Higher Ideation: Supporting Creative Thinking and Adaptive Expertise in Undergraduate STEM Students

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Table of Contents

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Preface and Contributions of Authors

I am the primary author of each manuscript and am therefore responsible for their content. I wrote the chapters independently with valuable feedback from Dr. Susanne Lajoie. An earlier version of Chapter 2 was written as partial fulfillment of my comprehensive exam, and as such it benefited from valuable feedback from Dr. Susanne Lajoie and Dr. Alenoush Saroyan as members of the comprehensive exam evaluation committee. Both manuscripts are being prepared for submission to a peer reviewed journal.

Chapter 2

Contributions

I selected the topics, conducted the literature reviews and wrote the entire manuscript. The current version incorporates feedback received on the initial version from my comprehensive exam evaluation committee, as above.

Chapter 4

Contributions

I wrote the manuscript in its entirety, with feedback on the completed draft from supervisory committee members Dr. Susanne Lajoie and Dr. Alenoush Saroyan. I was responsible for conceptualizing the proposed relationships among variables and generating the research questions. The data form a previously uninvestigated subset of a larger study, with data collection procedures for the larger study chiefly conducted by Dr. Amanda Jarrell and Dr. Tara Tressel. I contributed outcome measures of particular interest for my research, generated a qualitative research question for participants in my specific domain, and contributed to the collection of data and interaction with participants. I selected, proposed, and conducted the statistical analyses and interpreted the data. My conclusions are original and distinct contributions to knowledge.

Abstract

To better prepare university graduates for an increasingly unpredictable future, there is growing pressure to promote the essential abilities and aptitudes for adaptive (versus routine) expertise, creative thinking, and innovation. However, the mechanisms underlying the development and support of innovation skills in post-secondary achievement settings are underexplored. This dissertation addresses this gap. The first manuscript provides a comprehensive review and comparative analysis of the literature on adaptive expertise and creative thinking, suggesting that they overlap as "applied creative thinking". It further reviews research on how emotions and goals influence creative thinking. The second manuscript uses a mixed methods approach to empirically test the relationships between ideation (a type of creative thinking) on one hand, and achievement emotions, achievement goals, and learning strategies on the other. With a sample of 119 undergraduate STEM (Science, Technology, Engineering, and Math) students, we explored direct and indirect relationships between the constructs, as well as differences in patterns by gender and by year of study. We also obtained students' own perceptions of barriers and facilitators to creative thinking within their programs. Results of our mediation analyses suggested that hope was a particularly salient emotion for higher levels of ideation (both directly and indirectly), and mastery goals played a facilitating role. Conditional effects analyses revealed that positive emotions support ideation early in the program, and negative emotions suppress it later in the program, for female students. Critical thinking and creative thinking were closely related for both genders at every level of STEM study. Rigidity and evaluation were perceived as the main barriers to creative thinking, while flexibility and inquiry were identified as key facilitators. A new model for integrating the findings is proposed, and implications for theory and practice are discussed.

Résumé

Afin de mieux préparer des diplômés universitaires pour l'avenir, il existe une pression croissante pour réviser les résultats d'apprentissage de l'enseignement supérieur afin d'inclure également les capacités et aptitudes essentielles en matière d'expertise adaptative (par opposition à routinière), de pensée créative et d'innovation. Cependant, les mécanismes sous-jacents au développement et au soutien des compétences en innovation dans les contextes postsecondaires sont sous-explorés, et le but de cette thèse est de combler cette lacune. Le premier manuscrit fournit une analyse comparative de la littérature sur l'expertise adaptative et la pensée créative, suggérant qu'elles se chevauchent en tant que «pensée créative appliquée»; ainsi qu'une synthèse des recherches antérieures sur la manière dont les émotions et les buts influencent la pensée créative. Le second manuscrit utilise une approche de méthodes mixtes pour tester de manière empirique les relations entre l'idéation (une compétence d'innovation; appliquer les connaissances acquises pour créer de nouvelles idées), et les émotions, les buts, et les stratégies d'apprentissage, dans un échantillon de 119 étudiants de premier cycle en STIM (sciences, technologie, ingénierie et mathématiques). Nous avons exploré les relations directes et indirectes entre les concepts, et les différences dans ces relations selon le sexe et l'année d'études. Nous avons également demandé aux étudiants quels facteurs soutiennent ou empêchent la pensée créative dans leur programmes, d'après eux. Les résultats de nos analyses de médiation ont suggéré que l'espoir était une émotion particulièrement importante pour des niveaux plus élevés d'idéation (avec des effets directs ainsi qu'indirects), et que les buts de maîtrise jouaient un rôle facilitateur. Les analyses des effets conditionnels ont révélé que les émotions positives soutiennent l'idéation au début du programme et que les émotions négatives la suppriment plus tard dans le programme, notamment chez les étudiantes. La pensée critique et la pensée créative étaient étroitement liées pour les deux sexes à tous les niveaux des études STIM. La rigidité et

l'évaluation ont été perçues comme les principaux obstacles à la pensée créative, tandis que la flexibilité et l'investigation raisonnée (« inquiry ») ont été identifiées comme des facilitateurs clés. Un nouveau modèle est proposé pour intégrer ces résultats, et les implications pour la théorie et la pratique sont discutées.

List of Tables

List of Figures

List of Appendices

Chapter 1. Introduction

During previous industrial revolutions, the slow pace of change allowed people and society time to adjust to new technologies and new ways of doing things. Today, the accelerating rate of scientific and technological breakthroughs has contributed to "knowledge mayhem" (Barnett, 2000), and labour markets are changing dramatically (Manyika et al., 2017; World Economic Forum, 2018).

Meanwhile, universities, governments and economic leaders (e.g., Government of Canada, 2018; Universities Canada, 2018; World Economic Forum, 2018; Wunker & Farber, 2015) have issued broad calls for innovation, as well as reskilling and upskilling the workforce. These demands for innovation in response to societal and technological transformations are intensifying pressure on the education sector: according to Jahanian (2018), "the future of work is changing faster than our old models of education can accommodate" (para. 20). However, a road map of "what" specifically needs to change, and "how", is as yet unwritten.

Educational research has routinely focused on learning outcomes measuring "how much" learning has occurred, using traditional academic metrics (such as GPA) as a barometer of knowledge acquisition. Less attention has been paid to how learners use and access their knowledge to make something of what they have learned; i.e., to create and innovate. An additional challenge arises from the fact that the meaning of the term "innovation" is often vague and sometimes used synonymously with basic research. To that end, the Conference Board of Canada (2018) has defined innovation as "a process through which economic or social value is extracted from *knowledge*—by creating, diffusing, and transforming *ideas*—to produce new or improved products, services, and processes" (para.5, italics added).

Building on this definition, which grounds innovation in *ideas* based on *knowledge*, the purpose of this dissertation is to develop a better understanding of the elements in higher education that support creative skills and adaptive expertise, versus routine knowledge acquisition. We will examine these questions through theories of creativity (the idea dimension) and theories of expertise (the knowledge dimension). The first manuscript (Chapter 2) begins by looking for common ground by reviewing, comparing, and contrasting the literature in these two separate strands of inquiry. We also provide a review focusing on constructs in educational psychology that are known to influence learning outcomes (namely, achievement goals and achievement emotions), and examine how they may be expected to influence creative thinking. The second manuscript (Chapter 4) addresses these questions through an empirical mixed methods exploration of the intersection between the achievement constructs and creative thinking. Data were collected from a sample of undergraduate Science, Technology, Engineering, and Math (STEM) students, and in addition to completing various self-report measures (including a measure of divergent thinking), the students were invited to share their perceptions of factors that support or suppress creative thinking in their respective programs of study. As predicted based on the review in Chapter 2, positive emotions were largely supportive, and negative emotions suppressive, of ideation. Chapter 4 discusses how certain emotions emerged as particularly influential, and significant gender and year of study differences were evident in the patterns by which affect and motivation impacted creative thinking. Limitations and future directions based on the findings are also discussed in Chapter 4. Finally, Chapter 5 provides an overall conclusion, implications for teaching and learning, and a summary of scientific contributions from this dissertation.

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Chapter 2. Manuscript 1

Adaptive Expertise and Creative Thinking: What Are They, and How Do They Relate to Achievement Emotions and Goals?

Abstract

This article presents a critical review and synthesis of theories in two distinct bodies of the research literature: adaptive expertise and creative thinking. Based on our analysis, we propose that the two constructs overlap as "applied creative thinking", denoting the kind of creativity that occurs when learned knowledge or acquired expertise is used adaptively and creatively. We further review influential theories in the domains of achievement emotions and achievement goals with respect to their influence on creative thinking in achievement settings. The findings broadly suggest that positive emotions and approach behaviours generally support creative thinking, particularly mastery approach which tends to be powered by creativity-supporting intrinsic motivation. For negative emotions and avoidance behaviours, we found mixed results in the literature, although they were more likely to hinder than help creative thinking. Implications for teaching and learning in achievement settings are discussed, and directions for future research to better support the skills and competencies needed by graduates in an innovation society are suggested.

The need for quality education has never been higher, but universities are often criticized for not producing graduates with sufficient ability or expertise in creativity or innovation (e.g., The Conference Board of Canada, 2016). In order to give university graduates the skills and attitudes they will need to be productive members of our rapidly changing society, higher education must approach teaching and learning with a sharper focus on flexible, adaptive skills and attitudes that support creativity and innovation, rather than imparting a body of inert knowledge. The purpose of this manuscript is to first outline the theoretical underpinnings of adaptive (in contrast to routine) expertise, as well as creative thinking, and draw some inferences about the linkages between the constructs. Secondly, we will examine how emotions and goals can interact in achievement settings to support or suppress adaptive, creative thinking in learning contexts. Finally, implications for higher education in the "innovation age" (Sawyer, 2014) will be discussed.

Conceptual Links Between Adaptive Expertise and Creative Thinking

Theories of Expertise

Theories of expertise describe how novices incorporate new knowledge with prior knowledge to gradually become experts in their domain (e.g., Chi, Glaser, & Farr, 2014; Lajoie, 2003; Sawyer, 2011). According to these theories, judicious, timely, and consistent use of relevant and targeted learning strategies allows novices to proceed through a continuum of levels of the "proficiency scale" of knowledge building, becoming first experts and then masters (Chi, 2006). Expert knowledge is built by reinvesting mental resources through continually higher levels of challenge (Tynjälä, Nuutinen, Eteläpelto, Kirjonen, & Remes, 1997). Viewing expertise as relative rather than absolute is based on the assumption that expertise can be developed by most students, conceptualizing learning as the path to expertise (Chi, 2006).

Experts are then recognized by "reproducibly superior performance" in "the representative activities that define the essence of accomplishment in a given domain" (Ericsson, 2006, p. 687). Other attributes include faster and more accurate performance in their respective domains, using higher levels of metacognition to access highly organized knowledge structures (Chi et al., 2014).

Adaptive expertise. There is evidence that qualitatively different types of expertise can be identified. Hatano and Inagaki (1986) referred to the two types as "routine expertise" and "adaptive expertise". Routine experts continue honing their skills to perform them with greater efficiency over time, while adaptive experts are able to access their interconnected knowledge networks fluidly and flexibly to push the boundaries, be creative, and innovate (Bransford, Brown, & Cocking, 2000). Adaptive experts' knowledge representations are more flexible, allowing them to respond to novel situations more effectively (Schwartz, Bransford, & Sears, 2005).

Different content domains offer different ways of organizing knowledge and developing adaptive expertise. In math learning, for example, researchers have found that the progression from conceptual to procedural knowledge (a form of adaptive expertise) is made possible by well-connected knowledge, allowing for transfer and flexibility as well as effective strategy use (Baroody & Dowker, 2013; Newton, Star, & Lynch, 2010). Similarly, in medicine, it has been suggested that the organisation and coordination of knowledge is more important (for expert performance) than the amount of knowledge (Eva, 2005).

One of the key tenets in theories of expertise is that once expertise is attained, there is a level of automaticity to learned tasks. The emerging expert's knowledge is contextually interlinked and connected into networks, allowing for the recognition of underlying patterns in

the domain. Such growing automaticity frees up cognitive resources for other tasks and allows learners not to be overwhelmed by the continual processing of previously learned material (Bransford et al., 2000). However, some theorists have argued that high levels of expertise may be an impediment to creativity and adaptability (Ericsson, 1996; 1998; Weisberg, 2006), and Davis, Rimm, and Siegle (2011) also suggested that the simple force of habit may inhibit creative thinking. The concern is that unless these tendencies are actively resisted, our universities may continue to produce graduates who possess expert knowledge but cannot reliably access or apply it fluidly or innovatively (Hatano & Oura, 2003; Sternberg, 2003).

Too much of a good thing? Even when education aims for adaptive, innovative knowledge building, these efforts can be hampered by routine expertise, the more efficient cousin of adaptive expertise (Schwartz et al., 2005). Researchers have found that the more practise individuals have with a given task or problem-solving algorithm, the less adaptively they will be able to meet changing task demands (e.g., Feltovich, Spiro, & Coulson, 1997). In workplace settings, employees with more experience on the job have been found to have more difficulties adapting to new organizational and task demands, regardless of chronological age (Niessen, Swarowsky, & Leiz, 2010). Sawyer (2012) argued, based in part on findings by Simonton (1983), that although learners must have enough training to internalize a domain, there may exist a tipping point beyond which further training only serves to "oversocialize" the learner and results in rigid thinking and behaviour. Sternberg and Frensch (1992) also pointed out how easily people can fall into mental routines and ruts in thinking because of the automaticity of processing in expert domains. While expert knowledge allows people to react more quickly and accurately in well-structured environments that respect established patterns of the domain, the knowledge does not always carry over into ill-structured problem spaces (Devine & Kozlowski,

1995). Sometimes domain rules can change as a result of external stimuli, and when that happens, experts have varying levels of adaptability to the new situation (Bransford et al., 2000).

