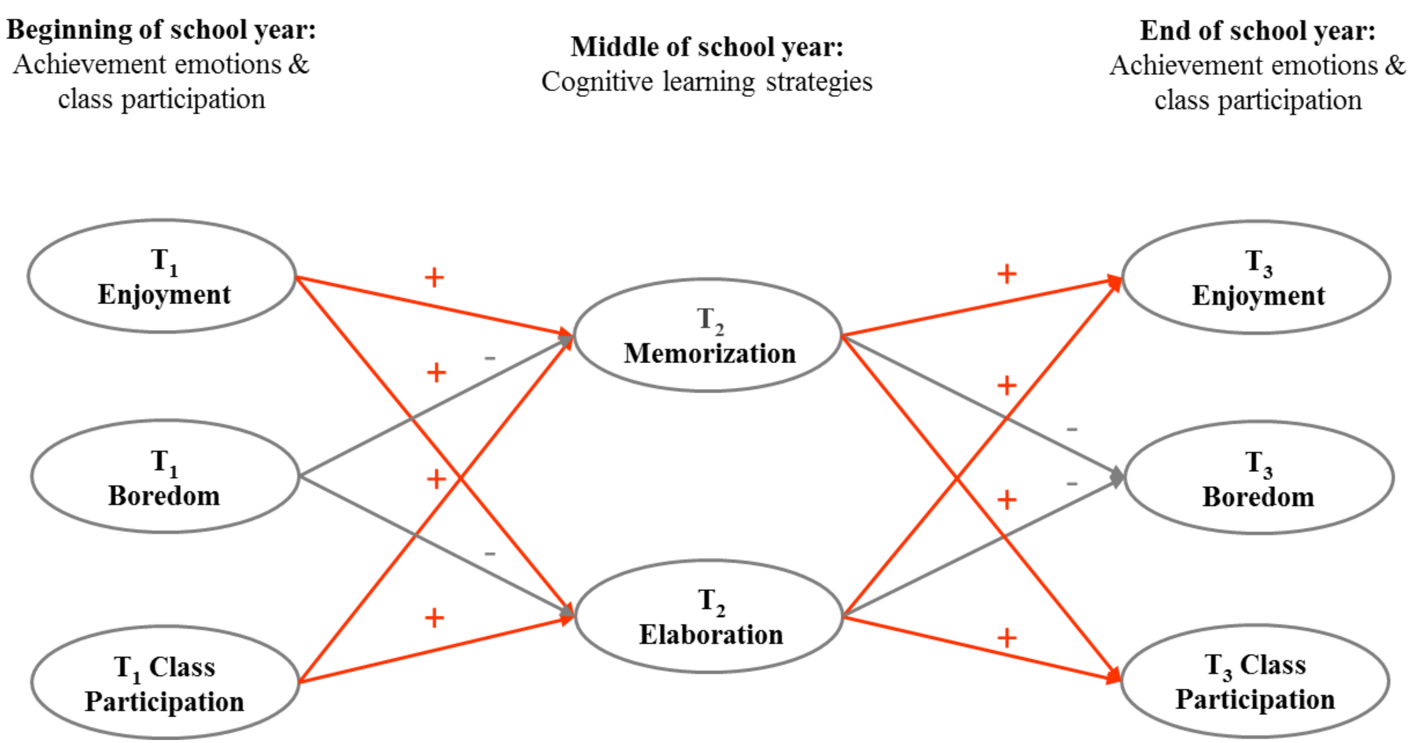


Figure 4.1: The proposed linkages between achievement emotions, cognitive learning strategies, and class participation (adapted from the control-value theory, Pekrun, 2006; Pekrun & Perry, 2014). All depicted variables pertain to learning during classroom instruction in mathematics.

4.4 Method

4.4.1 Participants and Procedure

The current study is part of a longitudinal research project examining emotions and self-regulation in mathematics classes of primary school students in Years 5 and 6 in England throughout a full school year. The project was designed as a multi-wave panel study involving self-reported assessments with three points of data collection separated by four-month intervals. Accordingly, achievement emotions (enjoyment and boredom) and classroom participation were measured near the beginning (T1) and at the end (T3) of the school year, and cognitive strategies in the middle of the school year (T2) (see Figure 4.1 for theoretical research model). Overall, the sample consisted of 1,014 students (male n = 528, female n = 486) from 55 different classrooms in 24 different schools (Year 5, n = 495; or Year 6, n = 519). At T1, participants had a mean age of 9.76 years (SD = .70) and the ethnic diversity is representative of the student population of England as almost a quarter of all pupils came from ethnic minorities (UK government, 2013) (with participants being primarily Caucasian (n = 783) and with smaller numbers from Asian (n = 110), Black (n = 40), or mixed heritage backgrounds (n = 81).

Due to the longitudinal design of the study, there is a certain proportion of missing data. While participant attrition at T2 was relatively small (n = 60 lost participants), it was substantial at the last assessment of the study (T3) (n = 521 lost participants). Little's test confirmed that missing data were completely missing at random (p >.05).

4.4.2 Measures

Psychometric properties of all variables are presented in Table 4.1. For all measures, higher scores reflect a higher endorsement of the corresponding construct.

Mathematics related achievement emotions. The enjoyment and boredom students experience when attending or learning in mathematics classes were measured using the respective scales from the *Achievement Emotions Questionnaire-Mathematics* (Frenzel, Thrash, et al., 2007; Pekrun et al., 2011). The enjoyment of mathematics scale (total of ten items) refers to attending class, studying, and taking tests and exams in mathematics lessons (e.g., "I enjoy my maths lessons"). The boredom in mathematics scale (a total of six items) measured boredom while attending class and doing homework in mathematics (e.g., "The work we do in maths lessons bores me to death").

Learning Strategies in Mathematics. Students' use of cognitive learning strategies in mathematics were assessed by administering the self-report scales developed for the Project for the Analysis of Learning and Achievement in Mathematics (PALMA, Pekrun et al., 2007). The learning strategies subscales assess memorization as well as elaboration. The memorization strategies scale refers to rehearsal regarding declarative and procedural knowledge (six items; e.g., "In maths lessons I try to memorize examples"). The elaboration strategies scale (Pekrun et al., 2007) was used to assess students' deep learning strategies related to the acquisition of declarative and procedural knowledge (nine items; e.g., "When learning new things in maths, I try to link the new ideas to things I already know").

Class Participation in Mathematics. Participation in activities and learning during mathematics classes was measured using an adapted[15] version of the *Engagement Versus Disaffection with Learning Questionnaire* (Skinner, Kindermann, et al., 2008). Each student reported on his or her own participation in class using five items tapping their effort, attention, and persistence while initiating and participating in learning activities in their mathematics classes (2 items for effort: "I try to do well in my maths lessons", "In my maths lessons, I try as hard as I can", 1 items for participation: "I participate in the activities and tasks in my maths lessons", 2 items for attention: "I pay attention in my maths lessons", "When I'm in my maths lessons, I listen very carefully"). All data were collected via self-report on 5-point Likert Scales (1 = *strongly disagree* to 5 = *strongly agree*). In the present study all reliability coefficients for all measures were good ($\alpha \geq .80$; see Table 4.1 for psychometric properties of all scales).

[15] The original scale concerned participation in school generally and consequently items were adapted to refer specifically to activities and learning in mathematics classes.

Table 4.1: Descriptive Statistics for the Study Variables.

	No. items	*M*	*SD*	*α*	*Mean* $r_{i(t-i)}{}^{a}$	ICC (1)	*Skewness*	*Kurtosis*
Time 1								
Enjoyment	10	4.10	.73	.89	.64	.20	-1.16	1.62
Boredom	6	1.91	1.07	.92	.78	.20	1.31	.91
Class Participation	5	4.52	.60	.83	.64	.11	-2.12	6.98
Time 2								
Memorization	6	4.11	.71	.81	.56	.09	-.89	.72
Elaboration	9	4.32	.60	.86	.60	.07	-1.19	1.96
Time 3								
Enjoyment	10	4.10	.78	.91	.68	.11	-.97	.59
Boredom	6	1.90	.99	.91	.75	.08	1.12	.45
Class Participation	5	4.51	.50	.81	.59	.07	-1.05	1.17

Note. [a] Mean of part-whole corrected item-total correlations. [b] Intraclass-correlation coefficient (1) indicating the proportion of variance that occurs at the class level.

4.5 Rationale for Analytic Approach

Confirmatory factor analysis (CFA) and structural equation modelling (SEM), performed with M*plus* (Muthén & Muthén, 2013) were used to test the psychometric properties of, and relationships between, achievement emotions, class participation and learning strategies as latent factors. Specifically, we tested the reciprocal effects model (including mediation) competitively against a baseline model, in which six additional direct paths, namely all possible paths from the achievement emotions and classroom participation at T1 to the achievement emotions and classroom participation at T3, were included (see Figure 4.1). Correlated uniqueness for parallel items at T1 and T3 were included in the SEMs to account for within-person dependencies (Marsh, Balla, & Hau, 1996). Age and gender were included as manifest predictors of T1, thereby controlling for variance attributable to these socio-demographics.

Following recommended procedures for emotion scales (Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011) residual variances were allowed to correlate for all items that represent one achievement setting (i.e., learning, classroom work, and testing). Analogous to this approach, both of the two items measuring effort and the two items measuring attention during class participation (at T1 and T3) were allowed to correlate. Similarly, the cognitive strategies scales comprised items indicating strategies relative to declarative and procedural knowledge and accordingly, residual variances were allowed to correlate for these respective items.

As students were nested in classes, we corrected for the clustering of the data using the "type = complex" option implemented in M*plus* (Muthén & Muthén, 2013). To estimate the model parameters, the robust maximum likelihood estimator (MLR) was employed, accounting for non-normality of the observed variables. We applied the full information maximum likelihood method to deal with missing data (Enders, 2006).

To evaluate the fit of the models we investigated both absolute and incremental fit indices, including the comparative fit index (CFI), the Tucker–Lewis index (TLI), the root-mean-square error of approximation (RMSEA), and the standardized root-mean-square residual (SRMR). Despite debates on cut-off values (Heene et al., 2011; Lance et al., 2006; Marsh et al., 2004), adequate and excellent fit of data, respectively, are typically considered in the following range: (a) CFI and TLI > .90 and ≥ .95, respectively (Marsh et al., 2005, 2004), and (b) RMSEA and SRMR < 0.08 and ≤.06, respectively (Hu & Bentler, 1999; MacCallum et al., 1996). We adopted recommendations by Trautwein et al. (2012) that at least two of these criteria should be met to consider a model to have a reasonably good fit to the observed data. For comparing the reciprocal effects and saturated models, we used the Akaike Information Criterion (AIC) (Akaike, 1987) and the Bayesian Information Criterion (BIC) (G. Schwarz, 1978), adjusted for sample size (Muthén & Muthén, 2013) as these are both methods of assessing model fit penalized for the number of estimated parameters. Low values for die AIC and aBIC indicate a better model fit (Kelava et al., 2011) and a loss of ΔAIC > 10 is regarded as substantial (D. R. Anderson & Burnham, 2002).

4.6 Results

4.6.1 Preliminary Analyses

CFAs revealed good fit for all scales (see Table 4.2) with adequate factor loadings (λ > .4) providing a sound measurement base for conducting the SEM. As recommended before testing a SEM (Schreiber, 2008), latent correlations between all measurement models (see Table 4.3) were investigated showing relative stability over time for the repeated measures: enjoyment (r = .57), boredom (r = .46), and class participation (r = .60).

Table 4.2: Confirmatory Factor Analysis for the Study Variables.

Scales	χ^2	*df*	CFI	TLI	RMSEA	90% CI_{RMSEA}	SRMR	Factor Loadings
T1								
1. Enjoyment	100.13	23	.99	.97	.06	[.045, .067]	.02	.44 – .85
2. Boredom	4.70	4	1.00	1.00	.01	[.000, .049]	.00	.76 – .85
3. Class Participation	2.79	3	1.00	1.00	.00	[.000, .050]	.01	.57 – .78
T2								
4. Memorization	16.65	5	.99	.98	.05	[.024, .074]	.02	.46 – .79
5. Elaboration	54.40	22	.99	.98	.04	[.025, .051]	.02	.55 – .70
T3								
6. Enjoyment	144.16	23	.96	.92	.10	[.084, .117]	.04	.48 – .84
7. Boredom	32.31	4	.99	.95	.12	[.082, .157]	.02	.69 – .88
8. Class Participation	3.44	3	1.00	1.00	.02	[.000, .078]	.01	.62 – .67

Note. χ^2 = chi-square; df = degrees of freedom; CFI = comparative fit index; TLI = Tucker-Lewis index; RMSEA = root-mean-square error of approximation, SRMR = the standardized-root-mean residual; CI = confidence interval [lower, upper].

Table 4.3: Standardized Bivariate Latent Correlations between Learning-Related Emotions, Cognitive Strategies, and Class Participation

		T1			T2		T3		
		1.	2.	3.	4.	5.	6.	7.	8.
1. Enjoyment	T1	-							
2. Boredom		-.64	-						
3. Class Participation		.71	-.61	-					
4. Elaboration	T2	.40	-.25	.43	-				
5. Memorization		.34	-.19	.32	.81	-			
6. Enjoyment		.57	-.45	.42	.44	.36	-		
7. Boredom	T3	-.37	.46	-.38	-.23	-.16[a]	-.59	-	
8. Class Participation		.50	-.41	.60	.49	.49	.71	-.55	-

Note. For all coefficients, $p < .001$ except [a] $p = .009$. Latent correlations were modelled without including any directional paths amongst constructs but included correlations of residual variances as described in the ‘Analytic Approach’ section. By the above mentioned model fit criteria the mediation model showed a very good fit to the data: $\chi^2(1568) = 2604.07$, $p < .01$; RMSEA = .03 with 90% Confidence Interval [.024, .027], SRMR = .05; CFI = .95, TLI = .94, AIC = 107546.18, aBIC (adjusted sample size) = 107994.24.