The pattern recognition that is a hallmark of expertise relies on stimuli that correspond with patterns that follow the rules within the known domain, triggering routine responses and thought patterns. Some experts are unable to detect anomalies and apply their expertise to the new conditions because their knowledge is "conditionalized" to the original circumstances (Bransford et al., 2000). An often-cited example is Luchins' (1942) water jug task. In this experiment, participants were asked to solve a series of problems involving water jugs, and the same type of solution was initially the most effective (and correct) one for many problems solved in sequence. However, when the problem parameters were changed, participants continued to apply the same solution even though a simpler one was available, demonstrating the so-called *Einstellung* effect (Luchins, 1942). In the context of expertise, the *Einstellung* effect illustrates how routine expertise can lead to functional fixedness, or the automatic, habitual selection of previously known solutions (Duncker & Lees, 1945). The development of adaptive expertise can thus be impeded by automaticity (Mylopolous & Woods, 2009), and Barrett (1998) suggested the need to deliberately interrupt routine habits for creative adaptability.

In general, researchers agree that adaptive expertise subsumes routine expertise (Hatano & Oura, 2009; Martin, Petrosino, Rivale, & Diller, 2006). The efficiency afforded by the speedy (routine) recall of foundational knowledge is often the basis of innovation in a domain (Schwartz et al., 2005), and adaptive experts are able to use their domain content knowledge to respond to new situations innovatively. In doing so, they draw on additional cognitive and metacognitive skills to move beyond routine expertise (Crawford, Schlager, Toyama, Riel, & Vahey, 2005; Martin et al., 2006), and create new knowledge through their responses (Mylopoulos & Woods,

2009). One of the most commonly used definitions of adaptive expertise captures these distinctions: "Whereas routine experts are able to solve familiar types of problems quickly and accurately, they have only modest capabilities in dealing with novel types of problems. Adaptive experts, on the other hand, may be able to invent new procedures derived from their expert knowledge." (Holyoak, 1991, p. 312). The role of metacognition is especially important when inventing new procedures that go beyond well-established skills, and when tasks involve effortful searching and development of new alternatives (Kozlowski et al., 2001). Routine expertise tends to develop first, and adaptive expertise may emerge later when experts need to apply their knowledge flexibly due to a challenging situation.

Settings for adaptive expertise research. The literature acknowledges two distinct settings for cultivating the complex competencies required for adaptive expertise, namely higher education (including continuing education) and the workplace (Hytönen, Palonen, Lehtinen, & Hakkarainen, 2016). With new technologies continually disrupting organizational cultures and work methods (Vaill, 1996), it is not surprising that research on adaptive expertise also takes place in organizational settings.

One of the foci of organizational research on adaptive expertise is the concept of personal adaptability, which has become a necessary "career metacompetency" in the 21st century (Hall, 2002). The ability to learn includes individual understanding of what kind of learning is needed, as well as the initiative and motivation to pursue relevant learning opportunities (Hall & Chandler, 2005; Schraub, Michel, Shemla, & Sonntag, 2014). Additionally, incidental learning occurs when workers simply adapt to unexpected and previously unknown situations in the environment. Individuals in novel situations who already possess a level of expertise in their field tend to react in ways that create new knowledge while

they solve problems at the "growing edge" of their expertise (Bereiter & Scardamalia, 1993). This concept has parallels with the notion of the mathematical "edge of chaos" (Farmer, 1986), which sometimes applies to strategic organizational change under the umbrella of complexity theory (Burnes, 2005). Individuals creating new knowledge on the "growing edge" need to be mindful of not falling *off* the edge, while at the same time pushing the outer edge of their envelope. Venturing too far from current expertise would cause "chaos", or at least the appearance of extreme incompetence. Successfully innovative organizations, like innovative individuals, must keep a firm footing in their sector(s) of core competencies, while at the same time enacting disruptive change around the edges.

New solutions devised by adaptive experts become a part of the shared knowledge within the community of practise. However, because new solutions arise from day-to-day practise, they can be ad hoc or unplanned, reinforcing the view that adaptive experts have of themselves that does not extend to being a knowledge creator or innovator (Mylopoulos & Scardamalia, 2008). Bereiter and Scardamalia (1993) framed expertise as an active process rather than simply the possession of inert knowledge. Promoting the concept of adaptive expertise and innovation as a productive process that experts engage in through their daily problem-solving activities would support the development of more effective knowledge-sharing among experts (Mylopoulos & Scardamalia, 2008). It would also allow experts to elevate the construct of adaptive expertise into a deliberate, purposeful process within their communities of practice.

This concludes the review of adaptive expertise. In the next section we will review a second main construct, creative thinking, followed by a critical analysis suggesting linkages and common ground between the two.

Creative Thinking

Creativity in school. The focus of the current paper is on higher education, but many of the studies about creativity and education have taken place in K-12 settings. A brief overview of this body of work is included here, because much of what is fundamentally understood about creativity has been studied in school environments. Understanding this research, even though it was conducted with a younger demographic, can provide insights into cultivating creativity in higher education.

Traditional types of teaching and learning, prevalent in many schools, may have a detrimental effect on the creativity of K-12 learners, and consequently such learners may arrive at the doors of higher education less than optimally creative. Young children are intrinsically and naturally creative, learning about their world through play and the exploration of objects and thoughts without undue directive control from outside. In the early years, human imagination is allowed free rein to build and create images of possible but not yet available ideas and concepts (Vygotsky, 2004; Kudryavtsev, 2011). Land and Jarman (1993) found that students typically experience a considerable decrease in their ability to engage in creative activity as they progress through the school system, and Ross (1976) discovered a decline in creativity from early adolescence (sixth grade) to later adolescence (tenth grade). Creative thinking scores have been decreasing overall among students since 1990, even as IQ and SAT scores have been rising (Kim, 2011).

The decrease in creative thinking through the teen years is all the more perplexing when viewed through Piaget's (1972) theory of formal operations. According to this theory, the most advanced level of cognitive development occurs after age 12, when the mind is able to imagine abstract concepts and use them to solve problems. Intuitively, one might expect a newfound

ability for abstract thought to contribute to an increase, rather than a decrease, in creativity among adolescents, because the mind is now able to conceive of a multitude of prospective ideas and possibilities which are not yet evident or tangible. Nonetheless, traditional methods of schooling--coupled with the intense pressure to conform to peer expectations in adolescence--may be at least partly to blame for a drop in creativity through secondary school. This raises the possibility that one of the roles of higher education may be to reawaken the creative potential that has been suppressed through adolescent schooling.

Compared to the prescribed nature of K-12 schooling, post-secondary education offers more options that may better align with the particular personal interest of learners. According to Renninger, Hidi, and Krapp (2014), student interest may engender deeper engagement and consequently better learning. However, there is little evidence that interest also leads to more creative thinking in post-secondary education. The supportive roles of enjoyment and interest have also been implicated in the theory of flow, or the state of being so totally engrossed in an activity that actions flow effortlessly and creativity seems to come naturally (Csikszentmihalyi, 1975, 1988).

Another factor that may contribute to the detrimental impact of conventional schooling on creativity is the standardized nature of the curriculum. Teaching every learner the same content regardless of interest, ability, or innate differences is not conducive to fostering creativity within the individual. Learners vary widely in their individual strengths and challenges, and Gardner's (1982, 2011) work on multiple intelligences provides a useful framework for understanding some of these differences and how to support creativity through individual strengths. He suggested that the nature of creativity varies by domain, and believed that psychometric creativity tests provided, at best, impoverished data. Gardner (2006) also claimed

that specific domains involve certain combinations of intelligences which differ between, for example, physics and political science. Accordingly, creativity within each domain should draw on different intelligences.

The testing and assessment of classroom learning in traditional schools is often task-extrinsic, and studies have shown that incentives and rewards arising from within this structure, such as grades in school, further contribute to a decrease in performance and interest in activities that are thus rewarded (e.g., Condry, 1977; Deci, 1971). Hennessey and Amabile (1987) also found that extrinsic situational factors can decrease creativity by decreasing intrinsic motivation. Situational motivation and perceptions of autonomy are positively related to flow (Kowal & Fortier, 1999), suggesting that learners need freedom and autonomy to control their learning environments in ways that optimize the context and content to support their innate strengths, aptitudes, and abilities. Optimal motivation results when the three main components of self-determination theory (relatedness, competence, and autonomy) are present and balanced within individuals (Deci & Ryan, 1985; Vallerand, Pelletier, & Koestner, 2008), and this balanced optimal motivation supports optimal creativity in learning settings. We will return to the connection between motivation and creative thinking later in this paper.

Changing definitions and theoretical perspectives in creativity research. Definitions of creativity are numerous and varied, but most of them follow the "bipartite standard definition" (Runco & Jaeger, 2012) whereby creativity includes both originality (novelty, uniqueness, newness) and effectiveness (value, appropriateness) (e.g., Amabile, 1983; Eteläpelto & Lahti, 2008; Gajda, Beghetto, & Karwowski, 2017; Lubart, 1994; Sternberg & Lubart, 1995; Walsh, Chappell, & Craft, 2017). Originality by itself might result in useless products or ideas and conversely, effective products or ideas alone may not contribute to new understanding or

knowledge. The conceptual overlap of the bipartite standard definition of creativity with routine and adaptive expertise will be discussed in a later section that links the two constructs.

One of the distinctions often made when discussing theories of creativity is between creative *persons, products, and processes* (Rhodes, 1961) and we will refer to these three P's throughout this section. More globally, Sullivan (2017) identified three main approaches among theories on creativity since the mid-20th century: the cognitive-psychology approach, the social-psychology approach, and the sociocultural approach. Although there is no clear beginning or ending date for each approach, recent theories generally place more emphasis on the sociocultural and collaborative aspects of creativity (Sawyer, 2011). In this section, we will outline the theoretical underpinnings of the construct of creative thinking, using the three approaches identified by Sullivan (2017) as a skeleton framework to build a narrative of the most influential theories during this active period in creativity research, and anchor the theories with reference to the 3P (person-product-process) trichotomy, as appropriate. The three approaches and 3P trichotomy are neither mutually exclusive nor necessarily clearly inclusive, but they contribute different insights to the argument and we will attempt to thread both organizing themes through the discussion.

In the early days of modern scientific creativity research (e.g., Guilford, 1950; Torrance, 1962), cognitive psychologists considered creativity to be an ability residing within the *person*, and research was focused on individual capacity for creative cognition. This view endured for decades, and Sternberg (1988) also focused much of his work on the psychology of the individual creative person. The person-oriented view was further entrenched by Simonton's (1994, 2003) and Gardner's (1993) work on eminence and creative genius. Researchers with this approach were interested in the personal capacity for creative cognition in individuals, and in

how eminent creators brought these abilities to bear to manifest their creativity. Only later did theories of creativity grow to encompass the social and contextual factors that may influence individuals' ability and willingness to express their personal creativity.

Beyond the cognitive psychology view. Subsequent theories of creativity added a layer of complexity to the "person" view by considering the interactions of the creative individual and his or her ideas with the environment, foreshadowing the social psychology perspective to come. Researchers became interested in the differing levels of impact that a creative person's output had on the domain, and the concept of "big C" and "little c" creativity was born as an accessible analogy for the societal importance of the creative acts and outputs under consideration. Big C embraced the person view of creativity, and described the domain-changing, eminent accomplishments of creative genius such as those studied by Simonton (1994) and Gardner (1993). However, by definition, others have judged the output of these eminent creators favourably in the field, and there is thus also *product*-orientation and a social psychology approach (Sullivan, 2017) to this view. In general, if we accept that effectiveness, usefulness, or value is a characteristic of creativity (e.g., Amabile, 1983; Eteläpelto & Lahti, 2008; Gajda et al., 2017; Lubart, 1994; Runco & Jaeger, 2012; Sternberg, 2006; Sternberg & Lubart, 1995; Walsh et al., 2017), then we must also accept that creativity is at least in part product-oriented. Without a creative product (some kind of visible, audible, perceptible or somehow tangible output of creative thinking or performance) it would be impossible to make value judgements. However, the product view is not without criticism. Runco (2004), for example, criticized the product view for confusing creativity with productivity. Additionally, the product view is "backward looking" because it compares new creative products with established standards in the field, potentially obscuring lessons to be learned from real-time creativity-in-the-making (Moran & John-Steiner,

2003). Here we should pause to note the conceptual similarity of the retrospective nature of the product view of creativity with theories about (routine) expert performance where, as mentioned earlier, assessments are designed to compare current performance with previously established standards (Ericsson, 1996; Lajoie, 2009).

In contrast to Big C and its focus on the "impressive" nature of creative outputs, little c creativity is conceptualized as a description of smaller acts of everyday creativity that require some expertise or knowledge and may contribute to the field, but are not genius, domain-altering breakthroughs (e.g., Beghetto & Kaufman, 2007; Runco, 2004). Beghetto and Kaufman (2007) found that having only two categories, Big C and little c, was inadequate to appropriately capture the nuanced types of creativity that occur, and suggested a refinement to the "false dichotomy" of Big C and little c. They posited that creativity can also be found in small, seemingly insignificant acts of learning, which they called "mini-c creativity". At the mini-c level, creativity refers to the transformation and interpretation that a learner applies to incoming information to build knowledge (cf. Mayer, 1996), in order to be able to later access the information for creative outputs (cf. Bransford et al., 2000; Schwarz et al., 2005). Kaufman and Beghetto (2009) further carved out the concept of "pro-c creativity", by which they meant the creativity that takes place in professional settings and can result in increased recognition in one's profession.

The social psychology focus (Sullivan, 2017) had much in common with the product view, and also produced several major theories of creativity that have stood the test of time. Among the best known are Amabile's (1983, updated in 1996 and 2013) componential model of creativity (Fig. 2); Sternberg and Lubart's (1991) investment theory of creativity; Csikszentmihalyi's (1988) systems view of creativity; Mumford, Mobley, Reiter-Palmon,

Uhlman, and Doares' (1991) creative process model; Runco and Chand's (1995) two-tier model of creative thinking; and Plucker, Beghetto, and Dow's (2004) conceptualization of creativity as the interplay of attitude, process, and environment.

In simplified form, Amabile (1983) initially proposed that three components at the individual level, namely domain expertise, creativity-relevant processes and task motivation come together for creativity to occur at their intersection. The impact of the social environment on the process was added only later (Amabile, 1996), reflecting the field's growing understanding of the critical impact the social environment can have on creativity. Amabile's (1983) multi-component model, especially after the (1996) inclusion of the effects of social environment, was one of the earliest theories looking at creativity holistically and systemically. Sternberg and Lubart's (1991) investment model suggested that creative individuals "buy low" (create ideas, or make existing ideas their own to develop further) from a group of ideas or thoughts that are not yet very popular (risking social criticism), and develop them to be able to "sell high" (successfully share them with their field or domain, underlining the importance of social connections in validating the creative output and approving of its usefulness). While acknowledging the role of the social context, other theories (Sternberg & Lubart, 1991; Sternberg, 2006) also still highlight the "product" aspect of creativity: The *value* of the creative product or idea is at the heart of the investment theory.

Csikszentmihalyi (1988, 2014) offered a systems view of creativity, pointing to the interactions between the individual, the field (social institutions that act as judges to determine the value of creative output), and the domain (a stable culture within which the new ideas are sustained over time). The systems view is a type of *process* view, and also an example of a social psychology approach because it takes into account complex multifaceted interactions not

only within the individual, but also the potentially recursive exchanges with his or her environment.

Finding and solving problems. Problem solving is often thought of as a specific kind of creative thinking; researchers have observed that "creativity" and "creative problem solving" are often used interchangeably in the literature (Basadur, Graen, & Green, 1982). Mumford, Medeiros, and Partlow (2012) applied the idea of creativity as a process to creativity as problem solving. They proposed that creative problem solving has four distinct stages and can only result from "the effective execution of complex cognitive processes" (p. 30), which they outlined in their Creative Process Model (Figure 3).

This creative process model specifically presumes that information and knowledge (expertise) lie at the heart of problem solving, that new knowledge is considered and incorporated with prior knowledge to generate new ideas, and that these ideas are then evaluated and developed into a creative project (Mumford et al., 2012). As the name indicates, this is a *process*-oriented model, but it is worth noting that the authors identified the purpose of the process to be a creative project, which will have as its outcome a *product*, and all the steps in the model are presumed to be completed by an individual (*person*).

Runco and Chand (1995) also adopted a *process* view of creativity: "In the natural environment, it is the interaction and collaboration of operations which get things done" (p. 245). However, while Mumford et al.'s (1991, 2012) creativity model was essentially a problem *solving* model, Runco and Chand's (1995, Fig. 4) two-tier model of creative thinking was based instead on problem *finding*, under which they included problem identification and problem definition. This distinction is important, because researchers have found that the most creative people are those who transform ideas into new problems by asking surprising questions, rather

than simply solving old problems (Sawyer, 2008). However, there are no specific tests for problem finding as yet (Sullivan, 2017), and this could be one of the reasons why problem finding has been considerably less researched than problem solving. Finding problems in ill-structured domains is particularly challenging (Osburn & Mumford, 2006), but thinking about problems from as many perspectives as possible is a good starting point for finding and formulating good problems (Csikszentmihalyi, 1996).

The central tenets of Runco and Chand's (1995) theory held that skills, knowledge, and motivational components work together to produce creative thinking. Comparing it with a simplified illustration of Amabile's (1998) componential theory (Fig. 5) highlights the considerable conceptual similarities between the two: Runco and Chand's (1995) "procedural and declarative knowledge" correspond with Amabile's (1998) "expertise"; Runco and Chand's (1995) component skills of "problem finding", "ideation", and "evaluation" are essentially examples of Amabile's (1998) "creativity skills", and both models highlight "motivation" as a critical component of creativity.

Given the multitude of theories and models of creativity presented above, we can see that defining, delimiting, and synthesizing these interrelated perspectives on creative thinking is a monumental task. This challenge was nonetheless taken up by Plucker et al. (2004), who analyzed 90 research articles about creativity (sampled from three different creativity journals) to examine the various definitions used and attempted to integrate them to arrive at a consensus. Their proposed definition is multifaceted and manages to include all three views (person, product, and process), the common bipartite definition (novel and useful), as well as the social context: "Creativity is the interaction among *aptitude, process, and environment* by which an

individual or group produces a *perceptible product* that is both *novel and useful* as defined within a *social context.*" (p. 90, italics in original).

Winds of change in creativity research. Plucker et al.'s (2004) proposed definition explicitly raised the possibility of groups as creative agents, bringing us to the third approach to creativity research, namely sociocultural perspectives (Sullivan, 2017). Under the broad umbrella of social constructivist learning pedagogy (Piaget, 1985; Vygotsky, 1978) the sociocultural perspective on creativity allows researchers to investigate and conceptualize creativity as an action that occurs naturally and normally through interactions in learning settings. This perspective proposes that creativity is at the heart of learning, which in itself is not a new idea—even Guilford (1950) stated that "a creative act is an instance of learning" (p. 446). However, in the sociocultural perspective the construction of new knowledge is seen as a creative act arising from collaborative interactions (Eteläpelto & Lahti, 2008; Sullivan, 2017), and "collaboration drives creativity because innovation always emerges from a series of sparks, never a single flash of insight" (Sawyer, 2008, p. 7). Individual and social processes co-exist under this view whereby social and cultural factors jointly impact the outcomes of cognition and creativity (e.g., Rojas-Drummond, Albarrán, & Littleton, 2008; Palincsar, 1998) and cognition, learning, and creativity are mutually supportive (Beghetto, 2016). Although sociocultural influences on creativity have been identified as far back as Kroeber's (1944) work, the focus then was on the more direct impact a given culture or environment (such as war) might have on an individual's creativity (Simonton, 1975). Gradually this strand of inquiry grew to include the idea of culture as a possible source of diversity, which Simonton (2000) suggested may directly facilitate creativity. The contemporary sociocultural approach to studying creativity (Sullivan, 2017) is far more complex, and includes strands of research on creative identity as a project

constructed within self-other relations (e.g., Glăveanu & Tanggaard, 2014). Under the sociocultural approach, data are collected within authentic learning communities through close observation of interactions, discourse, and tools, and then analyzed with microgenetic methods (Gajda et al., 2017). Current directions in creativity research also include the development of theories supporting ethically framed co-creativity that acknowledges shared values (Wix & John-Steiner, 2008), aiming to offer tools for learning experiences that are more empowering and inclusive (Walsh et al., 2017) than the intense competitive mentality often entrenched in achievement settings.

This concludes the reviews of the distinct bodies of literature on adaptive expertise and creative thinking. We will now explore conceptual links between the two constructs and examine how they are related.

Conceptual Links between Adaptive Expertise and Creative Thinking

Common ground. We propose a direct conceptual parallel between the notions of routine and adaptive expertise (Hatano & Inagaki, 1986) and the bipartite standard definition of creativity (Runco & Jaeger, 2012), which includes the dimension of value (effectiveness, appropriateness) and novelty (originality, uniqueness). Specifically, routine expertise can be compared to the value dimension of creativity, whereby the generated products or ideas effectively and efficiently solve a problem or meet a need, but do not add anything new to the domain. Adaptive expertise, on the other hand, is understood as creating new knowledge or adapting to tasks in new ways and is thus contributing novelty to the effective and efficient nature of routine expertise (cf. Schwartz et al., 2005). Another foundational definition that highlights the creative nature of adaptive expertise, and thus the link between the two constructs, is Holyoak's (1991) claim that adaptive experts invent new procedures based on their expertise.

Beghetto and Plucker (2006) echoed the belief that creativity plays a role in developing new and meaningful knowledge (moving from routine expertise to adaptive expertise), and Mylopoulos and Woods (2009) also saw adaptive experts as creators of new knowledge. The "mini-c" concept of learning as individual creativity (Beghetto & Kaufman, 2007) is also directly relevant to the link between creativity and adaptive expertise, especially in light of contemporary socio-cultural perspectives suggesting that new knowledge is constructed collaboratively through creative interaction (Eteläpelto & Lahti, 2008; Sullivan, 2017). Domain-changing "big-C" creativity is the output of adaptive expertise that has been judged favourably by others in the domain, and "pro-c" (Beghetto and Kaufman, 2007) is regular adaptive expertise in normal work settings.

Measuring adaptive expertise and creativity. Adaptive expertise and creative thinking share the same problem: they are difficult to measure and assess. Adaptive expertise has a proliferation of inconsistent definitions and conceptualizations (Pulakos, Arad, Donovan, & Plamondon, 2000), making comparisons across different studies a challenging task. In creativity assessment, researchers have also identified multiple inherent challenges (e.g,. Lindström, 2006; Plucker & Renzulli, 1999; Runco, 1984; Sternberg & Lubart, 1999; Torrance, 1988; Treffinger, 2009). Divergent thinking tests have been common due to their ease of administration and a tendency to view them as predictive of all creative ability, but the two constructs are not equal (Runco & Acar, 2012). The reliability and validity of many assessments have suffered due to the imprecision of the construct being measured (Barbot, Besançon, & Lubart, 2011). As our understanding of adaptive expertise and creative thinking has improved, newer types of assessment have emerged that use a more fine-grained lens to study changes in specific, clearly delimited components of creativity. These components include changes in fluency and

flexibility in problem solving induced by changes to the environment (e.g., Jia et al., 2017), adding to the hundreds of creativity measures already in use.

The specificity-generality debate. The debate about whether creativity is domain-specific or domain-general has not yet been settled (e.g., Baer, 1991, 1998; Plucker & Beghetto, 2004). According to Plucker (1998), the specificity-generality argument is circular, and he hypothesized that the methods used for measuring creativity may bias the findings. For example, research designs that measure creativity through a version of the consensual assessment method (Amabile, 1983, 1996) usually view creativity as domain specific because they are focused on a particular creative product within a domain. On the other hand, researchers measuring general thinking abilities (such as divergent thinking) often favour the domain-general view (Torrance, 1968) because the tests were originally based on the assumption that creative achievement in this area is predictive of creativity in other areas.

Comparably, research in adaptive expertise using measures designed to capture adaptation in performance after a change in the task (e.g., Kozlowski et al., 2001) often hold a domain-specific perspective, as compared to the domain-general perspective of inventories such as Pulakos et al.'s (2000) Job Adaptability Inventory, which measures broad and relatively stable aspects of adaptive performance.

To further complicate matters, even the notion of "domain" is somewhat vague and not clearly defined (Baer & Kaufman, 2005; Ennis, 1990). Nonetheless, the debate rages on. Baer (2015) claimed that "[e]xpertise does not usually require creativity, but creativity generally does require a certain level of expertise" (p. 165). However, this argument fails to take into account the difference between routine and adaptive expertise (Hatano & Inagaki, 1986). Routine expertise may be domain specific, but adaptive expertise requires domain-general skills and

attitudes in addition to domain specific expertise, no matter how "abstract, more principled, and more organized for use [expert knowledge is compared to] the novice's knowledge base" (Schraagen, 1993, p. 285).

Paraphrasing the popular "10,000-hour rule" for expertise, Gardner (2006) claimed it takes ten years to master a domain before creativity can emerge (domain specific focus), and Kim (2011) similarly suggested that becoming an expert is such a time-consuming process that it is rare to find true creativity in any domain. Kim (2011) nonetheless acknowledged Leonardo da Vinci's exceptional creativity in multiple domains. Meanwhile, Amabile's (1983) list of creativity-relevant skills included "appropriate cognitive style [and] implicit or explicit knowledge of heuristics for generating novel ideas" (p. 362; domain general focus). Domain-general, content-free heuristics have been proposed for problem-solving and creative and critical thinking (cf. Newell and Simon's (1972) "weak methods"), but Schwartz et al. (2005) believed that such methods are too inefficient for the complex problems we face today.