4.6.2 Structural Equation Modeling for Mediation Analysis

The mediation model contained paths from achievement emotions to class participation and from class participation to achievement emotions, as well as autoregressive relation (see Figure 4.2). By the above mentioned model fit criteria the mediation model showed a very good fit to the data: $\chi^2(1568) = 2604.07$, p <.01; RMSEA = .03 with 90% Confidence Interval [.024, .027], SRMR = .05; CFI = .94, TLI = .94, AIC = 102957.30, aBIC (adjusted sample size) = 103407.18. Concerning the direction of the observed relationships, the specific beta coefficients are shown in Figure 4.2. The results revealed that enjoyment at T1 positively predicted memorization ($\beta = .27$, $p < .001$) and elaboration at T2 ($\beta = .22$, $p = .004$). Boredom at T1 did not predict either cognitive strategy at T2 ($\beta < .09$, $p >$. 10). Class participation at T1 predicted memorization ($\beta = .19$, $p = .003$) as well as elaboration strategies ($\beta = .32$, $p >$ .001) at T2. While controlling for the influence of emotions and class participation at T1, memorization at T2 did not predict the emotions experienced at T3 ($\beta_{enjoyment} = -.04$, p = . 758/ $\beta_{boredom} = .08$, p = . 461) but predicted class participation ($\beta = .30$, $p = .008$). Elaboration at T2 positively predicted enjoyment ($\beta = .34$, $p = .004$) at T3 but not boredom ($\beta = -.18$, $p = .094$) nor class participation at T3 ($\beta = .05$, $p = .660$).

4.6.3 Comparison with Baseline Model

Upon additionally including the six direct paths into the model, all of the goodness-of-fit indicators remained nearly the same ($\chi^2(1562) = 2592.19$, p <.01; RMSEA = .03 with 90% Confidence Interval [.024, .027]; SRMR = .05; CFI = .94; TLI = .94, AIC = 102953.69; aBIC = 103414.11). While the baseline model showed slightly better AIC and aBIC values, the differences did not suggest a substantially better fit (ΔAIC < 10). This evidence indicates that the mediational model did not fit worse than the less restricted baseline model, which suggests that the mediational model can be accepted (Chen, 2007).

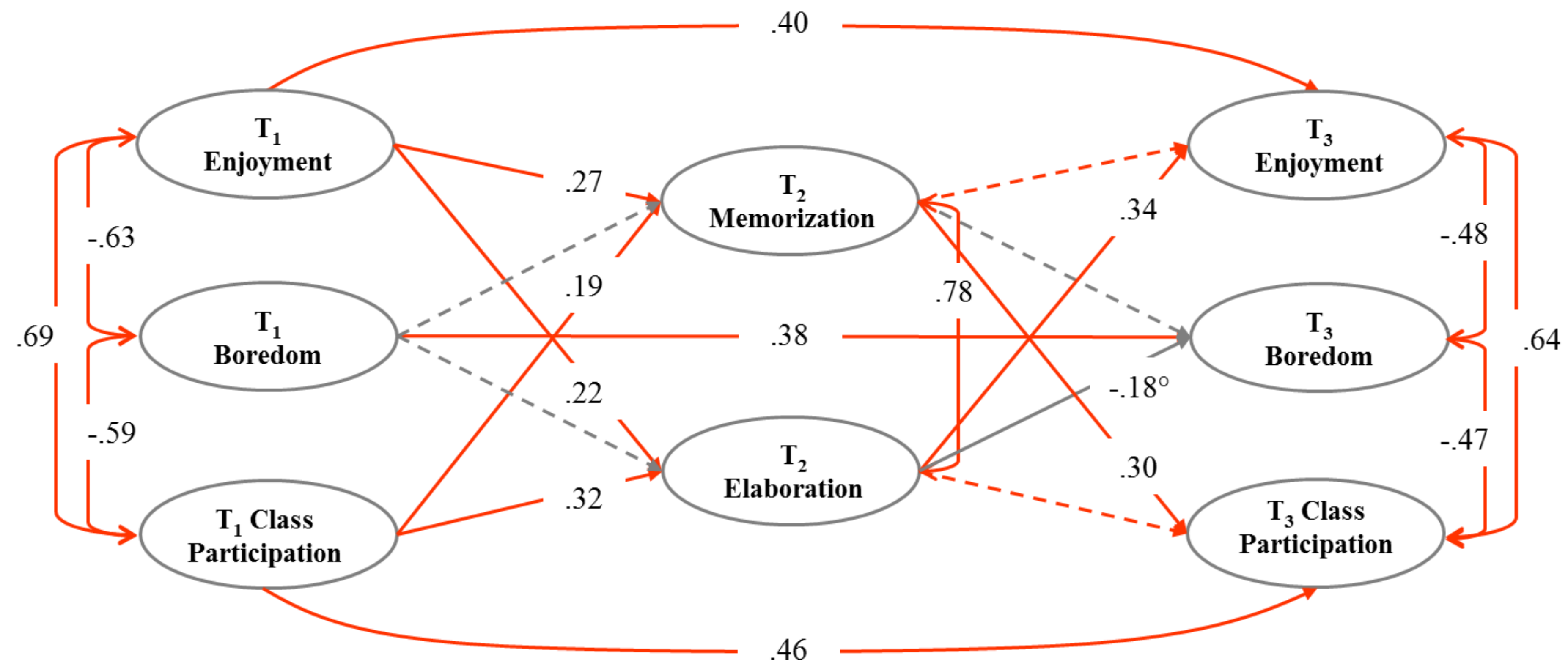


Figure 4.2: Standardized path coefficients in the SEM. For clarity cross-lagged paths from T1 to T3 learning-related emotions and engagement, and paths for covariates (gender and age) are not depicted. All coefficients are statistically significant at $p < .01$ except °$p = .09$. Non-statistically significant paths ($p > .09$) are depicted with broken lines. Explained variances for enjoyment, boredom, and class participation at T3 were $R^2 = .37$, .21, and .44, respectively; all ps <.001.

4.6.4 Estimates of Indirect (Mediated) Effects

Indirect paths were examined from: (i) T1 emotions to T3 class participation via the mediating role of cognitive strategies and (ii), from T1 class participation to T3 emotions via the mediating role of cognitive strategies. Mediating effects were assessed based on a percentile bootstrapping method based on 10,000 resamples by creating 95% confidence intervals around the estimate of the indirect effect (Hayes, 2013). Confidence intervals that cross zero indicate a statistically significant indirect effect. Total indirect effects investigating the impact of emotions at T1 (i), revealed that T2 cognitive strategies mediated relations from T1 enjoyment to T3 class participation, $\beta = .09$, *SE* = .03, 95% CI [.017, .082]. Upon investigating the specific indirect effects, it was found that mediation occurred based on the specific indirect effect through memorization strategies, $\beta = .08$, *SE* = .04, 95% CI [.016, .178]. The total indirect effect from T1 boredom to T3 class participation via the mediating role of cognitive strategies was not significant, $\beta = .03$, *SE* = .02, 95% CI [-.005, .032].

The total indirect effect from T1 class participation to T3 enjoyment via the mediating role of cognitive strategies, $\beta = .10$, *SE* = .03, 95% CI [.083, .412] was statistically significant, based on the specific indirect effect via elaboration, $\beta = .11$, *SE* = .05, 95% CI [.032,.221]. The total indirect effect from T1 class participation to T3 boredom via the mediating role of cognitive strategies, $\beta = -.04$, *SE* = .02, 95% CI [-.010, -.263] was not statistically significant as neither one of the specific indirect paths reached statistical significance (see Table 4.4 for all coefficients of total, total indirect and specific indirect paths).

Table 4.4: Coefficients for Indirect Effects of Achievement Emotions/Class Participation (T1) on Achievement Emotions/ Class Participation (T3) as Mediated by Cognitive Strategies (T2).

	Indirect effects							
	from enjoyment T1 to participation T3		from boredom T1 to participation T3		from participation T1 to enjoyment T3		from participation T1 to boredom T3	
Mediator	*β (S.E.)*	*95% CI*	*β (S.E.)*	*95% CI*	*β (S.E.)*	*95% CI*	*β (S.E.)*	*95% CI*
Total effect	.09 (.03)	[.037,.173]	.03 (.02)	[-.001,.081]	.10 (.03)	[.046,.183]	-.04 (.02)	[-.083,.018]
Total indirect effect	.09 (.03)	[.037,.173]	.03 (.02)	[-.001,.081]	.10 (.03)	[.046,.183]	-.04 (.02)	[-.083,.018]
Specific indirect effect								
Memorization	.08 (.04)	[.016,.178]	.03 (.02)	[-.003,.076]	-.01 (.02)	[-.041,.048]	.01 (.02)	[-.017,.064]
Elaboration	.01 (.03)	[-.031,.078]	.00 (.01)	[-.011,.027]	.11 (.05)	[.032,.221]	-.06 (.03)	[-.115,.031]

Note. Beta coefficients represent standardized effect sizes for the total and specific indirect effects. CIs are percentiles from bootstrapping estimated 95% confidence intervals based on resampling with 10.000 replacements with bias correction [lower, upper].

4.7 Discussion

The aim of this study was to investigate the reciprocal relations between achievement emotions and class participation to better understand how these mutually reinforce each other over the period of a school year, while accounting for the mediating role of learning strategies. Specifically, we tested and found reciprocal relations between activity-focused emotions and classroom participation reported at the beginning and end of the school year. Furthermore, the findings provide empirical support for the mediating role of cognitive strategy use as hypothesized in our theoretical model. The longitudinal study design accounts for autoregressive and reciprocal effects of emotions and classroom participation and therefore offers insight into their functioning over time (Bryan, Schmiege, & Broaddus, 2007).

Our first hypothesis, stating that enjoyment relates positively and boredom negatively to class participation was supported. Enjoyment and boredom in the beginning of the school term strongly correlated with class participation towards the end of the school year (relations with enjoyment were positive, whereas relations with boredom were negative). This is in line with a previous finding revealing that positive emotions may fuel students effortful involvement in learning activities (Skinner, Furrer, et al., 2008). This suggests that students who enjoy mathematics classes and activities opt to participate actively in future activities and learning, whereas bored students withdraw from active participation.

In accordance with Hypothesis 2, findings revealed that cognitive strategies mediated the relationship between enjoyment experienced in the beginning and class participation reported towards the end of the school year. This result supports the mediating mechanisms suggested by the CVT and reveal that learning strategies establish an important link between students' emotions and classroom participation. The finding highlights the functional importance of positive emotions by instigating cognitive processes that, in turn, determine active classroom participation. Specifically, Hypothesis 2a was supported as higher levels of enjoyment reported in the beginning of the school year related to students' greater usage of cognitive strategies in the middle of the year. Importantly, positive relations were found for both memorization and elaboration strategies. These results resonate with the broaden-and-build account of positive emotions (Fredrickson, 2001), mirror findings showing enjoyment to relate to a broad range of strategic learning behaviors (Chatzistamatiou et al., 2015b; Goetz, Hall, et al., 2006; Reschly et al., 2008) and indicate that students who experience high intensities of enjoyment respond more flexibly in employing different kinds of strategies relative to task demands, phase of learning, or given abilities (Pekrun & Perry, 2014). This suggests that enjoyment of learning is linked to frequencies in adaptive strategies which is an important implication for research on self-regulated learning (Ahmed et al., 2013; Cleary & Zimmerman, 2012) Further, we predicted that the experience of boredom would be negatively related to usage of learning strategies. This was not supported and is therefore not consistent with suggestions derived from CVT. However, this finding mirrors the null-effects from a recent study using undergraduates student´s (Ranellucci et al., 2015) but could potentially be explained by the observed multicollinearity with enjoyment. It would be important to reveal experimentally if boredom is negatively related or unrelated to strategy use, as this might be an important link helping to explain why bored students perform worse or even drop out of school (Ahmed et al., 2013; Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010; Schukajlow & Rakoczy, 2016).

We expected that usage of cognitive strategies during activities in mathematics classes promotes positive self-perceptions, which in turn fuel participation in the classroom. Our study findings provide partial empirical support for this assumption in showing memorization strategies, but not elaboration strategies, to positively predict an increase of active participation in activities and classroom learning by the end of the school year. Possibly, memorization strategies may indeed be more adaptive for tasks requiring learning off by heart (e.g., multiplication tables) during initial stages of learning (Murayama, Pekrun, Lichtenfeld, & Vom Hofe, 2013) or for learners who are still in the process of developing self-regulation such as elementary school children (Bronson, 2000; Hadwin, Järvelä, & Miller, 2011). Accordingly, this finding may reflect the notion that the most adaptive strategies for actively participating in classroom activities during elementary school may be memorization strategies (Alexander, Graham, & Harris, 1998; Paris & Paris, 2001). To investigate this assumption, future studies should use more fine-grained measures of more specific strategies in mathematics learning. Promisingly, candidate instruments are starting to emerge (Berger & Karabenick, 2016; Wang et al., 2016).

Hypothesis 3, stating that class participation in the beginning of the school year positively links with enjoyment and negatively boredom by the end of the year, was supported by strong correlations (class participation positively related with enjoyment and negatively with boredom as reported towards the end of the year). More specifically, mediational mechanisms linking class participation and subsequent achievement emotions, as stated in Hypothesis 4, were partially supported as a positive indirect effect of class participation on enjoyment, as mediated by elaborative learning strategies, was found. These reciprocal effects support predictions derived from the CVT and help to better explain how students' emotions rise or are undermined in school over time. With regard to Hypothesis 4a, class participation positively predicted strategy use, while these relations were stronger for elaboration than for memorization strategies. Along hypothesis 4b, we found elaboration strategies to positively predict enjoyment, whereas the negative relationship with boredom approached significance. On a cautious note, multicollinearity between the two cognitive strategies might explain why effects for memorization strategies might have been suppressed. Nonetheless, these findings provide a first empirical account for the notion that the usage of cognitive strategies increases subsequent enjoyment while possibly contributing to undermining boredom. It has been suggested that an increase in cognitive strategy use my elicit positive feedback from classmates and teachers, and thereby further increasing the enjoyment of learning during classroom instruction (Wang & Degol, 2014). Similarly, a student's sense of mastery and control of learning content during classroom activities and instruction may increase with greater usage of cognitive strategies and thereby fostering the joy of learning (Niemiec & Ryan, 2009; Skinner et al., 1990).