Schraagen (1993) claimed that general methods (such as reasoning skills and breaking problems into smaller sub-problems) were used by experts confronted by novel problems in their domain. However, the quality of the solutions was not comparable to the results of more advanced experts with deeper domain knowledge, suggesting that deeper domain-specific knowledge could result in superior outcomes. Sternberg and Lubart (1995) found that although creativity across domains was correlated for individuals, the correlations were low to moderate, while other variables measured in the study--including domain specific knowledge--were more strongly predictive of creativity. If there is a common thread among these diverse views, it could be that the more domain-specific knowledge and expertise an individual possesses, the more

valuable domain-general methods and aptitudes seem to become for individuals engaging in creative thinking and problem solving.

Findings like these beg for a broader perspective that does not force adaptive expertise or creative thinking into an "either-or" dichotomy, but rather allows for specificity and generality to co-exist and inform each other. This view was supported in multivariate research by Lubart and Guignard (2004) who found evidence that generalized ability, domain-specific abilities, and task specific abilities all play a role in supporting creativity. Hybrid models accounting for a blend of specificity and generality have also been proposed (Baer & Kaufman, 2005; Plucker & Beghetto, 2004). In adaptive expertise, Hesketh and Allworth's (1997) work supported the case for a broader perspective using a hybrid of domain specific and general dimensions, conceptualizing adaptive performance as a combination of cognitive skills (learning and problem-solving) and non-cognitive aspects (affective reactions to change).

Adaptive expertise as "applied creative thinking". Perhaps one of the easiest ways to understand the close links between adaptive expertise and creative thinking is to think of adaptive expertise as "applied creative thinking". As the name implies, adaptive expertise is rooted in expertise and is therefore concerned with how individuals are able to access and "play with" their knowledge. Adaptive expertise usually has an object, a goal, an output, or a product at the end of the process, even if the "product" is new knowledge. Creative thinking may be similarly focused and practical but can also have a freewheeling quality and be an activity in and of itself, engaged in purely as a mental exercise. In general, creative thinking is a broader construct, although most creativity theories also include a knowledge dimension. For example, Sternberg and Lubart's (1991) investment theory included knowledge as one of six components (the others were intellectual skills [synthetic, analytic, practical], thinking styles, personality,

motivation, and environment). Similarly, Amabile's (1983) componential theory included domain knowledge as one of three components (the other two being creativity-related process skills and intrinsic motivation).

Adaptive expertise is usually viewed as context-dependent, and both the social psychology and sociocultural perspectives of creativity make allowances for the impact of context and the environment. The next section will focus on two specific contextual influences on creativity and examine how the relationships between affect and motivation in achievement settings can support or suppress creative thinking.

The Roles of Achievement Emotions and Achievement Goals in Creative Thinking

In earlier sections of this paper we reviewed and linked theories of adaptive expertise and creative thinking, with a primary focus on their cognitive aspects. In the remaining sections, we will be using the term creative thinking to jointly refer to both constructs. By creative thinking we mean "applied creative thinking" as conceptualized above, i.e., the kind of creativity that is based on knowledge and its fluid and adaptive utilization.

Domain-specific and domain-general aspects of creative thinking address the *ability* of learners to think creatively. There is no doubt that higher order cognitive processes (Anderson & Krathwohl, 2001; Bloom 1956; Dietrich, 2004; Gardner & Gardner, 2008; Williams, 1969) are at the core of the operations that occur during the creative process. However, creative thinking also requires the *willingness* to do so. Of fundamental importance to any kind of creativity, yet sometimes overlooked, is the fact that being or becoming creative absolutely requires appropriate input from the "feeling processes" (Williams. 1969), and researchers now believe that the environment can significantly influence the link between affect and creativity-related processes

(Amabile, 2013; Amabile & Mueller, 2008; Sullivan, 2017), particularly through its influence on motivation (Amabile, 1983).

Although a thorough treatment of motivation-emotion-creativity linkages is beyond the scope of this review, it is helpful to situate the emotion-creativity connection within broader motivational constructs. Specifically, intrinsic rather than extrinsic motivation is believed to be most strongly associated with creativity in education, the arts, and organizational settings (Amabile, 1983, 1985; Amabile, Barsade, Mueller, & Staw, 2005; Csikszentmihalyi, 1990; Gardner, 1993; Runco & Chand, 1995; Sternberg & Lubart, 1991, 1995; Woodman & Schoenfeldt, 1990). Ryan and Deci (2000, p. 69) called intrinsic motivation "the prototypic manifestation of the human tendency toward learning and creativity", emphasizing the fundamental role it is believed to play in learning. Researchers have found that people only do creative work if they are intrinsically motivated and interested in the task; it is rare to see individuals produce truly creative ideas or products for purely extrinsic rewards (e.g., Sternberg & Lubart, 1999).

If we accept the blended and multi-componential perspectives of creative thinking involving domain-specific, domain-general, and task-specific abilities and processes (e.g., Baer & Kaufman, 2005; Lubart & Guignard, 2004; Plucker & Beghetto, 2004), we can see the difficulties in determining exact relationships between affect and creative thinking. Adding the influences of the context and environment, particularly in achievement settings, makes it clear that there are many interrelated processes at play, and unpacking them individually is a monumental challenge. Each different way of conceptualizing, operationalizing, and measuring creativity entails different underlying mechanisms, with attendant diversity in affective and motivational implications. Mumford (2003) observed that two recent creativity handbooks

contained theoretical frameworks based on “trait theory, operant models, associational models, conscious analogical reasoning models, expert systems theory, economic models, perceptual processing theories, and clinical theories concerning bipolar disorders” (p. 109). Against this background, it is not surprising that research on the role of emotions in creativity has produced conflicting results. Nonetheless, information processing tendencies underlying creative (and other) thinking are influenced by mood, and it can be helpful to have a broad understanding of which kinds of moods are known to support which kinds of thinking (Runco, 2014).

Influence of Affect on Creativity

For the purposes of this discussion, we adopt the perspective suggested by Pekrun (2006), wherein moods and emotions are viewed as existing on the same spectrum of affective processes, with moods characterized as low-intensity emotions. The terms mood and emotion are therefore used interchangeably.

Because research results on mood and creativity are mixed, definite proclamations of the influence of affect on creativity would be premature based on current research. The existing body of literature generally supports a link between positive emotions and creative ideation (fluidity, flexibility, and originality), wide associations, and making new combinations among disparate cognitive elements (Friedman, Fishbach, Förster, & Werth, 2003; Isen, Daubman, & Nowicki, 1987; Runco 2014); as well as (creative) risk-taking, rapid decisions, and increased use of heuristics (Isen & Daubman, 1984; Isen & Means, 1983; Isen, Means, Patrick, & Nowicki, 1982). Neuropsychological research has also found a positive relationship between positive mood and fluency, as well as positive mood and switching to novel (rather than familiar) stimuli (Ashby & Isen, 1999; Dreisbach & Goschke, 2004; Mitchell & Phillips, 2007). The mood-as-information theory (Dreisbach & Goschke, 2004) further supports these findings demonstrating

that heuristic processing (expansive, quick, big-picture thinking) results from positive moods, and analytic processing (paying close attention to small details) results from negative moods. The link between emotions and creativity may also be based on similar processes as those tapped into by Fredrickson and Branigan's (2004) broaden-and-build theory, which hypothesized that positive emotions broaden the scope of attention and thought-action repertoires, such that "joy sparks the urge to play [and] interest sparks the urge to explore" (p.1367). Playful exploration is clearly conducive to creativity. One of the most sweeping endorsements of positive emotions supporting creative thought was given by Amabile et al. (2005) who found evidence that positive affect is an antecedent to, concomitant with, and a consequence of creative thought. Others have found that while positive affect facilitates the quantity of ideas (through fluency and flexibility), it is not necessarily predictive of their quality (Vosburg, 1998; Weisberg, 1994).

Results from a series of experiments inducing negative affect (Isen et al., 1987) suggested that negative moods had no effect on creative thinking. Kaufman and Vosburg (2002), on the other hand, found that positive moods improved performance in early-stage (constraint-free) creative ideation, but negative moods improved performance later in the process--particularly under evaluative pressure or time constraints. These findings are consistent with the mood-as-information theory (Dreisbach & Goschke, 2004) that pointed to the relationship between negative moods and analytical thinking. Research has uncovered associations between some negative emotions and creativity in some contexts (e.g., Carlsson, 2003; De Dreu & Nijstad, 2008; George & Zhou. 2008). However, authors have urged caution in interpreting results from research with induced moods, suggesting that induced moods may not have the same effects as natural self-reported moods (Kwiatkowski & Parkinson, 1994).

Achievement Emotions

In this manuscript, we are specifically concerned with achievement settings which, by their mere existence, have an impact on emotions. Individual achievement in educational settings can determine future opportunities, and success or failure in higher education can have a major influence on learners' life trajectories. Emotions inevitably arise in relation to learning in such high-stakes settings, and students navigate these emotions differently depending both on the external context and on internal factors specific to the learner (Pekrun, Goetz, Titz, & Perry, 2002). Based on Pekrun's (2006) control-value theory of achievement emotions, we will briefly examine potential links between creative thinking and the emotions measured by the Achievement Emotion Questionnaire (Pekrun, Goetz, & Perry, 2005), namely enjoyment, hope, pride, and relief (positive emotions), and anger, anxiety, shame, hopelessness, and boredom (negative emotions). In addition to their positive or negative valence, these achievement emotions can be activating (enjoyment, hope, pride, anger, anxiety, and shame) or deactivating (relief, hopelessness, and boredom), thus conforming to Feldman Barret and Russell's (1998) 2 x 2 affect framework of valence x activation.

Achievement Goals

In addition to achievement emotions, factors surrounding achievement goals and their pursuit in achievement settings also play a fundamental role in learners' behaviours, activities, and outcomes—and, it turns out, in their propensity for creative thinking. In the regulatory focus theory for goal motivation in achievement settings, Higgins (1998, 2006) argued that the valence x activation dimensions of affect should be further enhanced by including the influence of promotion and prevention. Promotion is based on the survival need for nurturance, and behavioural *approach* is considered the preferred strategy to promotion goal achievement.

Conversely, prevention is based on the survival need for security; and behavioural *avoidance* is the preferred prevention goal achievement strategy in this case.

In a parallel and conceptually overlapping but distinct strand of research in learning, theorists (e.g., Dweck, 1986; Dweck & Leggett, 1988) suggested that there are two main types of achievement goals, namely mastery and performance goals (originally referred to as learning and performance goals). It was posited that learners with mastery goals were intrinsically motivated and tended to enjoy learning for its own sake, regardless of evaluation or assessment considerations, while learners with performance goals were motivated mainly to perform well on evaluations, often due to extrinsic factors. Harackiewicz, Barron, Pintrich, Elliot, and Thrash (2002) argued that the separation of approach from avoidance forms of these achievement goals is critical because approach and avoidance reflect important differences in the functionality of achievement goals. It was thought that achievement goals (mastery and performance) can either be approached for a positive outcome, or avoided to avert a negative outcome (Elliot, McGregor, & Gable, 1999). Today, many researchers prefer a trichotomous model that includes mastery approach, performance approach, and performance avoidance behaviours (Elliot, 1997; Elliot & Church, 1997; Elliot & Harackiewicz, 1996). Contemporary models propose a multiple goal orientation in which the divisions between mastery and performance goals, as well as between approach and avoidance goals, are less obvious and more dependent on the learning situation (e.g., Hulleman, Shrager, Bodmann, & Harackiewicz, 2010; Senko, Hulleman, & Harackiewicz, 2011). In general, learners exhibit various combinations of mastery and performance goals in learning situations (Elliot & Murayama, 2008; Linnenbrink-Garcia, Tyson, & Patall, 2008; Pintrich, 2000), further complicating the task of delineating simple effects of goals on creative thinking. Nonetheless, keeping in mind Amabile's (1983) postulate that environments (in our

case, achievement settings) influence creative thinking, we will now explore how specific achievement emotions and goals may interact to influence creative thinking in achievement settings.

Emotions, Goals, and Creative Thinking in Achievement Settings

Baas, De Dreu, and Nijstad (2008) hypothesized that activating mood states were more conducive to creativity than deactivating mood states. Amabile et al. (2005) also believed that positive emotions play a creativity-enhancing role. Therefore, of the nine AEQ emotions (Pekrun et al., 2005) in Table 1, we would expect enjoyment, hope, and pride to be highly conducive for creativity because they are positive and activating.

The corollary of this would suggest that negative deactivating emotions like boredom undermine creativity. This is indirectly supported by research. For example, Pekrun, Goetz, Daniels, Stupnisky, and Perry (2010) found that boredom is negatively related to intrinsic motivation which is known to have a strong positive relationship with creativity (Amabile, 1983, 1985; Amabile et al., 2005; Csikszentmihalyi, 1990; Gardner, 1993; Hennessey & Amabile, 1987; Runco & Chand, 1995; Sternberg & Lubart, 1991, 1995; Woodman & Schoenfeldt, 1990). In essence a lack of interest (i.e., boredom) leads to decreased creativity. The other negative deactivating emotion in the AEQ, hopelessness, has been found to be inversely correlated with problem solving confidence (Yang & Clum, 1994) which is a type of creative efficacy (Treffinger, Isaksen & Stead-Dorval, 2006). Baas, De Dreu, and Nijstad (2011) suggested that positive deactivating emotions (i.e., relief), also lead to a decrease in creativity because they occur in relation to the ending of a negative event (Pekrun et al., 2002) and thus disengage the individual (Carver, 2004).

The effects of negative activating emotions (anger, anxiety, and shame; Pekrun et al., 2005) on creativity are more complex, and regulatory focus and achievement goals are believed to play a role in these mechanisms. Carver (2006) observed that approach and avoidance motivations in various forms seem to be deeply embedded in human behaviour and thus make for useful organizing themes. With respect to their influence on creativity, these parallel strands of research [i.e., goal approach and avoidance behaviours (e.g., Elliot, 1999; Elliott and Dweck, 1988), and promotion and prevention goals (e.g., Higgins, 1998, 2006)] are treated as comparable constructs. Indeed, Friedman and Förster (2000, 2001, 2002) found repeated evidence that moods associated with promotion as opposed to prevention were more conducive to creative insight and creative thinking. Promotion (approach) states appear to be accompanied by broad attentional scope, and because creative insight and ideation are based on combining previously separate constructs in novel ways (e.g., Mednick, 1962), broader cognition makes it easier for individuals to access and combine diverse mental representations to be creative. Prevention (avoidance) goals, by contrast, are thought to have a narrowing effect on attention, thereby restricting access to some concepts and limiting cognitive flexibility (Friedman & Förster, 2002; Förster and Higgins, 2005).

While approach and avoidance goals have their own relationships with creativity as outlined above, negative activating emotions (anger, anxiety and shame; Pekrun, 2006) may play a mediating role, depending on the object focus of the emotion. As discussed, the literature is mixed on the influence of negative emotions on creativity, and some researchers have found that conflict-related emotions can support rather than suppress creativity (e.g., Carlsson, 2003; De Dreu & Nijstad, 2008; George & Zhou, 2008). Examples of these mixed results are discussed below.

Anger can follow from failure perceived as resulting from the actions of others, or stem from a task that is perceived to be too difficult (Pekrun, 2006), which can potentially result in renewed efforts to achieve the original (or modified) goal despite setbacks. This mechanism would result in approach behaviour which supports creativity. On the other hand, cognitive tuning theory (Schwarz, 1990; Schwarz & Bless, 1991) is based on the notion that affective states are perceived as indicators of the nature of the environment. Negative states signal a threat, tending to elicit analytic, detail-oriented approaches which are not as conducive to creativity.

Anxiety can decrease intrinsic motivation (Pekrun, 2006) and by extension creativity (Amabile, 1983), but is viewed as activating because it can lead to increased efforts to avoid negative outcomes. Avoidance behaviours are associated with lower creativity as we saw above, suggesting that anxiety should have a detrimental influence on creative thinking. However, in another example of mixed results regarding negative emotions and creativity, Carlsson (2003) found that individuals in a high-creativity group also had high scores in anxiety, relative to individuals in a low-creativity group.

Shame in achievement settings is thought to be a consequence of failure due to either controllable (low effort) or uncontrollable (low ability) factors (Pekrun, 2006; Weiner, 1985). Although Pekrun et al. (2002) classified shame as an activating emotion, other researchers have characterized it as deactivating in nature because it can motivate individuals to withdraw and disengage (Tangney, Wagner, Fletcher, & Gramzow, 1992), especially when viewed as resulting from uncontrollable factors. Disengagement is deactivating and thus considered detrimental to creativity and may be a risk under conditions of stereotype threat (eliciting shame from belonging to a group perceived inferior in terms of ability). Negative stereotypes were found to

be associated with relatively better analytical performance (consistent with other research suggesting a narrower focus under threat conditions, e.g., Friedman & Förster, 2005; Förster and Higgins, 2005) while conversely, positive stereotypes led to higher creativity (Seibt & Förster, 2004). On the other hand, shame may also be redirected as anger towards others in an attempt to repair damage to the individual's self-view (Lewis, 1971), in which case the activation mechanisms outlined in relation to anger (above) may apply.

Trichotomous Achievement Goal Framework

Further links between creativity and achievement goals (mastery approach, performance approach, and performance avoidance goals) can be inferred from extensive research showing that mastery goals tend to be powered by intrinsic motivation (see meta-analysis by Rawsthorne and Elliot, 1999), which, again, is strongly associated with creative thinking (e.g., Amabile, 1983, 1985), while performance goals often have a relatively larger component of extrinsic motivation (which is less supportive of creative thinking; Amabile, 1985). Mastery approach, performance approach, and performance avoidance goals differentially direct learners to interpret and respond to feedback and other performance information acquired along the way, and each goal orientation may evoke different mechanisms supporting or suppressing creativity. For example, learners with mastery approach goals tend to use task feedback adaptively to activate further learning goals, and any setbacks are viewed as opportunities for learning (Dweck & Leggett, 1988; Heyman & Dweck, 1992). Thus, learners with mastery goals remain actively involved and are more likely to use heuristics (which is supportive of creative problem solving; e.g., Yilmaz & Seifert, 2011). Mastery goals also predict all three of the positive activating emotions (enjoyment, hope, and pride) and negatively predict boredom and anger (Pekrun, Elliot,

& Maier, 2006) which, along with the activating approach nature of further self-set learning goals, is likely to support creativity through the mechanisms outlined earlier.

Performance approach goals, for their part, are also activating in nature but may (by definition) have a stronger extrinsic motivation component, which is less supportive of creative thinking. Positive feedback (success) during the process may lead to some positive affect with creativity-supporting results, and performance approach goals were found to predict hope (Pekrun et al. 2006). Negative feedback, on the other hand, *may* lead to renewed efforts (which would have positive effects on creativity), but for learners with performance approach goals it may also be perceived as being due to lack of ability and thereby elicit helpless behaviours (Heyman & Dweck, 1992). Helplessness is closely related to hopelessness (Abramson, Metalsky, & Alloy, 1989), and would be detrimental to creativity.

Finally, performance avoidance goals may be the least creativity-supporting among the three goal orientations. In Pekrun et al.'s (2006) study, performance avoidance goals predicted boredom, anxiety, and hopelessness. Whether the outcomes (final or interim) of performance avoidance goals are positive or negative, the resulting emotions are likely to be deactivating, negative, or both (relief if a feared outcome was successfully avoided; anger, anxiety, shame, or hopelessness if it was not), with likely associated negative effects on creativity.

To summarize part two, the field agrees that positive, activating emotions, particularly when experienced during approach behaviours, are conducive to creativity. Beyond this, the literature is mixed and many other factors come into play. One of the most important factors appears to be task outcome (Baas et al., 2011; Pekrun, 2006). When a goal is successfully reached (or anti-goal successfully avoided), there is deactivation and disengagement, which reduces creative performance. These mechanisms may also account for the positive effect some

negative emotions have on creativity: unfulfilled goals and anti-goals activate, and activation supports creative behaviour (Baas et al., 2011). Some of the conflicting results in the literature may be based on methodological or definitional imprecision. Measuring a sub-component of creativity (such as originality or fluency) and making sweeping generalizations about results with regard to creativity as a whole only serves to muddy the waters, rather than advance the field.

Implications for Teaching and Learning in Higher Education

Higher education has an important role to play in teaching the creative thinking skills necessary for current and future generations. Historical findings have suggested that young adults recover more quickly from rigid thinking (Luchins & Luchins, 1959) and are less likely to have established set thinking patterns (Heglin, 1957), making young adulthood an optimal time for developing novel, flexible thinking skills. Hytönen et al. (2016) found positive correlations between personal orientation to adaptive expertise (individuals who emphasize "the importance of actively keeping up with the newest knowledge and professional practices as well as anticipating the competencies that would be needed in the future", p. 348) and academic guidance, but not between personal orientation to adaptive expertise and workplace guidance. This finding seems to support the idea that higher education settings may be uniquely positioned to help develop the capacity for creative thinking and adaptive expertise.

Based on Amabile's (1983) claim that social environments (such as achievement settings in higher education) can be manipulated to support creativity, we can specifically design learning environments to help develop and maintain creative thinking and adaptive expertise. [For a historical review of educational approaches to developing creativity, see Fasko (2001)]. Many educators have tried to introduce creative thinking programs and creative skill development packages for their students, with mixed results. Cropley (1997) pointed out that such

interventions often resulted in learners who may have had better results on the program tests but were only marginally (if at all) more creative in the broader target domain, and then only if the content of the tests was closely aligned with the activities in the domain. Given the complex and multifaceted nature of creative thinking, short term individual interventions cannot be expected to have a lasting effect. A broad culture of creativity, rather than individual interventions, should be carefully designed and nurtured based on constructing knowledge, coupled with developing the requisite skills and attitudes to playfully work with emerging expertise through exploration. Appropriate instructional approaches support students in looking beyond the obvious problems (Cropley, 1997), and toward asking the surprising questions that can lead to new insights and ideas (Sawyer, 2008).

Transformational Teaching

Much has been said about the importance of transformational leadership for supporting a climate of innovation in organizations (e.g., Bass & Avolio, 1993; Charbonnier-Voirin et al., 2010). Transformational teaching (Slavich & Zimbardo, 2012) is equally influential in supporting a culture of creativity in higher education. The impact of the expectations of others can be powerful (Bandura, 1992), and has a major role in "setting the mood". We argue that this is particularly true in achievement settings, where the interplay of learners' achievement goals and emotions (as discussed in earlier sections), combined with different instructional styles, can result in brilliant luminous creativity, frustration and false starts, or disappointment and suboptimal outcomes.

The critical role of the instructor is also captured by McWilliam's (2005, 2009) suggestion that beyond "sage-on-the-stage" or even "guide-on-the-side", "meddler-in-the-middle" is a better reflection of the role of instructors who are change agents, co-creating

knowledge with learners in increasingly complex settings (McWilliam & Haukka, 2008). Gajda et al. (2017) provided a list of teaching behaviours that have been found to support creativity (Appendix A).

Active Learning

In 1990, the American Psychological Association (APA) released the first report of their Learner-Centered Principles Workgroup, integrating research in educational psychology with other related research areas to outline a framework for active and reflective learning. This effort included 14 principles grounded in psychological factors ranging from cognitive and metacognitive, affective and motivational, developmental and social aspects, through to individual differences (APA, 1997; revised and updated version). The report was a major contribution to the paradigm shift in higher education, moving from passive didactic lecturing (with simple information transmission) to active approaches where learners are co-creators of knowledge (e.g., Paavola & Hakkarainen, 2005). Mylopolous and Woods (2009) observed that routine and adaptive expertise result from two distinctly different kinds of learning and suggested that we have traditionally overemphasized the kind of teaching that results in routine efficiency at the expense of adaptability and creative thinking. The understanding of underlying patterns is a hallmark of expertise, but rather than being drilled in the patterns explicitly, learners should be allowed to play with concepts to infer patterns through inductive learning (Bell & Kozlowski, 2008).

Error Framing

In contrast to traditional pedagogy which was based on teaching learners to arrive at pre-known routine solutions quickly and correctly, active learning environments invite learners to explore, experiment, and make errors. Imperfect and sometimes incorrect solutions are

generated with early knowledge, but studies have shown that learners in error-encouraging instructional settings are more likely to take risks and improve adaptive transfer of expertise after (not during) the task (Kapur, 2008; Keith & Frese, 2008; Schwartz & Martin, 2004). Learners undertaking unscaffolded, seemingly unproductive problem-solving efforts of ill-structured problems near the "*edge of chaos"* (Kapur, 2008; p. 383, italics in original) early in the learning process, followed by solving well-structured problems, became more adaptive and innovative problem solvers than those not encouraged to freely and safely approach the edge of chaos [cf. Bereiter and Scardamalia's (1993) "growing edge" discussed earlier]. While Schwartz et al. (2005) summarized their work on efficiency vs. innovation with the phrase "innovation favors the prepared mind", Kapur (2008) flipped it to "innovation prepares the favored mind" (p. 386), alluding to the positive influence of safe learning environments generally, and productive failure specifically, on preparedness to innovate and be creative. Framing errors as welcome guideposts during learning also supports mastery goals, known to further encourage creative thinking.

Conclusion

Much remains to be learned about the teaching, learning, and support of creative thinking skills in higher education. Adaptive expertise and creative thinking include cognitive and metacognitive habits that can be learned and practised (e.g., Bell & Kozlowski, 2010; Mylopoulos & Woods, 2009; Scott, Leritz & Mumford, 2004), and higher education is an optimal context for supporting, training, and practising these attitudinal and metacognitive skills. An accelerating rate of change means that we do not know today the specific skill set that will be necessary for learners to succeed and thrive in the decades to come – but we do know that flexibility, adaptability, and creative thinking are essential in navigating an uncertain world. This paper has reviewed literature on the theoretical underpinnings of adaptive expertise and

creative thinking, and we suggested "applied creative thinking" as a term that links the two by encapsulating the salient features of both. The multiple mechanisms by which achievement emotions and achievement goals may support or suppress creative thinking were explored, and finally some pedagogical implications for supporting creative thinking and adaptive expertise in higher education were discussed.

In an innovation society, many improvements are possible to better support learners in higher education to gain the 21st century competencies they will need. Graduates would benefit from better knowledge of idea generation, elaboration, and analysis; learning the tools for creative collaboration (communication skills, openness to input, group idea refinement and implementation); learning to tolerate ambiguity; asking insightful questions using multiple perspectives that aid in problem finding; and internalizing the notion that failures along the way are a welcome part of the learning and innovation process (e.g., Csikszentmihalyi, 1996; Palus & Horth, 2002; Partnership for 21st Century Learning, N.D.).