The present findings indicate that the respective dynamics during learning over a school year seem to mutually reinforce each other over time, in that students, who proactively participate with mathematics classes and activities from the outset of a school year, also use more cognitive strategies. This in turn positively impacts the joy of classes and activities. These findings are in line with propositions from CVT, suggesting that more control of class-related actions and outcomes, which become automatic and non-reflective over time, give rise to the enjoyment of learning while undermining boredom (Pekrun & Perry, 2014).

4.7.1 Limitations and Directions for Future Research

Although the strengths of self-report instruments have been recognized for their practical usefulness and for enabling large-scale testing (Schellings & Van Hout-Wolters, 2011), it would be important to validate students responses externally by means of other types of assessment methods (Pekrun & Schutz, 2007; Pintrich, 2004; Schellings & Van Hout-Wolters, 2011; Zimmerman & Schunk, 2011). For example, video-supported observations could provide alternative ways for measuring affective variables or using data derived from additional sources, for example, teachers, parents or log-files from classroom discourse (Azevedo, 2015).

Furthermore, the present study is limited by assessing only two achievement emotions and it is important that future studies investigate functional differences of other emotion groups (i.e., negative-activating and positive-deactivating emotions). For example negative-activating emotions have been found to facilitate rigid ways to cognitively engage with problems (Fiedler & Beier, 2014) and might therefore exert complex effects for cognitive strategy use and class participation. Anxious students might therefore stick to the strategy that first comes to mind for solving a problem which might therefore be adaptive or maladaptive relative to the task, activity or phase of learning.

4.7.2 Conclusion

The present study contributes to our understanding of functional emotional reactions for students' adaptive learning and participation in mathematics classrooms and supports the mediating role of cognitive strategies as predicted by the CVT. Our results highlight the importance of fostering enjoyment and reducing, or preventing, the experience of students' boredom during learning and classroom activities throughout the year. Accordingly, we hope to encourage educators to spark enjoyment and diminish boredom by fostering students' use of learning strategies as well as their active participation during classroom learning and activities.

5 General Discussion

While it is a core principle in the CVT that emotions function context-specifically, this ‘situativity’ of emotions has not always been directly addressed and therefore constitutes a ‘quiet’ condition often only implicitly acknowledged in academic emotion research (J. C. Turner & Trucano, 2014). This dissertation lends itself to the notion that attending to the ‘grain size’ of the measurement of emotions warrants a more differentiated analysis of the respective functions of emotions for learning processes (Efklides & Volet, 2005). Taking a situated perspective of academic emotions into account, this dissertation aimed to elucidate the interrelations of learners’ emotional experiences with cognitive, motivational and behavioral processes that operate during learning in the academic context of mathematics. In order to tackle the problem of contextually bound emotional experiences, the three presented empirical studies investigated the CVTs’ purported causal role of emotions, in their functions for higher cognitive, motivational, and behavioral activity during learning, at different ‘levels’ of learning. The overall findings from the studies provide further evidence for the central assertion of the instrumentality of emotions for learning (Pekrun, 2006; Pekrun & Perry, 2014); specifically that emotions effect and interlink with cognitive, motivational and behavioral processes which together determine complex thinking, learning, achievement and academic development. Most importantly, however, the findings accumulated empirical evidence for these mechanisms across the postulated levels of situational specificity, indicating that emotions do not only influence cognitive-motivational processes moment-specifically but that their effects carry over to determine habituated learning experiences as well. Here, the most fundamental principle in the CVT concerning emotion-effects, as outlined in the cognitive-motivational model by mediational principles seems applicable across these levels. Indeed, the CVT is a powerful framework as it situates emotions in a broader functional context of human adaptation by integrating cognitive, motivational and behavioral factors of learning that are described relative to their functional dependencies of each other.

This specific emotion-effects portion of the CVT will now be more closely examined in light of the presented empirical findings, in order to revisit the, at the outset presented, overarching framework that may help to unravel functional mechanisms of emotions across different levels of specificity[16]. Then, the discussion will carry on to address issues beyond

[16] For a summary of all findings relative to the initially posed research questions, please see the overall summary of this dissertation (pages IX-XI).

the scope of the chapters of each study, to highlight how the empirical findings as well as respective strengths and weaknesses of the studies can help to outline avenues for future research. This chapter will conclude with practical implications for educational practice in mathematics derived from the three studies presented.

5.1 Revisiting the Specificity Assumption: Situating the empirical data for Enjoyment at different 'Levels'

In order to revisit, the at the outset presented overarching theoretic frame (see Table 1.2), to further discuss the 'situativity' of emotional experiences during learning and to specify this aspect of CVT more closely, the data accumulated in the three presented studies relative to the discrete positive activating emotion 'enjoyment' (see for an overview Ainley & Hidi, 2014) will serve as the running example and will be integrated into the presented model. The framework suggests that, as postulated in CVT, cognitive, motivational and behavioral mechanisms mediate effects of emotions on learning and performance. However, these processes should be further unpacked according to their 'granularity' of the hierarchical level at which they are functioning, in order to better differentiate functions of transient emotional states from more habituated emotional predispositions (Sansone & Thoman, 2005).

5.1.1 Level 1: 'The intrapsychic Level'

The 'lowest' level of the model (see Table 1.2; L1) might also be referred to as the level of experiential states and attempts to elucidate the effects of emotions based on a cognitive-neurobiological approach (Dai & Sternberg, 2004). Here, the multi-componential architecture describing the different components of emotions (Ellsworth & Scherer, 2003; Fontaine, Scherer, & Soriano, 2013; Frijda, 1986), can help to specify how emotions support or impede cognitive, motivational and behavioral processes at the brain level (Damasio, 2001). In study 1, students were consciously aware of the feeling component of the to-be-evoked emotion 'enjoyment' as this emotion-label was explicitly stated as part of the emotion induction procedure. However, the methodological approach employed took advantage of the interrelated architecture of emotions in that the change of the feeling component was supposed to synchronize all other components respectively (Scherer, 2004, 2009). Therefore, the change in the other components may have contributed to the underlying mechanisms in our findings. Here, however, it is important to note the changes in these components must not necessarily result in observable action, which often makes measuring these emotion facets difficult (Shuman & Scherer, 2014). Therefore, we refrained from directly measuring these processes and instead diverged to an implicit approach, of testing respective emotion effects, in which the experimental tasks were designed to demand the processes, that were believed to be ‘set off’ due to the experience of enjoyment. These respective functions of the different components of enjoyment signify the regulatory impact of emotional episodes over cognitive, motivational and behavioral processes that, together with the supporting function of the motor-expressive and physiological component, result in action tendencies and impulses, respectively. We have explained our findings, in that enjoyment resulted in greater performance on the idea generation task, relative to changes in the cognitive component (see chapter 5.2.1. for a more detailed discussion of the theoretical underpinnings of study 1). However, previous research derived theoretic explanations also from the physiological component, as it has been proposed that enjoyment increases levels of dopamine in the brain thus resulting in creative functioning (Ashby, Isen, & others, 1999). Similarly, enjoyment has also been described to result in energizing action tendencies instigated through an approach motivation (Elliot, 2006), which might also account for the effects in our data (i.e., refers to the action tendency component). The multi-componential conception of emotions explicates how complex the effects of emotions are relative to this fundamental level. Therefore, future research might investigate if the paradigm presented in study 1 can be transferred to other components of emotions with their own respective action impulses, in order to investigate if the corresponding mechanisms also carry over to influence judgements, decisions, and reasoning (Fontaine et al., 2013; Pekrun, 2016).

5.1.2 Level 2: ‘The person-situation Level’

One level up (see Table 1.2; L2), emotions arise, fluctuate and change, in conjunction with a functional context (e.g., a mathematical task). By definition, this level concerns activity emotions, such as task-related enjoyment, which has been defined to ”relate to inherent properties of task material or the process of dealing with such material” (Pekrun et al., 2002a, p. 98). Accordingly, the focus of the effects of emotions concerns no longer mental-cognitive/motivational/behavioral functions only but additionally involves more molar constructs such as volition, interest, and behavioral manifestations of learning.

In line with this definition, the second study presented herein (chapter 3), found epistemic enjoyment to be an activating emotion that emerged relative to dealing with a complex mathematical task and furthermore fostered cognitive and motivational task engagement. Interestingly, results from the experimental study (study 1, chapter 2) revealed that momentary and, importantly, task-unrelated enjoyment did not affect the motivation to engage in a cognitive task. This finding incidentally speaks against the notion that a positive mood can be interpreted as task interest (N. Schwarz, 1990), is in line with other findings (Efklides & Petkaki, 2005) and argues in favor of critically attending to measuring effects of emotions ‘level-appropriately’. In line with our findings from the second study, task-related enjoyment (i.e., of epistemic nature) “comes with successful performance of the activity and sustains persistence” (Ainley & Hidi, 2014, pp. 214–215). This suggests that functional mechanisms of task-related enjoyment qualify by continuous competence appraisal of the ongoing performance (Elliot & Harackiewicz, 1994; Pekrun & Perry, 2014; Puca & Schmalt, 1999). Our findings directly speak to these appraisal mechanisms, as enjoyment was found to be a mediator between contextual appraisals and motivation as well as cognition. Further, and in line with Pekrun and colleagues’ (2002) theorizing, we found that task-related enjoyment not only enhanced intrinsic motivation but also directed attention towards the task, which in turn enhanced the quality of task performance. Despite the correlational nature of our findings, the indirect effect examining these links provides additional empirical support for the postulated sequence of these mechanisms. Further research should set out to investigate the functions of emotions for other variables operating at this task-specific level. For example, based on suggestions from CVT, possible candidates might be the effort invested in a task, the meta-cognitive mechanisms operating during task completion or the learning strategies employed during task engagement (Fiedler & Beier, 2014; Goetz, Hall, et al., 2006; Pekrun et al., 2002a; Pekrun & Perry, 2014). According to the spirit of the framework, in detecting effects of task-related enjoyment, these mechanisms would need to be assessed task-specifically and should not diverge to assessments of more ‘global nature’ (e.g., Berger & Karabenick, 2016).

5.1.3 Level 3: ‘The person-domain Level’

In order to better describe how emotions are functional in the process of learning over time, it is necessary to assume a more general perspective of emotional experience in a domain (see Table 1.2.; L3) (Sansone & Thoman, 2005). Here, it has been suggested that “with repeated engagements, feelings of […] enjoyment become interconnected with the cognitions and values generated from experience in the domain” (Ainley & Hidi, 2014, p. 216). Relative to the domain of mathematics, such individual concepts have been referred to as a learners’ “mathematical dispositions” and indicate that these mechanisms constitute an integral aspect of students’ self-regulated learning in mathematics (De Corte et al., 2011).

Self-regulation has been described to be one of the main goals of long-term learning, which entails meta-cognitive awareness and the respective control over one's cognitive activities. In that respect, the third study of this dissertation found that students' mathematics learning-related enjoyment promotes the usage of cognitive learning strategies which in turn determined the engagement (operationalized as class participation) in future mathematics classes and activities. Most strikingly, an indirect effect investigating these mechanisms over time, found that cognitive learning strategies mediated the relations between students' enjoyment in mathematics classes and class participation in mathematics.

These findings suggest that the emotional connotations that are carried along a study domain contain powerful functions in determining cognitive and behavioral learning. Hence, a key feature of this 'third order' level focuses on a learners' subjective but conscious (i.e., fully represented in semantic memory) emotional experiences, that are, like other forms of conceptual knowledge, learnt over time. As argued in the introductory chapter of this dissertation, emotions measured at this general level operate in conjunction with learner's beliefs (which are socio-culturally constructed relative to the academic domain; Mesquita, Boiger, & De Leersnyder, 2016), and thought to be caused by and exert influence on domain values (Wigfield & Eccles, 1992), domain specific-self-efficacy (Bandura, 1986; B. J. Zimmerman, 1989) and domain-specific achievement goals (Elliot & Dweck, 2005; Harackiewicz & Elliot, 1993). Just as general goal orientations frame the mindset for future learning, the presented empirical data strongly suggest that the experience of subjective enjoyment (reported relative to the 'third level') functions to influence the general strategies employed as well as learning behaviors that are shown, which overall determines the self-regulatory quality of a student in that respective domain.

5.1.4 In prospect

It is important to note that the studies presented herein apply to the 'between-person' approach of investigating the *inter*individual dynamics of emotional and psychological functioning. While inter-individual perspectives can explain individual differences in the effects of emotions, within-person analyses provide a deeper understanding of the structure, changes, and variations of emotional states within an individual over time (Pekrun, 2006; Pekrun & Schutz, 2007). Therefore, an *intra*individual perspective should be mapped orthogonally onto the presented framework in order to elucidate mechanisms between and within students for learning (personal communication with Prof. Thomas Goetz on December 6th 2016; Goetz et al., 2016; Pekrun, 2006). Such an approach aims to provide sound empirical evidence that research findings indeed apply inter-individually and thus can be used for educational practice (Vogl, Murayama, & Pekrun, 2016).

In order to illustrate the possible utility of such a framework, recent empirical findings support the importance of sensitivity to 'level-differences' and document, for example, that upon integrating task-specific control mechanisms as a mediator, relations between a general self-concept in a domain and task-specific outcome emotions were found (Tornare et al., 2015). Similarly, the general enjoyment of learning about science was only found to predict engagement in specific scientific problems, upon including the mediational mechanisms of topic specific interest in science (Ainley & Hidi, 2014). Therefore, these findings suggest that it is of utmost importance to attend to the specific measurement levels not just for emotions but relative to the mechanisms determining the process of learning under investigation, respectively (J. C. Turner & Trucano, 2014).

The ultimate end would be to investigate if and how repeated situation specific positive emotional experiences can contribute to sustained and possibly domain-overarching and life-long enjoyment of learning. Research on interest, which is a construct closely related to enjoyment (Ainley & Hidi, 2014; Frenzel, Pekrun, Dicke, & Goetz, 2012; Hidi & Renninger, 2006; Renninger & Hidi, 2011), has postulated a similar goal. Theories of academic interest propose that "situational interest [i]s an antecedent of sustained individual interest and thus [acts] as a prerequisite for interest development" (Kiemer, Gröschner, Pehmer, & Seidel, 2015, pp. 100–101). Accordingly, investigating the effects of academic emotions together with their respective functions at each level may help to unfold how to foster adaptive learning-related emotional experiences that carry through life-long-learning.

5.2 Strengths, Limitations and Implications for Future Research

Despite the prominent advances in revealing mechanisms in the effects of emotions, the presented studies additionally exposed a number of avenues for future research that require further commenting. Generally, all studies attempted to maximize the external validity of the results, as implied in the focus of contextualizing emotions in respect to authentic mathematical tasks or learning environments. However, this comes with the tradeoff of in the generalizability of the findings. Evidently, all the presented findings must critically be investigated for their replicability in other domains. The issue of generalizability also pertains to the samples employed in our studies (i.e., mathematics students in primary and post-secondary education) and warrants future studies to examine the functional role of emotions in other age groups and other groups of student samples.

Additionally, study 2 and 3 relied on the use of self-reports to measure links between emotions with cognitive, motivational and behavioral mechanisms during learning. This is problematic in that some of the shared variance may be due to the use of the common methodology, and as such may inflate relationships between emotions and cognitive, motivational and behavioral relationships (Linnenbrink & Pintrich, 2004; Spector, 2006). Here, future studies would be well advised to mix the methodological approaches employed (for an overview see Azevedo, 2015), in order to answer to such validity concerns and to problems of response bias (Goleman, 1995; Kahneman, 2013; Rasinski, Visser, Zagatsky, & Rickett, 2005; Robinson & Clore, 2002; Tourangeau & Yan, 2007). Some examples include online observations based on log-file data (Azevedo et al., 2013), retrospective coding of videos by trained judges (D'Mello & Graesser, 2012), or physiological and behavioral instrumentation, such as eye-movement data (Arroyo et al., 2009; Calvo & D'Mello, 2010).

While study 1 and 2 make a strong case in investigating changes in emotional experiences relative to the quality of performance, replications of the third study of this dissertation, should investigate if changes in student's emotions and self-regulated learning translate into changes in behavioral outcomes, that are not self-reported (e.g., such as grades, teacher reports, classroom observations, etc.). A last remark to employing self-report instruments in mathematics learning is that most of the original scales that are available to date are not grounded in the perspectives of mathematics education (Schukajlow et al., 2012). While we tried to account for this shortcoming by tailoring the instruments 'level' appropriately (i.e., adjusting scales to the specific tasks, learning activities or the mathematics domain), the field is clearly lacking internally and externally valid, and reliable instruments intended to measure learning as situated in specific domains or academic activities.

In what follows, the strengths and limitations of each study are to be discussed in the following section. More specifically, the advantages and disadvantages of the theoretical rationale behind the studies and the instruments, study design, and data analytical techniques that were used will be illuminated.

5.2.1 Critical Deliberations on Study 1

Theoretical Considerations. Although the results from Study 1 provide some nice initial support for our postulation that enjoyment and anxiety may modulate cognitive processes in such a way, in that they differentially support *scientific* reasoning, it must be acknowledged that the data do not speak to the cognitive processes underlying these effects. That is, while we have strong theoretical accounts for arguing along the lines of previous research, in that students in positive activating emotions are more flexible information processors (Baumann & Kuhl, 2005; Isen, 2008) and that the experience of negative-activating emotions aids to focus on single stimulus features and thus provides cognitive stability (Goschke & Bolte, 2014), this study does not allow to draw definitive conclusions about why the effects occurred. While we attempted to account for the fact that emotions might impact motivational mechanisms for engaging in the tasks and thus possibly influencing performance (Bless & Schwarz, 1999; M. S. Clark & Isen, 1982; Isen, 1987) — by controlling a number of relevant task-related motivational mechanisms respectively (i.e., intrinsic and extrinsic motivation to perform the task, effort invested and concentration) — on hindsight, these mechanisms serve to control processes operating at Level 2, but did not control for other mechanisms that might have been elicited according to Level 1 postulations (as suggested earlier in this chapter, see 5.1.1).

Notwithstanding, the current findings align with the established assumption of emotional functionality asserting that emotions serve a signaling function that adaptively directs cognitions, motivations and behaviors (Frijda, 1986; Lazarus, 1991). This widely accepted view is not only explicated by the *Affect-as-Information* account (Bless & Schwarz, 1999; N. Schwarz & Clore, 1996), but more importantly, in line with the conceptualizing from CVT. Along these lines, we hypothesize that positive-activating emotions widen attentional breath (Fredrickson & Branigan, 2005; Rowe et al., 2007), loosen cognitive control (Dreisbach & Goschke, 2004; Goschke & Bolte, 2014), and facilitate access to more remotely associated ideas in semantic memory (Isen & Daubman, 1984; Topolinski & Deutsch, 2013). Despite entering speculative grounds, it is important to remark that the critical feature for performing the generation task was to retrieve a vast amount of ideas from semantic memory. Since the measure labeled ‘cognitive flexibility’ was the prominent feature in revealing significant differences between the enjoyment and the anxious emotion group, it seems reasonable to argue that one of the main driving forces for causing these effects was the increased spread of associations in semantic memory (e.g., Topolinski & Deutsch, 2013).

In untangling underlying effects of negative-activating emotions, it must be remarked that these are believed to be less symmetrical than effects of positive affect (Hirt et al., 1996). Specifically, it was suggested that here, in addition to the cognitive mechanisms operating, individuals in negative affective states will engage (often unaware) in mood repair (through cognitive reappraisal or re-regulation, to neutralize the subjective negative experience) which substantially complicates matters. Our findings mirror these complexities in that effects emerged comparatively less strongly, relative to the positive emotion-effects, and did only reach significance on one of the indicators for performance on the idea evaluation task. In spite of these theoretical issues, our findings nonetheless are in line with the theoretical account for describing the effects of negative activating emotions. These typically hold that intense negative emotional experiences instigate a more local focus and narrow attention (Wegbreit et al., 2015), provide robust maintenance and proactive control (Goschke & Bolte, 2014), and activate only immediately relevant information in semantic memory (Storbeck & Clore, 2005). As significant differences between the enjoyment and anxiety group emerged in respect to identifying presented ideas as false, possibly mechanisms allowing item-specific analyses of these information, such as the focusing of attention, may be responsible for the presented effect (Pekrun & Stephens, 2012).

Nonetheless, all these cognitive mechanisms and modes are operating together while reasoning and as such believed to be the joint mediational force enhancing the generation as well as evaluation of *scientific* ideas. In that respect, the presented results extend upon numerous empirical studies that indicated that the subjective experience of emotions can play an important role in shaping cognitive processes, such as attention, cognitive control and memory (Fiedler, 2001; Fiedler & Beier, 2014; Goschke & Bolte, 2014; Isen, 2008; N. Schwarz, 1990). Indeed, our findings show that emotion-effects can exceed these first stages in information processing, and ultimately, carry over in effecting complex reasoning.

In light of the need to clarify the mechanisms underlying these effects, it is important to remark that the in Study 1 presented causal emotion-cognition effects speak against the recently postulated *Cognitive Malleability Approach* (or *Affect-As-Cognitive-Feedback* account) (Hunsinger, Isbell, & Clore, 2012; Jeff R Huntsinger & Ray, 2015; Jeffrey R Huntsinger et al., 2014; Isbell, Lair, & Rovenpor, 2013). This model was designed to reconcile with inconsistent findings in the emotion-effects literature and describes that any currently accessible ‘processing style’ is moderated by emotional cues that either encourage to keep (‘go’ signal) or to discard (‘stop’ signal) respective processing inclinations. Our results however, indicate that it is plausible to argue that automatically elicited, rather fixed, emotion-effects affect cognitive processes, which indeed is the more established theoretical account. Further, another recently proclaimed emotions-effects model is the *Dual Pathway to Creativity* (Baas et al., 2008; De Dreu, Baas, & Nijstad, 2008; Nijstad, De Dreu, Rietzschel, & Baas, 2010). Here, yet again, the attempt was to account for inconsistent findings in the emotion-creativity literature. While this model is in line with the CVT notion that higher levels of emotional activation stimulate cognitive performance, it confounds motivational and cognitive explanations in how positive-activating and negative-activating emotions modulate cognitive performance. As such, the CVT provides a rather innovative integrative frame as it acknowledges that several causal pathways might operate through which emotions effect task performance (i.e., cognitive, motivational, behavioral mechanisms). Critically, the CVT does not account them as being mutually exclusive and thus indicates rather complex mediational mechanisms through with emotions influence performance.

Study Design and Emotion Elicitation Method. In terms of the experimental design employed in study 1, it must be acknowledged that the control group was confounded in the two primary dimensions of emotions, namely valence and arousal. Accordingly, future studies should be sure to base their design on the minimally required four-quadrants of the prominent conceptualization of emotions, in order to contrast two activating emotions (e.g., enjoyment (positive) and anxiety (negative)) with two deactivating emotions (e.g., boredom (negative) and relief (positive)) (Pekrun & Perry, 2014).

Further, the presented experiment employed the autobiographical recall method accompanied with music in order to stimulate emotional experiences in participants (Lench et al., 2011; Quigley et al., 2014). This method is based on appraisal theories and empirical research revealing systematic linkages between appraisals and emotions (Moors, Ellsworth, Scherer, & Frijda, 2013; Shuman & Scherer, 2014). The assumption underlying this method is that an emotional prompt, asking to retrieve an emotional experience labeled ‘anxiety’ for example, should evoke the same underlying appraisal constellations (e.g., an important event, with little perceived control, etc.), motivational-behavioral impulses (e.g., escape), physiological and motor-expressive changes, and overall affective experience (e.g., uneasy feeling) across all participants (see further principle of relative universality; Pekrun & Perry, 2014, p. 137). This technique was coupled with the presentation of standardized music, that has been shown to amplify the subjective experience of the emotion (Jallais & Gilet, 2010; Lench et al., 2011; e.g., Spachtholz, Kuhbandner, & Pekrun, 2014). Such complex and dynamic appraisal mechanisms explain why such an *internal* emotion induction procedure is particularly effective in eliciting high intensities of discrete emotions (Quigley et al., 2014; Salas, Radovic, & Turnbull, 2012). Problematically, however, it has recently been found that this method elicits a number of incidental emotions when negative emotions are intended to be induced (Mills & D’Mello, 2014). Therefore, study 1 should be replicated with other induction methods in order to ensure that the patterns of our findings will be obtained using different mood induction procedures and to additionally address the debate of inducing discrete emotional states only (for overviews of induction procedures see Lench et al., 2011; Quigley et al., 2014).

5.2.2 Critical Deliberations on Study 2

Theoretical Considerations. Study 2 assumed a mean-level perspective on how epistemic emotions function during task completion and these relations, in turn, were analyzed across students. While this is a valid first step in addressing the functions of emotions during complex reasoning and learning, this approach possibly masks mechanisms that are critically important to gather a more fine-grained understanding of the functional properties of epistemic emotions.

First, in order to truly account for the mechanisms operating at the postulated 'Level 2' of emotional specificity, a more dynamic perspective is clearly needed to better untangle the rise and effects of these highly 'situated' emotions (J. C. Turner & Trucano, 2014). For example, negative-activating epistemic emotions, such as confusion or frustration, may very well be ascribed productive functions, that were not detected because our study was not sensitive to situation specific impasses or the resolution thereof (D'Mello & Graesser, 2012). Therefore, future work must attend to measuring emotions dynamically as they occur. Coupled with learning processes aiding to overcome such impasses, future research should set out to assess whether certain emotions trigger specific impasse-resolution strategies, how quickly students react to those emotions, and whether there are non-linear relations that need to be taken into consideration (Muis, Pekrun, et al., 2015).

Second, the emerging sequences of epistemic emotions have been addressed relative to their respective incidences and transitions of these naturally occurring emotional states (D'Mello & Graesser, 2012). Here, our data do not allow revealing how these states transient between one another. However, our data indicate, for instance, a strong oscillating dynamic between confusion and frustration which is in line with the postulations from D'Mello and Graesser (2012). The authors suggested that bidirectional pathways might be possible in explaining how students transient between frustration and confusion. Such epistemic transitions might be an interesting endeavor for future research, and for instance, help to untangle the strong positive correlations we found between surprise, curiosity and confusion (Meier, 2014; Vogl et al., 2016).

Instruments and Study Design. One further limitation of study 2 was the use of single-item measures of epistemic emotions which were only administered once upon task completion (see for a discussion on short versus long questionnaires; Gogol et al., 2014). If the purpose of future research is to capture and measure the real-time enactment processes of epistemic emotions, then these affective dynamics will have to be sampled more frequently throughout a learning process. Here, the experience sampling method (Csikszentmihalyi & Larson, 2014) is a methodological approach that readily lends itself to account for the time-varying process view of learning situations, in interaction with personal and situational characteristics. This method, however, ultimately prompts other considerations, such as choosing the unit of analysis. Researchers will have to decide if emotional experiences should be sampled by events (e.g., with the occurrence of an impasse), or by time (e.g., intervals of seconds, minutes or hours versus randomized sampling (as an example for the latter see Goetz et al., 2010)), or both? The major advantage of event sampling is that one can document the activities aiming to resolve impasses, thus providing functional information of epistemic emotions. Time sampling, such as coding activity continuously every 30-second (interval-based), more readily allows to detect trajectories of emotions but may downplay the interaction or the meaning in the activity.