In order to impart these competencies to learners, education needs to address all three parts in Amabile's (1996) componential theory: expertise, creativity skills, and motivation. Some are easier to tackle directly (expertise, cognitive creativity skills), while others (motivation, affective creativity skills) may need a more indirect and thoughtful approach, paying careful attention to the learning environment and implicit messages therein. By addressing these concerns, educational researchers can make great contributions toward helping ensure that future university graduates go out into the world as not as "excellent sheep" (Deresiewicz, 2014), but as empowered, self-aware, independent, and creative problem solvers and change makers.

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Tables

Table 1

The Nine Achievement Emotions Measured by the AEQ. Adapted from Pekrun et al., (2005)

	Activating	***Deactivating***
Positive	Enjoyment, Hope, Pride	Relief
Negative	Anger, Anxiety, Shame	Boredom, Hopelessness

Figures

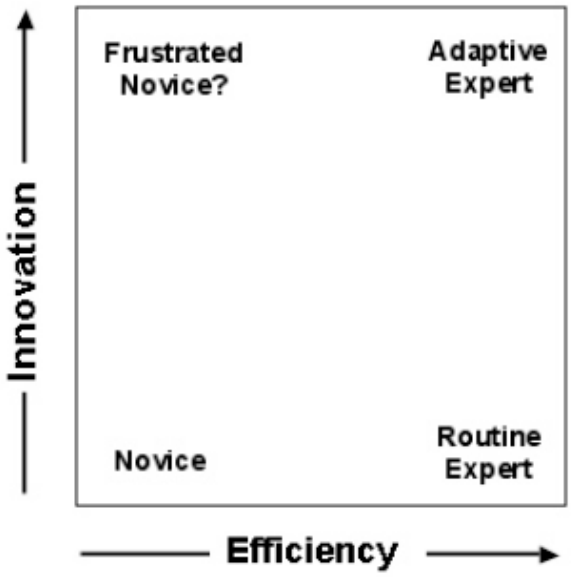

Figure 1. Two dimensions of learning and transfer. Schwartz et al. (2005, p. 40).

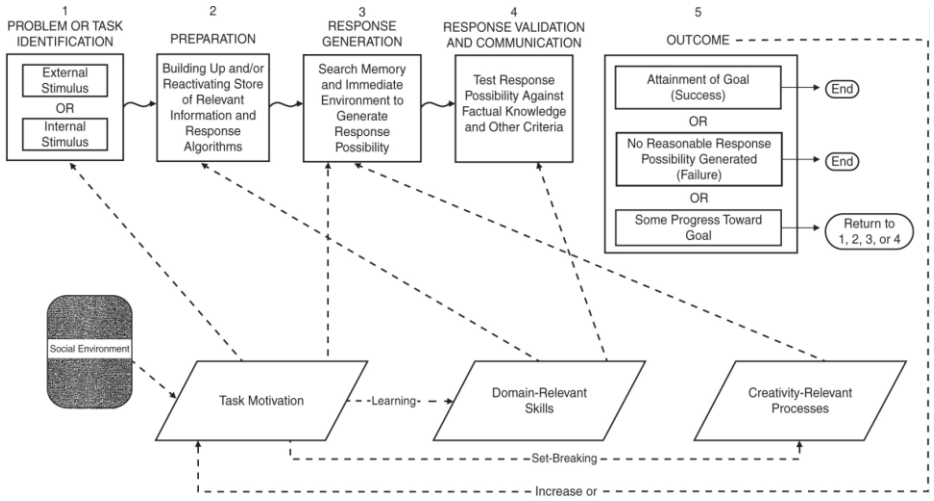

Figure 2. The componential theory of creativity. Amabile (1996, p. 113)

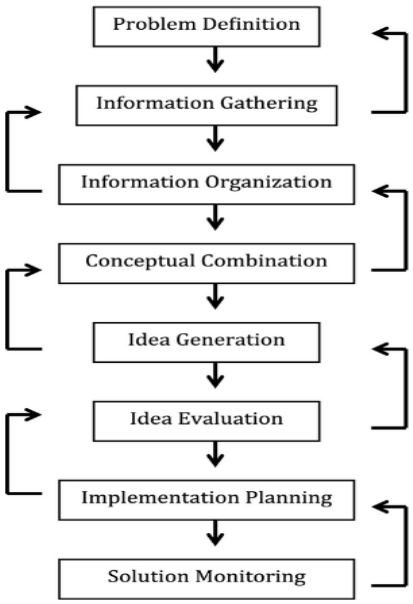

Figure 3. Creative process model. Mumford, Medeiros, and Partlow (2012), updated from the initial version in Mumford et al. (1991).

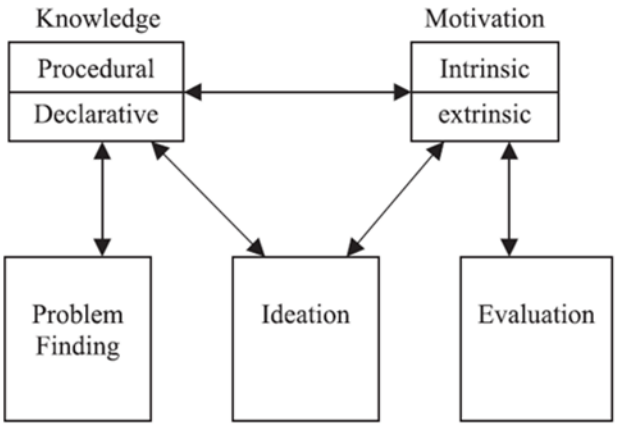

Figure 4. Two-tier model of creative thinking. Runco and Chand (1995).

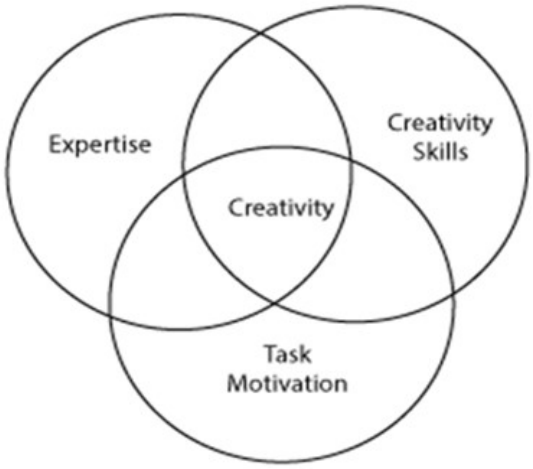

Figure 5. Simplified componential model of creativity. Amabile (1998).

Appendix A

Supportive teacher behaviours for creativity (adapted from Gajda, Beghetto, and Karwowski, 2017, p. 251):

- Establishing improvement-focused learning goals;
- Providing opportunities for students to use their imagination while learning;
- Encouraging students to take sensible risks and act independently;
- Teaching with a more game-like or playful approach;
- Providing opportunities for choice and discovery;
- Encouraging flexible thinking and confidence in students' ideas;
- Treating student questions and ideas (especially unusual and unexpected ones) seriously;
- Refraining from premature assessment of students' ideas;
- Demonstrating a belief that teaching should go beyond imparting simplistic and factual knowledge; and
- Supporting students when they fail by showing them ways to learn from their mistakes.

Chapter 3: Bridging Text

The previous manuscript first reviewed, compared, and contrasted the separate strands of research literature on adaptive expertise and creative thinking in educational settings. We were particularly interested in the adaptive expertise construct and its relationship to creative thinking because theories of expertise are a useful lens for how people learn and build the knowledge on which they can later base their ideas. Next, we surveyed the educational psychology literature on two extensively researched constructs, namely achievement goals and achievement emotions, to determine how they have previously been linked to creative thinking. Though we found some links, particularly in the broader psychological literature, between affect, motivation, and creativity, explicit relationships between these constructs and how they support creative thinking in educational settings was lacking, particularly in regard to interrelationships between constructs and any gender differences. Broadly speaking, there was evidence to support the idea that positive emotions support creativity and mastery goals support intrinsic motivation, which is also supportive of creativity.

Given the growing need for innovation, flexible cognition, and creative thinking skills among university graduates, the second manuscript empirically tested the relationships of the creativity, affect, and goal constructs in undergraduate STEM students. It provides an abbreviated literature review of the constructs reviewed more extensively in the previous chapter, as well as a brief review of two additional constructs included in the study, namely learning strategies and gender differences, as they relate to creative thinking. In this exploratory mixed methods manuscript, we aimed to combine statistical rigour (through quantitative analyses using well known, validated scales) with the lived experiences of STEM students and their perceptions of creativity through open-ended questions.

Chapter 4. Manuscript 2

Applied Creative Thinking in STEM: The Influences of Achievement Emotions, Achievement Goals, and Learning Strategies on Ideation

Abstract

In an innovation society, STEM students and graduates are expected to use their learned knowledge and acquired expertise adaptively and creatively. However, education research that targets innovation skills and applied creative thinking within STEM programs is limited. The purpose of the present empirical study was to explore the roles played by affective and motivational processes, as well as learning strategies, in relation to creative thinking in higher education. Undergraduate STEM students (*N*=119) self-reported their typical achievement emotions, goals, and learning strategies, as well as their levels of ideational behaviour. Additionally, students responded to an open-ended question about factors they believe support or suppress their creativity with respect to their programs of study. Results provided evidence that in general positive emotions and mastery approach goals supported creative ideation and negative emotions suppressed it. Findings also revealed that motivational and affective processes impact ideation differently in female vs. male students, and at different times in the program. Females showed significant positive relationships between hope and ideation early in the program, but negative emotions were significantly (negatively) associated with ideation later. Both male and female students, in all years, showed evidence of strong links between critical thinking and creative thinking, and flexible learning environments with inquiry methods were most supportive of ideation. The ACE (affect, cognition, and environment) model of ideation was proposed as a new framework that integrates previously separate strands of research in creative thinking, and implications for theory and practice in STEM education are discussed.

The World Economic Forum (2018) has provided a list of "trending" skills for the year 2022, and the 10-item list is long on skills that have traditionally been treated as secondary considerations or accidental by-products in higher education. The list includes ideation, innovation, and creativity skills of various types, and the purpose of this empirical manuscript is to address the development of these sought-after future skills. "Innovation starts with an idea", according to the Canada Foundation for Innovation (2017, p. 8), and learners and graduates in an innovation society must be willing and able to generate ideas. However, there is a dearth of empirical research on factors that contribute to the development of ideational ability alongside content learning.

The STEM (Science, Technology, Engineering, and Math) student population is of particular interest because graduates in these fields have opportunities to effect change through scientific research and technological innovations. However, not all STEM students or graduates are equally able to creatively generate ideas from their learned knowledge, and our focus is on exploring factors that may impact their ideational behaviour (Runco, Plucker, & Lim, 2001). The tendency to have many ideas is a type of creative thinking, and there are examples in the broader literature of how creativity is influenced by affect, motivation, and goals (e.g., Amabile, 2005; Runco, 2014; Ryan & Deci, 2000). Additionally, the strategies used for learning[1] can influence the availability and accessibility of learned knowledge (Mumford, Baughman, Supinski, & Maher, 1996; Pintrich, Smith, Garcia, & McKeachie, 1991). However, research on the interplay of these factors in the context of applied creative thinking (i.e., using learned knowledge to generate new ideas) in STEM is scarce. The present study addresses this gap in

[1] There are many terms used in the literature for the habitual sets of actions students undertake while learning. Historically, the traditions for measuring "learning strategies" differed from those measuring "study strategies", but Entwistle & Peterson (2004) proposed that the two traditions have been merged in recent work. The current manuscript uses the term "studying" to refer to the application of learning strategies, and the terms "study strategies" and "learning strategies" are used interchangeably.

the literature, and the results from this study can inform the design of learning environments that help nurture ideas and innovation tendencies among university students.

The following literature review serves to provide context for the study at hand by first synthesizing relevant research in the field of expertise, conceptualized as the foundational knowledge and skills from which new ideas can be generated. Then we will briefly review selected affective and motivational processes, namely achievement emotions and achievement goals, in relation to ideation. Following that, we will provide an overview of relevant literature on learning strategies because research suggests that the *way* we learn may have an impact on what we are later able to *do* with what we learn (i.e., whether our learning supports ideation or not). Finally, because we are also interested in exploring gender differences in STEM creativity, we will briefly look at the body of literature on gender differences in creative thinking.

Ideation Based on Expertise

Individuals differ in their tendency and ability to think creatively and generate ideas that can lead to innovation. Runco et al. (2014) defined ideation as "the label given to the process resulting in ideas" (p. 186) and claimed that this process is at the root of all "creative" activity. Building on Baer's (2003) assertion that ideation is founded on knowledge, we further argue that ideation is specifically based on knowledge that is flexible (adaptive) rather than rigid (routine). We are drawing on theories of adaptive expertise (Bransford, Brown, & Cocking, 2000; Hatano & Inagaki, 1986; Schwartz, Bransford, & Sears, 2005), which broadly refer to the fluidity and flexibility that enable individuals to access their interconnected knowledge networks and respond to novel situations effectively (Bransford et al., 2000). Viewing expertise as relative rather than absolute (Chi, 2006) allows us to consider learning in STEM as a process for building expertise. However, not all expertise is created equal: Adaptive expertise differs from routine expertise

(Hatano & Inagaki, 1986; Schwartz et al., 2005). The latter, by definition, is most effective in well-defined domains with specific known answers, where it enables individuals to react adeptly and skillfully to predictable patterns that respect the established traditional structure of the field (Devine & Kozlowski, 1995). Because of the routine and predictable nature of these patterns and domains, technology based on artificial intelligence is developing algorithms for completing tasks more cheaply and rapidly, and increasingly taking over routine occupations.