Statistical Method. The data of study 2 (as well as study 3) were analyzed employing structural equation modeling (Muthén & Muthén, 2013) to evaluate the entire model in order to better account for the overall emotional, cognitive and motivational landscape of the processes involved while students completed the complex mathematical proof (Kline, 2015). While the model fit indices suggested a good fit to our data, it must be acknowledged that our sample size ($N_{\text{Study 2}} = 80$) was inadequate to account for the complexity of the model relative to the large number of estimated parameters. By nature, however, the constructs under investigation are latent variables, that is, not directly observable, and therefore it was decided not to conduct manifest paths analysis possibly entailing fallible measures due to uncorrected measurement errors (Cole & Preacher, 2014). Latent structural equation modeling is the more powerful alternative to manifest paths analysis (e.g., allows correlating error terms), that can help to account for the non-normal distribution and ordinal measure of emotion constructs (Kline, 2015). Nonetheless, it is important to remark that the robust maximum likelihood estimator employed thereof, is only recommended to provide stable results with a greater sample size ($N > 200$) (Hox, Maas, & Brinkhuis, 2010). Despite these critical points, it must be remarked that the observed effect sizes indicate substantial magnitude in the outcomes of our findings, which thus deserve a replication. Future studies should therefore either focus on testing simpler models (e.g., focusing on specific hypotheses for rise and effects of single discrete epistemic emotions (e.g., Vogl et al., 2016)), replicate our findings with a greater number of participants, and/or additionally consider error reduction as well as error correction strategies to reduce the impact of measurement errors (Cole & Preacher, 2014).

5.2.3 Critical Deliberations on Study 3

Theoretical Considerations. Study 3 investigated the consequences of achievement related emotions over time and the presented findings resonate with recent calls for the importance of integrating emotions into models of self-regulated learning (Boekaerts & Pekrun, 2015; Efklides, 2011; Pintrich, 2004; B. J. Zimmerman, 2000). However, these accounts provide only limited theoretical explications of how emotions are thought to influence learning and adaptive functioning during self-regulation. In that respect, the CVT accentuates that “[s]elf-regulation presupposes flexibility in adapting one’s actions to task demands” (Pekrun & Perry, 2014, p. 133) and thus is explicitly assuming a perspective describing a regulatory function of emotions for adapting cognitions to the situational specificity of a learning environment. In terms of specific predictions regarding effects of discrete emotions, propositions in CVT ‘mash up’ the regulatory notion of emotions with strategic approaches to learning. In essence, in CVT it is postulated that:

> “[P]ositive activating emotions are expected to promote use of flexible, deep strategies, whereas negative activating emotions facilitate rigid ways to solve problems. […] By contrast, deactivating emotions can undermine any strategic efforts and just promote superficial processing of information” (Pekrun & Perry, 2014, p. 133).

As only the execution of a strategic approach, but not the strategy itself can be labeled ‘flexible’ or ‘rigid’, these links must be further qualified in order to articulate the specific mechanisms driven by emotions referring to ‘the regulation of strategy use’ and the ‘strategic approach employed’ during self-regulation. Turning to the herein presented findings, study 1 found enjoyment to support the spread of associative or flexible cognitions, which is a cognitive function that might help to more flexibly adjust a strategic approach or cognitive learning strategy relative to task demands. This assumption is further underscored by the findings provided in study 3, where enjoyment was not only related to ‘deep’ strategic approaches (i.e., elaboration), but links were also found between enjoyment and memorization (i.e., a more ‘superficial’ strategic approach). In light of this data, what seems theoretically plausible is that emotions serve a regulatory function in supervising the learning process. Thus, discrete emotions may not necessarily be dedicated to any one specific cognitive strategy, but instead modulate the regulatory mechanisms that help to explain why students experiencing enjoyment, seem to better attune to the demands of the respective learning situation and are better able to select strategies 'task appropriately' by taking advantage of the flexible nature of the modulated cognitions.

In line with this reasoning, study 1 found that anxiety supported item-specific and bottom-up processing and might thus 'tune' regulatory mechanisms as to function more rigidly. That is, a narrow thought-action repertoire might undermine regulatory search processes, and leave a student to be 'stuck' with the specific items that were activated in memory, thus possibly limiting the array of strategic approaches. This, however, also means that anxiety must not necessarily be maladaptive per se. That is, if the strategy that was pulled from and activated in semantic memory is task-appropriate, then emotion-effects must not always be dysfunctional.

Likewise, negative deactivating emotions were found, based on study 1, to discourage cognitive functioning and as such would not be expected to stimulate the regulation of learning. While the CVT hypothesizes deactivating emotions to promote the use of more superficial, shallow processing strategies (Pekrun, 2006; Pekrun & Perry, 2014), the findings from study 3 suggest that boredom does not initiate any strategic approaches to learning.

Such a 'situation-specific' theoretic account (see Figure 5.1) underscores the importance of the context in which learning related emotions are embedded (e.g., which task is employed, or which projects need to be tackled) (see Efklides, 2011). Additionally, emotions' impact on functions of cognitive regulation can help explain why empirical findings often report enjoyment to correspond to a broad range of strategic approaches to problems or activities during learning, why anxiety might be found to lead to adaptive, yet fewer strategies, and why boredom is at times unrelated and other times negatively related to strategic approaches during learning (Ahmed et al., 2013; Chatzistamatiou et al., 2015b; King & Areepattamannil, 2014; Pekrun et al., 2002a; Ranellucci et al., 2015). Future research is warranted to test these postulations experimentally.

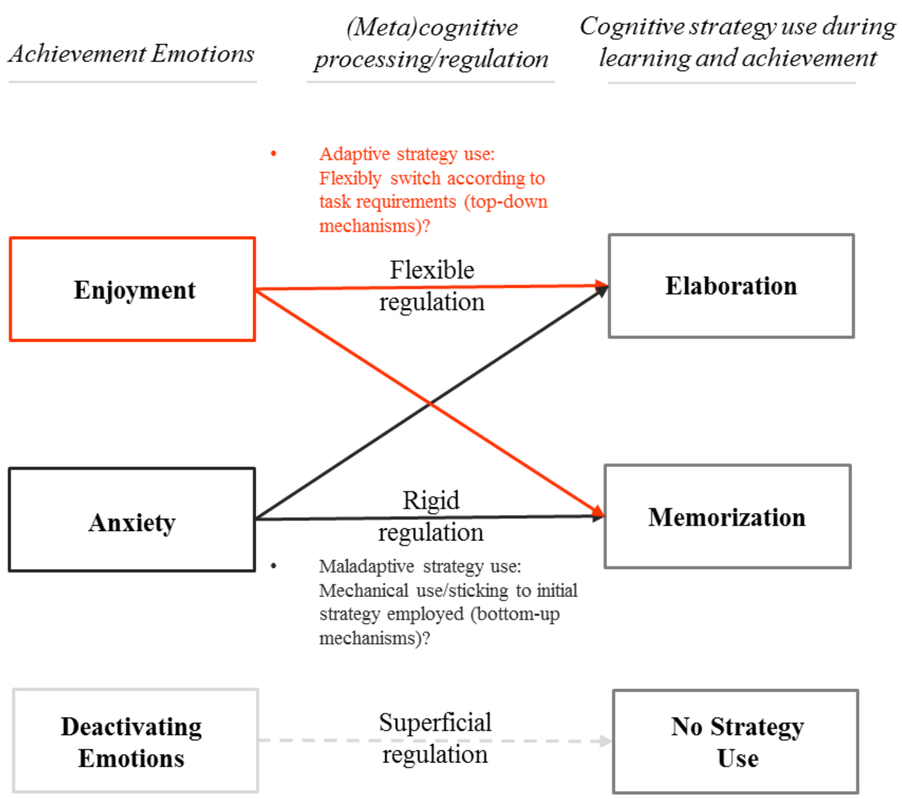


Figure 5.1: Model explaining emotion regulation during self-regulated learning to account for specific strategic approaches employed.

Study Design and Instruments. While our longitudinal three-wave panel design served to temporally separating emotional experiences from cognitive and behavioral learning during classroom activities, it would have been imperative to assess all constructs at all measurement points in order to fully account for all autoregressive relations in the model.

Further, our data revealed problems of multicollinearity between measures. Future research may therefore revisit the instruments employed (Berger & Karabenick, 2016; Gogol et al., 2014) or critically discern to what extent primary school students are able to sufficiently differentiate the constructs under investigation (Dignath, Buettner, & Langfeldt, 2008; Wigfield, Klauda, & Cambria, 2011).

5.3 General Implications for Educational Practice in Mathematics

The presented findings do not only underscore that mathematical thinking is an emotional endeavor but show that students' emotional experiences can have an important effect on how they process information, learn, or develop mathematical skills and knowledge

(Goldin, 2014; Meyer, 2014; Pekrun, 2014). More precisely, this dissertation highlights that a one-sided approach to considering positive emotions as ‘good’ and negative emotions exclusively as ‘bad’ oversimplifies the contextually bound and situated dynamics that co-direct learning processes (Goetz, Zirngibl, Pekrun, & Hall, 2003; Järvenoja, Järvelä, & Malmberg, 2015; Op’t Eynde, De Corte, & Verschaffel, 2006; Tulis & Fulmer, 2013). Accordingly, the findings can be used to infer how to create supportive educational contexts (for an overview of instructional practices see Pekrun, 2014).

The data presented herein document that temporary experience of some negative emotion, such as anxiety, can be adaptive when detailed and analytical thinking is required.

In fact, Study 1 suggests that positive-activating and negative-activating emotions have complementary benefits for complex and challenging mathematical problems. Thus, teachers should not only acknowledge positive and negative emotions as a natural part of complex reasoning, but interpret emotional profiles during learning as helpful signals for detecting adaptive or maladaptive actions and behaviors therein. Thus, on the one hand, teachers need to equip students with the necessary capabilities of tolerating episodes of negative emotional experiences. Given the negative effects that frustration and boredom had in study 2, it is, on the other hand, imperative for teachers to provide strategies for overcoming and down-regulating negative feelings (J. E. Turner, Husman, & Schallert, 2002), to interfere with potential viscous circles of emotional transitions between frustration and boredom during complex tasks (D’Mello & Graesser, 2012).

With regard to fostering self-regulated learning, the results from study 3 suggest that interventions that aim at stimulating positive emotions can enhance students’ adaptive strategy use and learning behaviors. Moreover, additionally providing meaningful learning and cognitively activating tasks does not only encourage cognitive partaking and interest in the classroom activities but, in turn, fosters students’ enjoyment of learning. Additionally, findings from study 2 encourage interventions targeting control and value appraisals as a means to foster task-related enjoyment and curiosity during challenging tasks. More specifically, authentic tasks (i.e., highlighting personal meaning and relevance) may tip off students’ value appraisals, while structural scaffolds during complex problem solving might assist with keeping the challenge of a complex mathematical task under students’ control.

In conclusion, the results of the current set of studies provide compelling evidence for the importance of emotions in learning and achievement of students in mathematics. Overall, the results suggest that advancing higher order mathematical thinking is the mix of emotional experiences with focused attention, motivational spirit, extending knowledge and engaging in mathematics thinking. In that line, our findings complement the view that in addition to the ‘will’ and ‘skill’ required for complex mathematical thinking, students do benefit from the ‘thrill’ (Ahmed et al., 2013, p. 159; Pintrich & De Groot, 1990).

5.4 In Conclusion

The primary goal of this dissertation was to gather a more detailed understanding of what constitutes emotional experiences during learning and to unravel their intricate relations with cognitive, motivational and behavioral processes. The dissertation emphasized that the main problem to better understanding the functions and consequences of emotions and how they ultimately play out in the learning process, is to determine the ‘right’ level of measurement in order to understand the role, triggers, emergence and development of emotions during learning. In line with CVT, the ‘situativity’ of emotions has been described to be critically important for discerning the underlying mechanisms of emotion-effects. Therefore, the theoretical deliberations as well as the empirical findings presented concern the attempt to further dismantle the quality and direction of interaction of emotions with cognitive, motivational and behavioral mechanisms processes during learning. Hence, several research avenues were outlined throughout this dissertation hoping that the results of the current investigation will stimulate further studies on the interplay of emotions and academic learning. This - so the hope - may contribute to further refining and developing functional accounts of how emotions can be linked with cognitive, motivational, and behavioral consequences in achievement contexts.

6 Appendices

6.1 Appendix A

Coding of Studies identified through a Literature Search for Peer-Reviewed Empirical Publications from 2000 to 2016 on Emotions in Mathematics Contexts Referencing and/ or based on Control-Value Theory (Pekrun, 2006; Pekrun & Perry, 2014)

				Measures relating to Emotion Construct			
	Author(s) and Year of Publication	Emotion Construct	Measurement Level of Emotion Construct	Antecedents	Cognitive, Motivational or Behavioral Mechanisms during Learning	Performance / Achievement	Sample Age
1	Ahmed, van der Werf and Minnaert (2010)	Multi-componential measure of anxiety, anger, enjoyment and boredom	L2: task specific	Competence and value	-	-	Secondary school
2	Ahmed, Minneart, van der Werf and Kuyper (2010)	Positive and negative (composite scores based on discrete emotions)	L3: class	Competence and value	-	-	Secondary school
3	Ahmed, van der Werf, Kuyper and Minnaert (2013)	anxiety, boredom, enjoyment, and pride	L3: class	-	Cognitive and meta-cognitive strategies	Maths grade (L3)	Secondary school
4	Buff (2014)	Enjoyment of learning	L3: class	Control and value	-	-	Secondary school
5	Burić (2015)	joy, hope, pride, relief, anger, anxiety, shame and hopelessness	L3: class	Control, value and perceived teacher/parents support	-	-	Secondary school
6	Chatzistamatiou, Dermitzaki, Eflides and Leondari (2015)	enjoyment	L3: class	Self-efficacy, value, goals	Cognitive and meta-cognitive strategies	-	Elementary school
7	Dettmers, Trautwein, Lüdtke, Goetz, Frenzel and Pekrun (2011)	Composite measure: unpleasant homework emotions	L2: homework	Value and Expectancy	Homework Effort (L2)	Mathematics literacy (L3)	Secondary school
8	Dinkelmann and Buff (2016)	(Anticipatory) joy	L3: class/ L2: exam	Control and value	-	-	Secondary school

	Author(s) and Year of Publication	Emotion Construct	Measurement Level of Emotion Construct	Measures relating to Emotion Construct: Antecedents	Measures relating to Emotion Construct: Cognitive, Motivational or Behavioral Mechanisms during Learning	Measures relating to Emotion Construct: Performance / Achievement	Sample Age
9	Frenzel, Pekrun and Goetz (2007b)	enjoyment, anxiety, anger, and boredom	L3: class	Perceived classroom environment (e.g. quality of instruction, competition)	-	Maths grade (L3)	Secondary school
10	Frenzel, Pekrun and Goetz (2007a)	Enjoyment, Pride, Anxiety, Hopelessness and Shame	L3: class	Competence and value	-	Maths grade (L3)	Secondary school
11	Goetz, Cronjaeger, Frenzel, Lüdtke and Hall (2010)	enjoyment, pride, anxiety, anger, and boredom	L3: class	Academic self-concept	-	Maths grade (L3)	Secondary school
12	Goetz, Frenzel, Pekrun and Hall (2006)	Enjoyment, anxiety and boreodm	L3: class	-	-	Maths grade (L3)	Secondary school
13	Goetz, Frenzel, Hall and Pekrun (2008)	Enjoyment	L3: class	Academic self-concept	-	Maths grade (L3)	Secondary school
14	Goetz, Nett, Martiny, Hall, Pekrun, Dettmers and Trautwein (2012)	enjoyment, pride, anxiety, anger, and boredom	L2: homework/ L3: class	Academic self-concept (L3)	-	Maths grade (L3)	Secondary school
15	Holm, Hannula and Björn (2016)	enjoyment, pride, anger, anxiety, shame, hopelessness and boredom	L3: class	-	-	Maths grade (L3)	Secondary school
16	Kim and Bennekin (2013)	enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom	L3: class	Control and value	Effort-regulation	Maths grade (L3)	Post-secondary education
17	Kyttälä and Björn (2010)	anxiety	L3: class	Control and value	-	Achievement and career choice	Secondary school

	Author(s) and Year of Publication	Emotion Construct	Measurement Level of Emotion Construct	Measures relating to Emotion Construct: Antecedents	Measures relating to Emotion Construct: Cognitive, Motivational or Behavioral Mechanisms during Learning	Measures relating to Emotion Construct: Performance / Achievement	Sample Age
18	Luo, Ng, Lee and Aye (2016)	Enjoyment, pride, boredom and anxiety	L3: class/ L2: learning and testing	Self-efficacy, value and perceived parents support	Homework Effort (L2)	-	Secondary school
19	Muis, Psaradellis, Lajoie, Leo and Chevrier (2015)	Surprise, Enjoyment, Curiosity, Confusion, Anxiety, Frustration and Boredom	L2: task	Control and value	Cognitive and meta-cognitive strategies	Task achievement (L2)	Secondary school
20	Niculescu, Tempelaar, Dailey-Hebert, Segers, and Gijselaers (2016)	Enjoyment, anxiety, boredom and hopelessness	L3: course	Control	-	-	Post-secondary education
21	Peterson, Brown and Jun (2015)	Discrete emotions	L2: learning	-	-	Course grade (L3) and academic grade (L4)	Post-secondary education
22	Tornare, Czaikowski and Pons (2015)	joy, pride, contentment, worry, shame, hopelessness as outcome emotions	L2:task	Control	-	Task-performance (L2)	Secondary school

6.2 Appendix B.1.

Motivational Control Variables

After students had finished working on the tasks, they reported about their intrinsic and extrinsic motivation toward the tasks (Situational Motivation Scale; (Gillet, Vallerand, Lafrenière, & Bureau, 2013; Guay et al., 2000)). First, intrinsic motivation assessed the extent to which the task was done out of interest, volition and choice (Deci & Ryan, 2000) (8 items; example item: “I worked on the task because I thought it was interesting”; (Guay et al., 2000)). Extrinsic motivation measured the extent to which students pursued the task due to feelings of pressure or saw no personal value or purpose in the task (Deci & Ryan, 2000) (8 items; example item: “I worked on the task only because I felt that I have to do it”; (Guay et al., 2000)). Additionally, task-specific effort was measured indicating the amount of cognitive engagement with the task (7 items, example item: “I made an effort, regardless how much I liked the task”; (Wild & Schiefele, 1994)). Last, concentration was measured assessing distractibility and task-irrelevant thinking. The items were worded negatively (6 items; example item: “I noticed my thought wondering off while working in the task”; (Wild & Schiefele, 1994)) and accordingly, for ease of interpretation, the scale was inverted such that a higher score indicated more concentration allocated to the task at hand. All control variables were assessed on 5-point Likert scales indicating the extent of agreement (1= *not true of me at all* to 5 = *very true of me*). Table B.1.1. presents the self-report items and scale reliabilities for all self-report measures.

Several two-way analyses of variances were conducted to explore the impact of emotion groups on different motivational variables across the two different task types (see Table 2.1). No interaction effects between emotion groups and task type reached statistical significance, Fs (2, 240) < 2.49, ps > .085. While there were no differences between the emotions groups for intrinsic motivation nor effort, Fs (2, 119) < 2.15, ps > .12, the emotion groups approached significant differences with respect to the reported extrinsic motivation and concentration, Fs (2, 240) < 2.94, ps < .06. Post-hoc comparisons using tukey HSD tests revealed that students in the enjoyment group (M = 2.64, SD = .87) did not significantly differ (ΔM = .08, p = .54) with respect to the extrinsic motivation reported from students in the anxious group (M = 2.72, SD = .71) but with approached differences with the control group (M = 2.93, SD = .82; ΔM = .29, p = .06). Ratings from students in the anxious group did not differ from the other two emotion groups (ΔMs < .21, ps >.20). Further post hoc comparisons showed that students in the anxious emotion group reported significantly lower concentration

(M = 3.02, SD = .12) than students in the enjoyment (M = 3.85, SD = .13; p < .001) or control group (M = 3.59, SD = .13; p = .001) while differences between the enjoyment and the control group were not significant (ΔM = .26, p = .33).

Additionally, prior knowledge was measured using a knowledge test on geometry based on 49 forced choice questions (M = 40.45, SD = 4.69, *Min*.= 21.00, *Max.* = 49.00). All items met satisfactory item parameters with a difficulty index of $0.47 < P < 0.99$ (M (P) = .826; SD (P_i) = .123) as well as a discrimination index of $r_{j(t-j)} > 0.30$ (see Table in Appendix B.2. for items and frequencies of knowledge test). Two-way analyses of variances (3 emotion groups x 2 task types) revealed that students were equal across all experimental conditions (students scored on average 40 out of 49 points in each cell) with regard to their knowledge in geometry (see Table B.1.2.).

Table B.1.1: Self-report items measuring task-specific motivational variables.

Construct	*Reliability (Cronbach's α)*		German Items	Translation
	Generation	Evaluation	*Instruktion: "Ich habe die Aufgabe bearbeitet, …"*	*Instruction: "I worked on this task…"*
Intrinsic Motivation	.87	.83	…weil ich sie interessant fand.	…because I think that this activity is interesting.
			…weil ich sie gut fand.	…because I think that this activity is pleasant.
			…weil sie mir Spaß gemacht hat.	…because this activity is fun.
			…weil es eine Genugtuung für mich war.	…because I feel good when doing this activity.
			…weil ich glaube, dass es mir was gebracht hat.	…because I am doing it for my own good.
			weil ich glaube, dass ich etwas dazulernen konnte.	…because I think that this activity is good for me.
			…weil ich sie bearbeiten wollte.	…by my personal decision.
			…weil sie für irgendetwas wichtig sein könnte.	…because I believe that this activity is important for me.
Extrinsic Motivation	.80	.78	…weil ich dazu aufgefordert wurde.	…because I am supposed to do it.
			…weil ich sie bearbeiten musste.	…because it is something that I have to do.
			…weil ich keine andere Wahl hatte.	…because I don´t have any choice.
			…weil ich mich dazu verpflichtet gefühlt habe.	…because I feel that I have to do it.
			…obwohl ich den Sinn darin nicht gesehen habe.	There may be good reasons to do this activity, but personally I don´t see any.

Construct	*Reliability (Cronbach's α)*		German Items	Translation
	Generation	Evaluation	*Instruktion: "Ich habe die Aufgabe bearbeitet, …"*	
			…obwohl ich nicht überzeugt bin, dass es das Wert war.	I do this activity but I am not sure if it is worth it.
			…obwohl ich nicht weiß, was es mir gebracht hat.	I don´t know; I don´t see what this activity brings me.
			…obwohl ich sie zwecklos fand.	I do this activity, but I am not sure it is a good thing to pursue it.
Effort	.86	.83	Ich habe mich angestrengt, unabhängig davon wie sehr mir die Aufgabe lag.	I have made an effort, regardless of how much I liked the task.
			Ich habe nicht aufgegeben, unabhängig davon wie sehr mir die Aufgabe lag.	I did not give up, no matter how much I liked the task.
			Ich habe so lange intensiv gearbeitet, bis die Bearbeitungszeit abgelaufen war.	I worked intensively until the time was up.
			Ich habe versucht, das Beste aus mir herauszuholen, das mir möglich war.	I tried to give my very best.
			Ich habe so konzentriert wie möglich gearbeitet.	I worked as concentrated as possible.
			Ich habe mich nur soweit angestrengt, wie es unbedingt notwendig war.*	I only invested effort as absolutely necessary.*
			Ich war mit meinen Gedanken woanders.*	My thoughts were elsewhere but with the task. *
Concentration	.96	.94	Ich habe gemerkt, dass meine Gedanken abgeschweift sind.*	I've noticed that my thoughts were wondering off.*
			Es fiel mir schwer, bei der Sache zu bleiben.*	It was hard to stay on task.*

Construct	*Reliability (Cronbach's α)*	German Items	Translation
		Ich habe mich dabei ertappt, dass ich mit meinen Gedanken ganz woanders war.*	I have found myself that I was with my thoughts somewhere else.*
		Ich war unkonzentriert.*	I was not very concentrated.*
		Ich war leicht abzulenken.*	I was easily distracted.*
		Meine Konzentration hat nicht lange angehalten.*	My concentration didn´t last for long.*

Note. * Item was reversed.

Appendix: Knowledge Test in Geometry

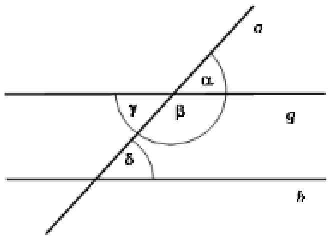
Table B.1.2: Frequency table of answers to test in geometry knowledge

Item	Mathematical statements which must be identified as “correct” or “incorrect”	Statement is true/false	Frequency correct	% correct
For every parallelogram it is true that:				
1	The opposite sides are parallel.	true	244	99.2
2	The diagonals bisect each other.	true	217	88.2
3	There are two adjacent angles, which are of equal size.	false	217	88.2
4	The sum of the interior angles is 360 °.	true	245	99.6
5	The figure is a rhombus.	false	175	71.1
6	The figure is symmetric under point reflection.	true	205	83.3
7	The opposite angles are of equal size.	true	237	96.3
8	The figure is symmetric under line reflection.	false	216	87.8
9	The opposite sides are the same length.	true	242	98.4
10	Adjacent angles add up to 180 °.	true	229	93.1
What needs to apply to conclude that two triangles are congruent?				
11	When their three side lengths match, they are congruent.	true	204	82.9
12	When their three angles are of equal size, they are congruent.	false	143	58.1
13	If two of their side lengths and the angles between them are of equal size, they are congruent.	true	215	87.4
14	If one of their angles and two of its side lengths are of equal size, they are congruent	false	156	63.4
15	If they match in the size of three angles and the length of the side, which is opposite of the smallest angle, they are congruent.	true	199	80.9
16	If they match in the length of three sides and one angle, they are congruent.	true	205	83.3
17	If they match in two of their side lengths and the angle, which is only adjacent to the longer of the two sides, they are congruent.	false	134	54.5
18	If they match in two angles and the side between these angles, they are congruent.	true	209	85.0
19	If they match in two of their angles and the side, which is only adjacent to smaller of the two angles, they are congruent.	true	115	46.7

In the sketch[a] g and h are parallel lines and a is any straight line which intersects g and h. Then the following are always true:				
20	α is half the size of β.	false	233	94.7
21	$\alpha = \gamma$.	true	242	98.4
22	$\alpha + \beta = 180°$.	true	242	98.4
23	$\alpha + \gamma = \beta$.	false	228	92.7
24	$\delta = \gamma$.	true	239	97.2
25	$\beta + \delta = 180°$.	true	235	95.5
26	$\delta = \alpha$.	true	243	98.8
27	$3 \cdot \gamma = \beta$	false	236	95.9
In any equilateral triangle applies:				
28	The three sides are equal.	false	201	81.7
29	There are two equal angles.	true	235	95.5
30	The triangle is point-symmetric.	false	202	82.1
31	The triangle is axisymmetric.	true	233	94.7
32	The sum of the angles is 180 °.	true	243	98.8
33	All angles are equal.	false	210	85.4
34	Adjacent angles add up to 180 °.	false	230	93.5
Which statements apply for every triangle?				
35	The perpendicular bisectors of the sides intersect in one point.	true	189	76.8
36	Each perpendicular bisector splits the opposite angle into halves.	false	194	78.9
37	The triangle is isosceles if one perpendicular bisector is also an axis of symmetry for the triangle.	true	223	90.7
38	The angle bisectors intersect in one point.	true	208	84.6
39	Each angle bisector passes through the midpoint of the opposite side.	false	167	67.9
40	The intersection of the three heights is the center of the circumscribed circle.	false	124	50.4
Which statements apply for every quadrangle?				
41	Each quadrangle, in which all four sides are of equal length, is a rombus.	true	180	73.8
42	Each quadrangle has a circumscribed circle.	false	167	67.9
43	A quadrangle with (at least) two right angles, and (at least) two equal sides is a square.	false	171	69.5
44	When a quadrangle has (at least) three right interior angle, it is a rectangle.	true	222	90.2
45	Each axial symmetric quadrilateral is a trapezoid.	false	114	46.3

46	If a rectangle has two pairs of sides with equal length each, it is a parallelogram.	true	156	63.4
47	A parallelogram, which has a right interior angle, is a rectangle.	true	220	89.4
48	Each quadrangle has an inscribed circle.	false	157	63.8
49	Each quadrangle, that has four right interior angles and four equal sides, is a square.	true	210	85.4
Total	49 statements			

Note. [a]Sketch for questions on lines:



6.3 Appendix B.2.

Consent Form

Erklärung zur Studienteilnahme:
Es freut uns sehr, dass Sie sich bereit erklärt haben, an unserer Studie teilzunehmen. Sie werden eine kurze Aufgabe aus dem Bereich der Geometrie bearbeiten, welche Ihnen zuvor genau beschrieben und erklärt wird. Sie werden zusätzlich gebeten, sich an einen bestimmten emotionalen Zustand zu erinnern. Dabei soll Ihnen passende Musik helfen, sich besonders gut in das emotionale Erlebnis hineinzuversetzen. Die Musik kann auch sehr unangenehm/negativ sein. Bitte entscheiden Sie selbst, ob Sie bei dem Experiment mitmachen möchten. Sie können das Experiment natürlich auch später jederzeit abbrechen.
Consent for study participation:
We are very pleased that you have agreed to participate in our study. You will work on a short task from the area of geometry. Instructions will be described and explained to you in detail beforehand. Additionally you will be asked to remember an emotional event in your life. While doing so, appropriate music will help you with better putting yourself into this state. The music can also be very unpleasant / negative. Please decide for yourself if you want to participate in the experiment. You can also stop the experiment at any time later.