Nonetheless, researchers believe that routine expertise also plays an important role in supporting innovation because the efficiency it affords in basic processing can be the basis for flights of fancy that allow for more creative thinking. Routine efficiency can thus be seen as a necessary foundation on which adaptive expertise is built (Carbonell, Stalmeijer, Könings, Segers, & van Merriënboer, 2014; Hatano & Oura, 2009; Martin, Petrosino, Rivale, & Diller, 2006). Learners who are supported beyond the routine to acquire adaptive expertise can create novel interdisciplinary re-combinations of concepts (Finke, Ward, & Smith, 1992). The creative process model (Mumford, Medeiros, & Partlow, 2012) posits that new knowledge is weighed and connected with prior knowledge to generate new ideas, which are subsequently evaluated and incorporated into creative projects and new solutions. Similarly, adaptive experts in professional domains can meet daily challenges through devising practical and novel solutions, which become accepted praxis through knowledge-sharing (Mylopoulos & Scardamalia, 2008), and gradually feed innovation within professional domains.

Are there factors that enable learning to occur in ways that allow for flexible, creative, and adaptive, rather than routine, retrieval and application of learned knowledge and skills? The literature recognizes relationships between affect, goals, and motivation on one hand, and creative thinking on the other, and these relationships will be examined in the next section.

The Roles of Affect, Goals, and Motivation in Creative Thinking

Affect. According to Amabile, Barsade, Mueller, and Staw (2005), there is evidence that positive affect precedes, co-exists with, and follows creative acts: Positive affect is thus present throughout the creative and ideational arc. The enjoyment of an activity is viewed as a prerequisite for the experience of flow, which is thought to promote engagement and creativity (Csikszentmihalyi, 2000). Broadly speaking, creative ideation is generally supported by positive affect through its impact on fluency, flexibility, and originality (Runco, 2014), as well as its reinforcement of wide associations and new combinations of previously separate cognitive elements (Fredrickson, 2001; Friedman, Fishbach, Förster, & Werth, 2003; Isen, Daubman, & Nowicki, 1987). Hirt (1999) claimed that the positive influence of positive moods on creativity is "remarkably robust" (p.241). However, others have cautioned that this deceptively simple relationship gives, at best, only a partial view of a multifaceted construct, and argued that the picture is more complex because "different moods are differentially related to different components" (Kaufmann, 2003, p.131).

Moods and emotions are viewed as existing on the same spectrum of affective processes, with moods characterized as low-intensity emotions (Pekrun, 2006). Differences between state and trait emotions are outlined in the literature, with state emotions generally described as transient responses to particular in-the-moment events, and trait emotions referring to more stable habitual tendencies (Zuckerman, 1960). Put another way, state emotions are thought to be more reactive to stimuli within the immediate context (e.g., Eid, Schneider, & Schwenkmezger, 1999), while trait emotions have been defined as predispositions to react or behave in a certain way in particular situations. The idea of tendency or predisposition goes back to the influential State-Trait Anxiety Inventory (Spielberger, Gorsuch, & Lushene, 1970), based on Spielberger's

(1966) finding that anxiety only impacted task performance when the experiment included a protocol for inducing stress. This suggested that traits (in this case, anxiety) did not represent a continuously higher level of experiencing that emotion, but rather the *tendency* to experience it under particular triggering circumstances (Fridhandler, 1986). Research has also found that expectations based on past experiences in similar settings or during certain events can have a powerful impact on the emotions experienced when thinking about those settings or events (Frijda, 1986; Schwarz & Clore, 2003).

The distinction between state and trait emotions has implications for the assessment of emotions for research purposes. Because of their temporary and transient nature, state emotions are best assessed through experience sampling, with data ideally collected in an ecologically valid setting during the event that is expected to give rise to the emotion in question (Schwartz, 2012). By contrast, given their more habitual nature, trait emotions are usually tapped into when collecting data through self-report questionnaires. Habitual emotions lend themselves to examinations of interindividual differences, as compared to intraindividual differences found with the more volatile state emotions (Hertzog & Nesselroade, 1987). Although self-reported levels of habitual trait emotions tend to be higher than measured state emotions (Bieg, Goetz, & Lipnevich, 2014), research has shown that traits contain elements of beliefs (cf. "the accessibility model of emotional self-report"; Robinson & Clore, 2002) and are more predictive of future behaviour (Wirtz, Kruger, Scollon, & Diener, 2003). The last two findings are particularly salient to the present study, where the outcome of interest (ideational behaviour) has been characterized as an indicator of creative *potential* (Runco, 2014) and is thus also forward-looking in nature.

Emotions are further categorized by valence (positive or negative) and by degree of activation (activating or deactivating; Feldman Barret & Russell, 1998; Pekrun, Goetz, & Perry, 2005; Watson & Tellegen, 1985). To simplify the relationship between affect and creative thinking, positive activating emotions (enjoyment, hope, pride) are generally thought to have a particularly supportive impact on creative thinking and ideation, while de-activating emotions (boredom, hopelessness [negative], and relief [positive]) tend to decrease creativity.

The research is mixed on the effect of negative activating emotions (anger, anxiety, shame, frustration) on creativity. Baas, De Dreu, and Nijstad (2008, 2011) proposed that all activating affective states are more supportive of creativity than deactivating states. Dreisbach and Goschke's (2004) mood-as-information theory also supports the idea that negative moods, and the analytic thinking they are associated with, can contribute to overall creativity in the convergent thinking phase; i.e., when it is time to narrow down options and implement one or two creative solutions from the ideas that were generated in the divergent phase. On the other hand, negative moods are thought to suppress the wide associations, freedom of thought, and heuristic processing required for divergent ideation (Dreisbach & Goschke, 2004; Isen & Daubman, 1984; Isen & Means, 1983; Isen, Means, Patrick, & Nowicki, 1982). There seems to be general consensus in the field on the supportive role of positive affect particularly in the divergent, idea-generating phase of creativity (Ashby & Isen, 1999; Fredrickson & Branigan, 2004; Friedman et al., 2003; Isen et al., 1987; Kaufman & Vosburg, 2004; Mitchell & Phillips, 2007; Runco, 2014).

The relationship between emotions and creative thinking is complex and possibly embedded within motivation and achievement goal mechanisms, which will be discussed next.

Goals and motivation. Research has shown that motivation is a critical component of creativity, and individuals only generate highly creative ideas when intrinsically motivated (Amabile, 1983; Ryan & Deci, 2000; Sternberg & Lubart, 1999). Achievement goal theorists (e.g., Dweck, 1986; Dweck & Leggett, 1988) suggested that the goals adopted by students at the beginning of a learning activity have the potential to determine the level and type of motivation experienced through the activity. In achievement situations, such as the higher education setting in the present study, achievement and competence are central features of the context. Mastery and performance goals form the main achievement goal framework and can be further subdivided into approach and avoidance in these two main goals (Elliot & Harackiewicz, 1996; Harackiewicz, Barron, Pintrich, Elliot, & Thrash, 2002). Avoidance goals are generally interpreted as the desire to avoid failure or loss of some kind (e.g., less than optimal achievement or performance of competence, whether factual or perceived), while approach goals are seen as the goals of choice for those who are intrinsically motivated to learn and perform (Elliot, McGregor, & Gable, 1999).

Intrinsically motivated learners are often focused on deeper understanding of the material, adopting mastery goals (Pintrich & Schunk, 1996) that support optimal task engagement (Elliot & Harackiewicz, 1996). They tend to enjoy learning for its own sake (Ryan, 1993) independently of external reward or punishment, and are cognitively and affectively immersed in the activity (cf. “flow”, Csikszentmihalyi, 2000). External constraints such as evaluation or rewarding desired behaviours have been found to decrease intrinsic motivation (Bem, 1972; Lepper, Greene, & Nisbett, 1973). We would therefore generally expect external constraints to suppress creativity, but a study by Conti, Amabile, and Pokkak (1995) found this

effect only in highly skilled participants. Participants with lower skills produced more creative output when told they would be evaluated.

Many questions remain about the links between creativity and affect, motivation and goal adoption. Because we are particularly focused on applied creative thinking (creative thinking based on learned knowledge), we must also look at whether the strategies used for building knowledge impact its subsequent availability. The next section therefore reviews the literature on links between creative thinking and learning strategies.

The Relationship Between Learning Strategies and Creative Ideation

The manner in which information is learned and encoded has been shown to influence how accessible it is later for creative purposes (Mumford et al., 1996). The information processing theory of learning holds that knowledge is constructed by learners through an active process of selection, organization, and integration of incoming information with existing knowledge (Mayer, 1996). Schemata and strategies in long-term memory are thought to guide learning, and the active processes through which incoming information is connected to prior knowledge can differ in both depth and breadth (Craik & Lockhart, 1972; Craik & Tulving, 1975). Cognitive processing can thus occur at deep or surface levels (Marton & Säljö, 1976), and these descriptors are also applied to various student approaches to learning (Biggs, 1993; Entwistle & Waterston, 1988).

Rehearsal, elaboration, and critical thinking are common learning strategies (Pintrich, Smith, Garcia, & McKeachie, 1993), but only the latter two are considered supportive of deep processing. Rehearsal strategies include memorizing and activating information in short-term working memory, which is not believed to help learners make connections to prior knowledge (Pintrich et al., 1991) and is thus considered a surface strategy. Deep strategies, by contrast, are

characterized by activities that allow the learner to consider new information, evaluate it, and link it with previously existing knowledge (Pintrich et al., 1991). Elaboration (e.g., trying to make connections between new material and what is already known) and critical thinking (e.g., thinking about alternatives based on available evidence, or questioning the credibility of new incoming information) are considered examples of deep strategies. Critical thinking can also entail using the process "in reverse", when learners attempt to apply prior knowledge to new situations to make decisions or solve problems (Pintrich et al., 1991).

Affect, goals, and learning strategies have direct effects on learners and learning outcomes and also interact with each other and with the environment, impacting learning processes in multiple ways. Some of the ways that these interactions have been examined in the literature are outlined below.

Interactions Among Affect, Goals, and Learning Strategies

Affect and goals. A series of correlational studies have revealed that mastery-approach goals were consistently (and positively) linked with positive affect, and inversely related to negative affect (Linnenbrink, 2007). Specifically, mastery goals were associated with higher positive activating emotions and lower overall negative emotions (Linnenbrink & Pintrich, 2002). Appraisals of positive affect are thought to launch learners on a path of growth and mastery goals (Boekaerts, 2007), while negative affect can be perceived as a threat signal that leads to minimizing potential harm through narrowing potential options for action (Fredrickson, 2001).

The directionality of the relationship between affect and goals has been the subject of much debate, and some theorists have suggested that goals predict affect (e.g., Dweck & Leggett, 1988; Pekrun, Elliott, & Maier, 2009). Learners who are intrinsically motivated and adopt

mastery goals to achieve competence in a task are thought to experience positive emotions when the progress towards the goals is proceeding as expected. If things do not go as planned and there is negative feedback along the way, intrinsically motivated learners can use negative emotions arising from an initial perceived failure as a signal to renew efforts, rather than to give up on the goal and direct their energy elsewhere (Pekrun, 2006). These renewed efforts may involve thinking creatively about what could be done differently "next time", which would support ideation. Some studies, however, have suggested that perceived failure to complete a task successfully may instead give rise to externally motivated negative emotions from apparent environmental threats (e.g., Schwarz, 1990), leading individuals to adopt analytic, detail-oriented thinking which is not supportive of creativity generally (Dreisbach & Goschke, 2004).

In contrast to the directionality of the two constructs in the preceding paragraph, other researchers have suggested models wherein positive affect leads learners to adopt mastery goals in learning, particularly when they perceive the classroom environment to be supportive (Linnenbrink & Pintrich, 2002). Similarly, Boekaerts (2007) proposed that positive emotions (relating to specific learning activities) guide learners to adopt mastery goals in relation to those activities. These last two studies showed that emotions can also predict goals rather than the uni-directional view (of achievement goals predicting emotions) espoused by earlier theorists. In fact, Linnenbrink and Pintrich (2002) claimed that the relationship is "bidirectional with goals and affect reciprocally related to each other" (p.75), implying that the theoretical ordering of one before the other in achievement settings is far from clear-cut. Amabile (1983) pointed out that while affect is directly related to creativity-related processes, the environment (context) has a critical impact on motivation. Personal goals within the context may thus influence the

relationship between affect and creativity (Amabile, 2013; Amabile & Mueller, 2008; Sullivan, 2017).

The aim of much of the research on achievement emotions and achievement goals summarized above was to explore the joint effects of these variables on traditional learning outcomes such as achievement as measured by grades. To our knowledge, neither direction (goals to affect or affect to goals) has been tested in models examining their potential joint or mediating influences on creative processes in higher education.