Allgemeines:
Die Studie wird zwischen 30 und 45min. dauern. Als Vergütung erhalten Sie im Anschluss 10,00€ in Bar oder eine Versuchspersonenstunde die Ihnen für mögliche Nebenfächer als Teilprüfungsleistung zur Teilnahme an Experimenten anerkannt wird.
Diese Studie wird als risikofreier Ablauf angesehen. Dennoch ist es den TeilnehmerInnen selbstverständlich erlaubt eine Pause einzulegen oder die Teilnahme zu unterbrechen, wenn körperliche Symptome aufgrund der Arbeit am Computerbildschirm (z.B. Schwindel, Kopfschmerzen, oder ähnliches) auftreten. Bitte teilen Sie der Versuchsleitung unverzüglich mit, falls es Ihnen während der Studie nicht gut gehen sollte.
General information:
The study will take between 30 and 45 minutes until completion. You can chose to be compensated with 10,00 € or course credit.
This study is considered to be risk-free process. Nevertheless, participants are of course allowed to take a break or interrupt the participation of the study at any point if physical symptoms due to work on the computer screen occur (i.e. dizziness, headache, or the like). Please inform the researcher immediately if you should feel physically unwell during the study.

Rechte:
Ihre Teilnahme an der Untersuchung ist freiwillig. Durch Ihre Einwilligung gehen Sie keine Verpflichtungen ein. Sie können die Einwilligung in die Untersuchung jederzeit widerrufen und die Untersuchung abbrechen, ohne dass Ihnen ein Nachteil entsteht. Sie können jederzeit

verlangen, die bisherigen erhobenen Daten bis auf weiteres zu löschen (mithilfe Ihrer anonymen Teilnehmerkennung).

Rights:

Your participation in this study is voluntary. Your consent does not imply any binding obligations. You may revoke your consent to the study at any time and terminate the investigation without incurring any disadvantage. If for any reason I wish to withdraw your data from this study, you are free to do so without providing any reason and the data will be destroyed (based on your anonymous identifier).

Datenschutz:

Angaben zu Ihrer Person werden nicht an Dritte weitergegeben oder veröffentlicht. Alle Angaben werden anonymisiert verarbeitet und sind nur Projektmitarbeitern zugänglich. Wir sind *nach DGPs-Richtlinien dazu verpflichtet, die Daten 10 Jahre lang aufzubewahren.*

Data protection:

No personal data will be disclosed to third parties no published. All data are processed anonymously and are only accessible to project staff. We are committed to keeping the data for 10 years, according to DGPs guidelines (German psychological association).

Leiden Sie derzeit an psychiatrischen Erkrankungen?	☐ nein	☐ ja
Are you currently suffering from psychiatric disorders?	*no*	*yes*
Haben Sie in letzter Zeit ein stark emotional belastendes Ereignis erlebt?	☐ nein	☐ ja
Have you latently experienced an extremely emotionally stressful event?	*no*	*yes*

Falls Sie eine der beiden Fragen mit „ja“ beantworten, müssen wir Sie leider bitten davon abzusehen, an der Studie teilzunehmen.

If the answer is "yes" to one of the two questions above, we must ask you not to participate in the study.

Ich habe die vorausgehende Erklärung gelesen und verstanden.

I have read and understood the consent form.

____

(Datum, Name & Unterschrift **VersuchsleiterIn**)

*(Date, name and signature of the **investigator**)*

Mir wurde die Untersuchung erläutert und alle Fragen wurden hinreichend beantwortet. Ich nehme freiwillig an der Untersuchung teil und bin mit den Untersuchungsbedingungen und Datenschutzbestimmungen einverstanden.

This study was explained to me and all questions were answered adequately. I voluntarily participate in this study and agree to all the stated conditions and data protection.

____

(Datum, Name & Unterschrift **TeilnehmerIn**)

*(Date, name and signature of the **participant**)*

6.4 Appendix B.3.

Emotion Induction and Manipulation Check

Employing an established emotion induction procedure using a combination of music and autobiographic recall (Lench et al., 2011; Quigley et al., 2014), students were asked to put themselves in a personal event for 3 minutes that either made them feel enjoyment or anxiety, while the control group was asked to remember a common Wednesday morning intended to evoke no emotional response and to suppress activation levels (Kuhbandner et al., 2011). Depending on which group students were randomly assigned to, they listened to normed instrumental music shown to amplify/dampen the intensity of the emotional state being elicited (Eich et al., 2007; Gerrards-Hesse, Spies, & Hesse, 1994; Västfjäll, 2002; Zentner, Grandjean, & Scherer, 2008). All induction procedures had a length of 3:00 minutes in duration and were successfully pretested. Students rated the experienced intensity of affective states (1 = *not at all* to 5 = *very strong*) such that changes in emotional states could be determined. The activation scale comprised three items (active, attentive and alert) taken from the 'Positive and Negative Affect Schedule' (PANAS; (Watson, Clark, & Tellegen, 1988)) and additionally the discrete emotions "enjoyment" and "anxious" were assessed.

Two-way analyses of variances (ANOVAs) investigated the differences of affective ratings before (baseline) and after the emotion induction (manipulation check). No differences between discrete emotion ratings were found between the emotion groups for the baseline ratings, (Fs (1,240) <.21, ps >.24). However, further ANOVAs revealed statistically significant differences (all ps <.005) with very high effect sizes (all η^2s >.04, range from .04 to .55) between the three experimental groups for all ratings after the emotion induction for all affective variables (see Table B.3.). Benchmark values for effect sizes (based on η^2) were interpreted to be small (η^2 < .0099), medium (η^2 < .0588), or large (η^2 < .1379) based on findings typically reported in educational sciences (Cohen, 1988; Richardson, 2011b) (see Table B.3.).

Between (emotion groups) -within (affect ratings) analyses of variances revealed further that relative to the ratings obtained before the emotion induction, ratings of the manipulation check had changed substantially with regard to the enjoyment, anxiety and levels of activation between all three experimental groups (between-within analyses of variances), Pillai´s Trace: Vs> 0.06, Fs(2,243) > 8.27, ps < .001, partial η^2s > .06 (see Figure 2.2). Planned comparisons revealed that students in the enjoyment group reported significantly higher ratings on enjoyment (M = 4.08, SD = .97) as compared to the anxious (M = 1.59, SD = .84, p < .001, $CI_{95\%}$ [1.041,1.524]) or the control groups (M = 2.90, SD = 1.11, p < .001, $CI_{95\%}$ [.412,.899]) (see Table B.3.). On the other hand, students in the anxious emotion condition reported significantly higher ratings of anxiousness (M = 3.21, SD = 1.32) as compared to the enjoyment (M = 1.24, SD = .48, p < .001, $CI_{95\%}$ [-2.238,-1.710]) or the control group (M = 1.22, SD = .45, p < .001, $CI_{95\%}$ [1.730,2.255]) (see Table B.3.). Based on activation ratings, we found that after the emotion induction the enjoyment (M = 3.58, SD = .88) and anxious (M = 3.37, SD = .94) emotion groups showed equal levels of high activation, p = .14, $CI_{95\%}$ [-.069,.490], while the control group (M = 2.86, SD = .91) showed significantly lower levels of activation as compared to the enjoyment (p < .001, $CI_{95\%}$ [.435,.999]) and anxious (p < .001, $CI_{95\%}$ [.229,.785]) experimental groups (see Table B.3.).

Accordingly, we found that the emotion induction successfully created emotion groups allowing to differentiate discrete emotions between the three experimental groups. Precisely, we found that students in the enjoyment emotion condition (representing positive-activating emotions) reported above-average ratings on “enjoyment” (M = 4.08, SD = .97) as well as activation levels (M = 3.59, SD = .87). Similarly, we found that students in the anxious emotion condition (representing the group of negative-activating emotions) reported above-average ratings on “anxiousness” (M = 3.21, SD = 1.32) as well as activation levels (M = 3.37, SD = .94). The control group reported below-average ratings for “enjoyment” (M = 2.31, SD = 1.20) as well as “anxiousness” (M = 1.22, SD = .45) while levels of activation (M = 2.86, SD = .10) were significantly lower as compared to the enjoyment and anxiousness group (ΔMs > .51, ps <.001). Importantly, all two-way analyses of variances confirmed that there were no statistically significant main effects for task type (Fs (1,240) <.31, ps >.21) nor interaction effects of task type with emotions groups (Fs (1,240) <.21, ps >.18) thus confirming that the changes between emotion groups occurred equally for both tasks (see Table B.3.).

Table B.3.: Descriptive Statistics (Means and Standard Deviation) for discrete emotion ratings (before and after emotion induction) across emotion groups and tasks and F-Statistics of Two-way ANOVAs for Effects of Induced Affective Experiences across task type.

	Generation Task M (SD)			Evaluation Task M (SD)					
Emotion	Enjoyment (N_{total} = 40)	Anxious (N_{total} = 42)	Control (N_{total} = 42)	Enjoyment (N_{total} = 39)	Anxious (N_{total} = 43)	Control (N_{total} = 40)	Task Type $F(1,240)^a$	Emotion Group $F(2,240)^a$	Emotion Group x Task Type Interaction $F(2,240)$
Baseline Measures									
Enjoyment	3.30 (1.02)	3.00 (1.13)	2.86 (.93)	2.87 (.95)	3.02 (.94)	3.05 (1.04)	.31	.35	2.06
Anxiousness	1.28 (.55)	1.31 (.68)	1.36 (.62)	1.23 (.54)	1.35 (.57)	1.25 (.54)	.25	.36	.33
Active	3.28 (.82)	3.31 (.98)	3.05 (.94)	3.05 (.94)	3.28 (.93)	2.88 (.94)	.23	2.73	.24
Awake	3.55 (.90)	3.31 (1.09)	3.38 (.88)	3.56 (.79)	3.47 (.91)	3.37 (1.03)	.21	.92	.18
Attentive	3.95 (.85)	3.71 (.89)	3.81 (.83)	3.74 (.79)	3.70 (.91)	3.85 (.94)	.29	.62	.42
Activation[b]	3.59 (.56)	3.44 (.77)	3.41 (.73)	3.45 (.65)	3.48 (.69)	3.37 (.84)	.30	.70	.31
Manipulation Check									
Enjoyment	4.13 (.79)	1.60 (.80)	3.02 (1.09)	4.03 (1.14)	1.58 (.88)	2.78 (1.12)	.93	132.54**(.53)	.31
Anxiousness	1.15 (.43)	3.17 (1.46)	1.29 (.51)	1.31 (.52)	3.26 (1.18)	1.15 (.36)	.11	147.28**(.55)	.64
Active	3.33 (1.16)	3.33 (1.16)	2.74 (.91)	3.64 (1.06)	2.93 (1.33)	2.77 (1.19)	.01	8.10**(.06)	2.06
Awake	3.80 (.88)	3.69 (1.07)	2.90 (.91)	3.74 (1.07)	3.60 (1.05)	2.83 (1.22)	.31	18.30**(.13)	.01
Attentive	3.30 (1.07)	3.45 (1.06)	3.00 (1.06)	3.72 (1.10)	3.19 (1.18)	2.90 (1.13)	.02	5.39*(.04)	2.13
Activation[c]	3.48 (.80)	3.49 (.94)	2.88 (.75)	3.70 (.94)	3.24 (.94)	2.83 (1.07)	.04	13.77**(.10)	1.41

Note. Measures of discrete emotions were obtained using a five-point rating scale assessing the intensity with which a discrete emotion was experienced: 1 = *not at all* to 5 = *very strong*) [a] Effect Sizes (η^2s) given in parentheses for significant results. *p <.005. **p < .001. [b]Mean rating across active, awake and attention (α = .66). [c]Mean rating across active, awake and attention (α = .80). No homogeneity of variances assumption were violated (all ps > .05).

6.5 Appendix B.4.

Piloting and coding experimental tasks

The generation task asked to list as many valid ideas as students could think of relative to the provided theoretic frame. We coded each person's responses on three dimensions (DeHaan, 2011; Guilford, 1967; Torrance, 1966): (1) fluency indicated the total number of generated ideas, (2) originality indicated the relative uniqueness score of each idea, and (3) total number of distinct theoretic categories from which the ideas were pulled. The first category was a simple count of the unique individual ideas produced by each student. To calculate originality (2), we created an originality score for each unique idea as the number of persons who did generate this idea, divided by the number of persons in the sample. Finally, to calculate cognitive flexibility (3), the compiled ideas were categorized independently by two mathematics experts resulting in seven unique theoretic categories covering the theoretic grounds of all generated ideas. Accordingly, it was calculated for each students from how many of those seven theoretic categories the ideas had been derived.

A third of the generated ideas were double coded by two independent raters resulting in a high interrater agreement (ICC = 0.88, Cohen's Kappa (k) ranged from .73 to 1.00, $M = .90$, $SD = .08$) indicating overall a very good reliability of the coding scheme (see Appendix B.5. for coding scheme and frequencies of responses).

The evaluation task asked to identify presented ideas as being "true" or "false". The two independent measures for the evaluation task were operationalized by the numbers of ideas correctly identified as "true" (validation of ideas) and "false" (refutation of ideas).

The pilot testing for both experimental tasks done with an independent sample of 53 mathematics students (34 male, 19 female), more than 25 per task type, who were of the same approximate age and mathematics study programs as participants in the main experiment. More than 25 students solved each tasks and results were analyzed by separate t-tests. Participants were asked two questions after working on the tasks: "How well do you think you did on the task?" and "How difficult did you find the task?" and responded on scales ranging from 1 = *very poorly/ not difficult at all* to 5 = *very well/very difficult*. An independent-samples t-tests for each question revealed that tasks were not significantly different (generation task: $M = 2.90$, $SD = .82$, evaluation task: $M = 3.08$, $SD = .86$) nor did students perceived competence relative to the task differ (generation task: $M = 2.48$, $SD = .91$, evaluation task: $M = 2.64$, $SD = .99$; ts > .68, $p < .37$). Participants were also queried about the intensity of the epistemic emotions they experienced (EES, (Pekrun et al., 2016)). Each item consisted of a single word describing one discrete emotion (e.g., curious, surprised, confused, anxious, frustrated, excited, bored) and were assessed as intensity ratings (1 = *not at all* to 5 = *very strong*). The independent-samples t-tests for each epistemic emotions separately revealed that tasks did not significantly differ in their emotional profiles regarding the epistemic emotions that were trigged (all ts > -.03, p < .45) (see Table B.4. for mean differences).

Table B.4.: *Pilot test for experimental tasks: Descriptive Statistics (Means and Standard Deviations) and independent samples t-tests investigating differences in reported epistemic emotions, task difficulty and self-reported competence between the experimental tasks.*

	Task Type		
	Evaluation	Generation	
	N = 27	N = 26	
Variables	*M (SD)*	*M (SD)*	*t*
Epistemic Emotions			
Curiosity	2.93 (1.04)	2.79 (1.03)	t (53) = .50
Surprise	2.30 (1.03)	2.36 (1.22)	t (53) = -.20
Confusion	2.67 (1.14)	2.55 (1.35)	t (54) = .34
Anxiety	1.41 (.89)	1.21 (.62)	t (54) = .99
Frustration	1.96 (1.16)	1.90 (1.08)	t (54) = .22
Enjoyment	2.15 (1.03)	2.31 (.85)	t (54) = -.65
Boredom	1.89 (1.01)	1.90 (.94)	t (54) = -.03
Task difficulty	3.08 (.86)	2.90 (.82)	t (52) = .80
Self-reported competence	2.64 (.99)	2.48 (.91)	t (52) = .61

Note. No mean difference was significant (all ps > .05 (two-tailed)).

6.6 Appendix B.5.

Experimental Task Instructions and Coding Schemes

Instruction for Generation and Evaluation Task

Betrachten Sie ein beliebiges Parallelogramm ABCD in der Ebene, über dessen Seiten [CD] und [DA] gleichseitige Dreiecke konstruiert wurden, wie beispielsweise in der folgenden Figur.

Consider an arbitrary parallelogram ABCD in the plane with equilateral triangles constructed over the sides [CD] and [DA], as for example in the following diagram.

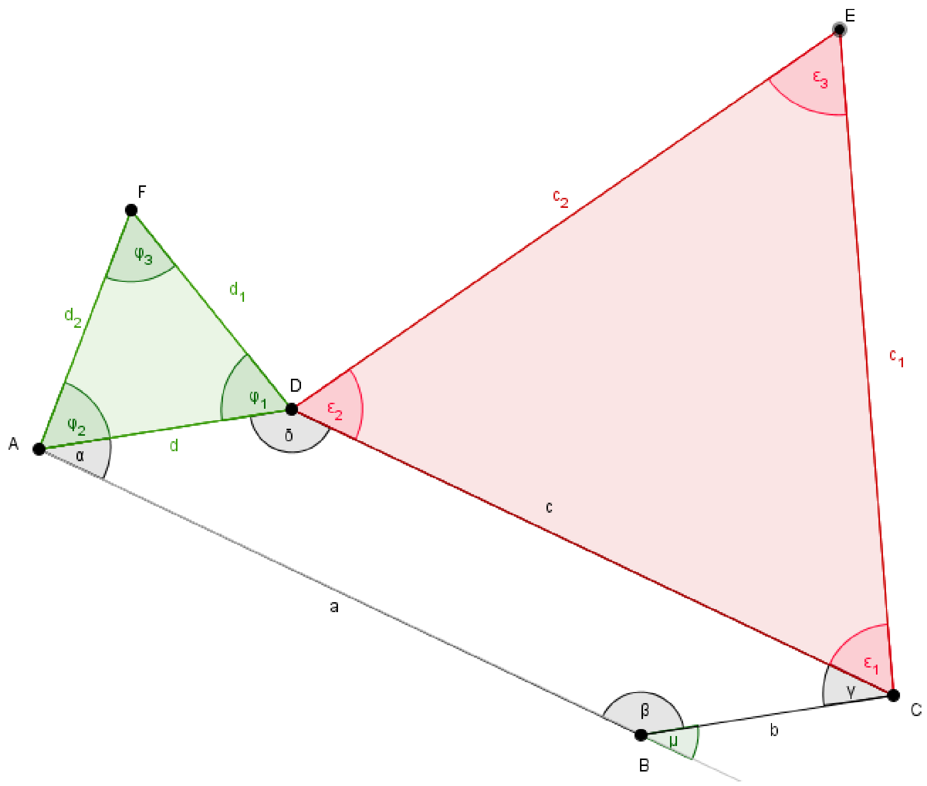


Abb. 1. Parallelogramm mit zwei gleichseitigen Dreiecken

Fig. 1. *Parallelogram with two equilateral triangles.*

Instruction for Generation Task

Bitte tragen Sie hier nacheinander die Aussagen ein!
Please write your statements here, one after the other!

	Aussagen / ***Statements***
1	
2	
3	
4	
5	
6	
7	
8	
9	
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11	
12	
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19	
20	
21	
22	
23	
24	
25	

Instruction and Coding Scheme for Evaluation Task

Wenn Sie die Aussage für richtig halten, setzen Sie bitte ein „X“ in die Spalte **Richtig.**

If you consider a statement as correct, please mark it with „X“ in the column ***correct.***

Wenn Sie die Aussage für falsch halten, setzen Sie bitte ein „X“ in die Spalte **Falsch.**

If you consider a statement as false, please mark it with „X“ in the column ***false.***

	Aussagen / Statement	Richtig/ *correct*	Falsch/ *false*
1	$\overline{CE} = \overline{DE} = \overline{AB}$	X	
2	Die Mittelsenkrechte von [AD] ist parallel zur Gerade FC. *The perpendicular bisector of [AD] is parallel to the line FC.*		X
3	$\overline{AC} = \overline{CF}$		X
4	$\gamma + \delta = 180°$	X	
5	$\measuredangle BAF = \measuredangle ECB$	X	
6	Die Gerade AF ist parallel zur Gerade CE. *The line AF is parallel to line CE.*		X
7	$\overline{DF} = \overline{AF} = \overline{CB}$	X	
8	$\overline{BE} = \overline{BA}$		X
9	$\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 60°$	X	
10	$\overline{CF} = \overline{CA}$		X
11	$\varepsilon_1 + \gamma = \measuredangle EDF$	X	
12	Das Parallelogramm ABCD ist punktsymmetrisch. *The parallelogram ABCD is symmetric under point reflection.*	X	
13	Das Dreieck BCE ist kongruent zu Dreieck FDE. *The triangle BCE is congruent to the triangle FDE.*	X	
14	$\measuredangle EDF = 90°$		X
15	Das Dreieck ABF ist kongruent zu Dreieck ECB. *The triangle ABF is congruent to the triangle ECB.*	X	
16	Die Dreiecke ABC und CDA sind kongruent zueinander. *The triangles ABC and CDA are congruent.*	X	
17	$\overline{BE} = \overline{BF}$	X	
18	Alle Winkelhalbierenden des Parallelogramms ABCD schneiden sich in einem Punkt. *The angle bisectors in the parallelogram ABCD intersect in exactly one point.*		X
19	F, D und B liegen auf einer Geraden. *F, D and B form a straight line.*		X
20	$\overline{EF} = \overline{EB}$	X	
21	$\measuredangle CDF = \measuredangle CDA$		X
22	$\overline{EF} = \overline{BF}$	X	
23	Die beiden gleichseitigen Dreiecke ADF und DCE sind punktsymmetrisch. *The two equilateral triangles ADF and DCE are symmetric under point reflection.*		X
24	$\delta + \measuredangle EDF = 240°$	X	
25	Die Dreiecke EDA und CDF sind kongruent zueinander. *The triangles EDA and CDF are congruent.*	X	

Bitte beantworten Sie die Aussagen der Reihe nach!

Please answer one statement after the other!

Coding Scheme for Idea Generation Task

Frequency Table of Number of Generated Ideas

Coded Variable	Generated idea	Theoretic Category[a]	Frequency	Cumulative %
1	Sum of interior angles in equilateral triangles: $\varepsilon_1 + \varepsilon_2 + \varepsilon_3 = \gamma_1 + \gamma_2 + \gamma_3 = 180°$	1	33	27.1%
2	All angles are equal in equilateral triangles: $\varepsilon_1 = \varepsilon_2 = \varepsilon_3$	1	90	73.8%
3	$\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \gamma_1 = \gamma_2 = \gamma_3 = 60°$/ $\varepsilon_i = \gamma_i = 60°$, $i \in \{1,2,3\}$	1	36	29.5%
4	$\alpha + \beta + \gamma + \delta = 360°$	2	27	22.1%
5	$A_{ABCD} = a \bullet h_a$	4	1	0.08%
6	Sum of adjacent angles in parallelogram: e.g. $\alpha + \beta = 180°$		15	12.3%
7	Sum of adjacent angles at crossing lines: $\beta + \mu = 180°$	3	31	25.4%
8	Equality of opposite angles in parallelogram: i.e. $\alpha = \gamma$; $\beta = \delta$	2	84	68.9%
9	Equality of corresponding at a tansversal of two parallel $\alpha = \mu$	5	41	33.6%
10	Opposite sides in parallelogram have equal length: i.e. $\overline{AB} = \overline{CD}$	2	92	75.4%
11	Properties of equilateral triangles concerning lengths of sides	1	88	72.1%
12	Opposite sides of a parallelogram are parallel: i.e. (AD || BC/AB || CD)	2	26	21.3%
13	Similarity of triangle ADF and triangle DCE (AAA similarity theorem), or there is an $x \in \mathbb{R}$, such that (at least two of the following): $\overline{AD} = x \bullet \overline{DC} = x \bullet \overline{CE} = x \bullet \overline{ED}$ $\overline{DF} = x \bullet \overline{DC} = x \bullet \overline{CE} = x \bullet \overline{ED}$ $\overline{FA} = x \bullet \overline{DC} = x \bullet \overline{CE} = x \bullet \overline{ED}$	6	4	3.27%
14	Pythagoras' theorem involving the height of an equilateral triangle	7	1	0.08%
15	The two triangles that arise from cutting a parallelogram along a diagonal are congruent.	6	1	0.08%
16	Arguments involving the definition angle measure via the full angle (360°).	3	2	0.16%
17	ADF or DCE are isosceles triangles	1	4	0.33%
18	FEB is equilateral	6	1	0.08%
Total	**18 unique generated ideas**	**7**	**577**	

Note. [a]Theoretical categories of idea based on which „cognitive flexibility“ as a dependent measure was scored: 1 = characteristics of equiliteral triangles, 2 = characteristics of parallelogram, 3 = Direct application of statements about angles at two crossing lines, 4 = Statements about relations of areas, and area formulas, 5 = Direct application of statements about angles at transversals oft wo parallel lines, 6 = Relations that go beyond direct application of single theorems about lengths and angles, 7 = Pythagoras theorem.

6.7 Appendix C

Coding Scheme for Quality and Quantity of Proof Performance

Coding scheme of proof performance

Order	Statement	Theoretical Argument
1	∡DAF = ∡DCE	characteristics of equilateral triangles
2	$\alpha = \gamma$	characteristics of parallelogram
3	∡BCE = ∡BAF	Based upon step 1 and 2, decomposing of angles
4	AB = CD	characteristics of parallelogram
5	CD = CE (or ED)	characteristics of equilateral triangles
6	AB = DE (or CE)	Based upon step 4 and 5, direct application of statements about angles at transversals oft wo parallel lines
7	AF = AD (or FD)	characteristics of equilateral triangles
8	AD = BC	characteristics of parallelogram
9	AF = BC	Based upon step 4 and 5, direct application of statements about angles at transversals oft wo parallel lines
10	3, 6, 9 → The two triangles that arise from cutting the parallelogram along a diagonal are congruent.	Based upon steps 1, 4, and 5; congruency
11	BF = BE	Based upon step 10, characteristics of equilateral triangles
12	FEB is equilateral	Based upon step 11, identifying relations that go beyond direct application of single theorems about lengths and angles
13	→ ∡BFE = ∡EFB	Based upon step 12, characteristics of equilateral triangles

For each step scored, the following quality indicator was coded:

Score	Quality of Level reached
0	Statement not mentioned and not marked in figure (and therefore no theoretical argument was provided)
1	Statement was claimed
2	Statement was marked in figure
3	Statement was marked and claimed in figure
4	Statement was claimed and theoretical argument was provided
5	Statement was marked in figure and theoretical argument was provided
6	Statement was marked and claimed in figure and theoretical argument was provided

Computations of Performance Indicators

Dependent Variable	Label	Computed by
1	the number of arguments logically constructed to formulate the proof (based on premises and conclusions	Absolute count
2	the number of arguments to which a mathematical justification had been added (i.e., a direct reference to a mathematical theory)	Absolute count
3	the quality of those arguments (i.e., integration of arguments)	Average argument quality for each step in proof path was divided by the total amount of steps claimed

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