Goals and learning strategies. Ames and Archer (1988) suggested that individual perceptions of classroom realities and situational demands determine the types of goals and subsequently the types of strategies selected by learners. Researchers investigating the interactions of these two constructs have consistently found that the *reasons* for studying have an impact on the types of strategies selected. "Task orientation" (an earlier construct similar to mastery goals; valuing learning for its own sake) was positively correlated with deep processing strategies, while "ego orientation" (similar to performance goals; aiming to demonstrate competence relative to others) tended to be linked with surface strategies (Nolen, 1988, 1996). Elliot et al. (1999) similarly found that mastery goals support deep processing strategies and performance goals predict surface strategies. More recently, Senko, Hama, and Belmonte (2013) discovered that mastery goals can support interest-based studying (sometimes to the detriment of exam scores) while performance goals tend to trigger vigilant cue-seeking that can prompt more flexible selection of study strategies.

Affect and learning strategies. Emotions have an important role to play in the strategies selected by students while learning. Pekrun (1998) made the distinction between extrinsic and intrinsic emotions, denoting the extent to which they relate to the task at hand (in this case,

learning), and suggested that positive intrinsic emotions facilitate learning because they direct positive attention and flexible cognitive resources to the task. Negative emotions, by contrast, may provoke learners to adopt rigid surface learning approaches and the use of simple algorithms for rehearsal and memorization (Pekrun et al., 2002). These findings are supported by Ashby and Isen's (1999) neuropsychological theory that pointed to higher brain dopamine levels as the mechanism by which positive affect influences many aspects of cognition, including both long (episodic) and short term (working) memory. Both are indispensable for learning and problem solving.

Much of the literature on the relationship between affect and learning strategies has been presented under the broader umbrella of self-regulated learning. In general, successful self-regulation in learning contexts is based on metacognitive flexibility that allows learners to plan, monitor, evaluate, and adjust their learning strategies using cognitively relevant and affectively adaptive approaches (Boekaerts & Niemivirta, 2000; Pintrich, 2004; Winne & Hadwin, 1998). Objective task difficulty is not always the deciding factor when adopting learning strategies. Instead, the metacognitive processes monitoring and controlling strategy selection are thought to be influenced by personal affect (Efklides, 2014).

Flexibility is supported by positive affect, and thus we would expect positive emotions to have a supportive effect on metacognition and adaptive self-regulated learning strategies. Recent empirical work in this area includes Ahmed, Van der Werf, Kuyper, and Minnaert (2013); Ranellucci, Hall, and Goetz (2015); and Villavicencio and Bernardo (2013). Although these studies include affect and learning strategies, their main focus is self-regulated learning and its impact on achievement (rather than ideation or creativity) and will thus not be reported here in greater detail.

Boekaerts (1987) argued that negative affect related to prior learning experiences may become encoded within individuals, provoking a protective, threat-avoidant response whenever a similar situation presents itself. Her "model of adaptable learning" (Boekaerts, 1992) is based on the assumption that learners continually evaluate their learning context as benign, neutral, or threatening, and decisions regarding the adoption of specific learning strategies are based on that evaluation. Other researchers have also suggested that beliefs, personal interpretations, and affective memories are critical to formulating responses and selecting learning strategies within a given context (e.g., Bandura, 1993; Higgins, 1987; Wigfield & Eccles, 2000).

Indeed, individual beliefs and perceptions seem to be at the core of the interaction of affect and learning strategies. Pekrun's (2006) Control-Value Theory of Achievement Emotions rests on the premise that learners' perceptions and beliefs of how much control they have over a learning activity, combined with their perceived value of the outcome of the activity, influence the emotions they are likely to experience. According to this theory, emotions will in turn influence the kinds of learning strategies adopted to navigate the activity in question.

As was the case with the research on achievement goals and achievement emotions, the investigations within the learning strategies domain have also tended to focus on how the different strategies impact *achievement*. To the best of our knowledge, empirical research on how learning strategies influence the adaptive (vs. routine) availability of learned material, operationalized here as ideational behaviour, has not yet been conducted.

Gender and Creative Thinking

Research has focused our attention on the "leaky pipeline" of women leaving STEM fields (Clark Blickenstaff, 2005), but not as much is known about the innovation gender gap (Beede et al., 2011). The present study will examine potential gender differences in factors

influencing ideational behaviour, and a brief review of relevant studies on gender and creativity is therefore provided here. No gender differences have been found in individual creative ability, the quality of creative products, or self-reports on creativity (for a more extensive review, see Baer & Kaufman, 2008; Goldsmith & Matherly, 1988; Kogan, 1974). The documented gender differences that do exist in adult creative eminence (Simonton, 1994) seem related to external influences such as sociocultural expectations and opportunities for education (Helson, 1990; Ruth & Birren, 1985), as well as unequal access to resources in general (Piirto, 1991; Simonton, 1994).

Piirto (1991) highlighted that gender differences in creative eminence appear after higher education—at an age when life choices (whether "freely" selected or based on societal pressure and norms) have an impact on the commitment to a domain. This finding suggests that there may be gender differences in the motivational mechanisms that influence creativity. Ruth and Birren (1985) argued that females may experience a lower "need of achievement in creative endeavors" (p. 101). Intrinsic motivation plays a vital role in supporting creativity (e.g., Amabile, 1983), and external rewards or constraints have the potential to decrease motivation (Lepper et al., 1973). To further complicate the gender issue with respect to motivation and creativity, Baer (1998) found that the creativity of female students was particularly vulnerable to the presence of external pressures, and that the creativity of girls (but not boys) was lower when participants were told that their creative output would be evaluated (Baer, 1997). Conti, Collins, and Picariello (2001) found a significant gender difference in creativity in competitive situations, where females were less creative than males--particularly when students were sitting in gender-segregated groups.

Baer and Kaufman (2008) concluded their paper on gender differences in creativity by suggesting that "looking for gender differences in the interactions among aptitudes, motivations, and opportunities would be one promising area to investigate" (p.99). Our study will address a part of this proposition, by exploring potential gender differences in the ways affect, goal motivation, and learning strategies interact to influence ideational behaviour in male and female STEM students. We will also explore whether effects differ based on the year of study in the program to determine when and where additional support may be needed.

The Present Study

Processes relating to affect, motivation, and learning strategies can impact creative thinking in individuals. Students in higher education, particularly in STEM fields, are implicitly saddled with the expectation that they will somehow, during their studies, develop the ability to generate ideas in order to creatively solve some of the world's most pressing problems. However, as discussed, there is a gap in the literature on how the constructs reviewed above interact in this specific population to support or suppress applied creative thinking or adaptive expertise, conceptualized as the generation of innovative ideas based on learned knowledge.

To that end, we will examine the patterns through which these factors may influence ideation among undergraduate STEM students by exploring the following research questions:

1) How are achievement emotions, achievement goals, and learning strategies related to ideational behaviour in STEM students?

2) Do emotions or goals have a mediating effect on each other, or on learning strategies, in relation to ideational behaviour in STEM programs?

3) Do these relationships and patterns vary by gender or by year of study in the STEM program?

4) What do STEM students perceive to be the biggest influences supporting or suppressing creative thinking in relation to their field of study?

The first question aims to clarify whether affect, motivation, or learning strategies have a direct relationship, individually, with the ideational tendencies of STEM students in their natural environment. The second question builds on the first and takes the inquiry further by exploring whether affect, motivation, or learning strategies influence *each other* in particular ways which may then have an impact on creative thinking. The third question probes whether male and female STEM students, or students at different levels of study, experience differences either in ideation itself, or in the interplay of how affect, motivation, and learning strategies influence their ideational tendencies. Finally, the purpose of the open response (fourth) question is to gain some insight into the lived experiences of STEM students, to better understand what they perceive as encouragement and barriers to creative thinking within their programs of study.

We believe this to be the first study that tests the impact of these factors on ideation and can therefore not formulate detailed hypotheses *a priori*. However, based on the body of literature reviewed in the broader fields of creative thinking and adaptive expertise, we can make the assumptions that positive affect, mastery goals, and deep processing (learning) strategies will generally be positively correlated with ideational behaviour in the context of STEM programs in higher education (research question one). The exact mechanisms and patterns through which this occurs have not been studied, and the remaining three research questions should therefore be considered exploratory and descriptive, with findings expected to further clarify the nature of these relationships in the context of the STEM environment, and to help illuminate potential future directions for further research in this underexplored area.

Methods

Participants and Procedures

The data analyzed in the present study were part of a larger study, for which participants were recruited from the Faculty of Science and the Faculty of Engineering at a large Canadian research university. The present sample data constitute a previously unexplored subset of the larger multi-phase data collection, which was approved by the Research Ethics Board. This subset of data has not been reported elsewhere. The university registrar sent a recruitment email to all undergraduate students in these faculties (N = 4,131), and students who volunteered to respond to questionnaires using an online collection tool were entered in a lottery for ten $10 gift cards. Informed consent was obtained from all participants, and standard demographic data (age, gender, year of study) were collected. The larger study involved collecting data over several months during the term, but only the measures relevant to the investigation at hand will be discussed. Our measures were included within two omnibus questionnaires comprising a total of 60 (phase 1) and 62 (phase 2) items, respectively. At the beginning of the study, participants were asked to select a specific compulsory course within their program to keep in mind while answering the questions. They were subsequently emailed a link inviting them to participate in phase 2 and were again eligible to win one of ten $10 gift cards.

For purposes of the current study, responses to two measures and an open-ended question from phase 1 (30 items in total), and two additional measures from phase 2 (45 items in total), were analyzed. All measures and reliability estimates are described below. The total number of students who completed both measures in phase 1 was 171 (51 males, 118 females, and 2 who did not specify gender; mean age = 19.73, SD =1.48). For phase 2, 124 students completed both

measures (31 males, 94 females; mean age 19.7, *SD*=1.29). The implications of the attrition between the two phases will be discussed below under the heading "missing data and attrition".

Measures

Four instruments were used to measure the four focal constructs in this study (ideational behaviour, achievement emotions, achievement goals, and learning strategies). The Runco Ideational Behaviour Scale (RIBS; Runco, Plucker, & Lim, 2001) for ideation; the Achievement Emotion Adjective List (AEAL; Raccanello, Brondino, Crane, & Pasini, 2016) for achievement emotions; the Achievement Goal Orientation Scale (AGO; Elliot & Murayama, 2008) for achievement goals; and the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich et al., 1991) for learning strategies. The instructions for each measure contained the words "in the context of your current program of study" to elicit responses pertaining specifically to the content of their program, as opposed to their general self-concept. Additionally, participants were instructed to select as their specific focus one of the required courses in the program, to eliminate the differences that can occur between studying required material and studying self-selected material out of interest (cf. favourite courses and least favourite courses, Ben-Eliyahu & Linnenbrink-Garcia, 2015). The instruments and their reliability coefficients are presented below, and the complete questionnaires can be found in Appendix B. Descriptive statistics for each variable are presented in Table 2.

The Runco Ideational Behaviour Scale (RIBS; Runco et al., 2001)**.** The 14-item RIBS is a validated self-report measure of ideational tendencies in natural settings. This measure contains items such as "I am good at combining ideas in ways that others have not tried", and "I have ideas about new inventions or about how to improve things". Respondents were asked to

rate the items on a Likert scale from 1 (not at all true of me) to 7 (very true of me). In our sample, Cronbach's α = .93, suggesting high internal consistency.

Achievement Emotion Adjective List (AEAL; Raccanello et al., 2016). This 30 item questionnaire measures 10 distinct emotions (hope, enjoyment, pride, shame, anger, anxiety, frustration, hopelessness, disappointment, and boredom) that are commonly experienced by learners while studying (Pekrun, Goetz, Titz, & Perry, 2002). The AEAL questionnaire was modified (Jarrell, 2018; Jarrell, Tressel, & Lajoie, 2018) from a back-translated version of the original Italian list (Brondino, Raccanello, & Pasini, 2014) to reflect English terms comparable to those found in other multi-item emotion questionnaires such as the Achievement Emotions Questionnaire (Pekrun et al., 2002) and the Epistemic Emotions Scales (Pekrun, Vogl, Muis, & Sinatra, 2017). The terms frustration and disappointment were added, and content validity of the modified scale was tested with a structured sorting task (Agarwal, 2011), yielding an accuracy rate of 82% (Jarrell et al., 2018).

Participants were instructed to rate the intensity of the emotions they felt while studying on a Likert scale from 1 (not at all) to 5 (very strong). For each emotion measured, the Cronbach's alpha scores were as follows: α = .78 (hope); α = .88 (enjoyment); α = .79 (pride); α = .81 (shame); α = .92 (anger); α = .89 (anxiety); α = .84 (frustration); α = .76 (hopeless); α = .83 (disappointment); and α = .86 (boredom). These coefficients are indicative of high internal consistency.

The Achievement Goal Orientation Scale (AGO; Elliot & Murayama, 2008). This validated instrument contains 12 items subdivided into 4 goal types, namely Mastery Approach (e.g., "My goal is to learn as much as possible"), Performance Approach (e.g., "My aim is to perform well relative to other students"), Mastery Avoidance (e.g., "I am striving to avoid an

incomplete understanding of the course material"), and Performance Avoidance (e.g., "My goal is to avoid performing poorly compared to others"). Participants were asked about their goals for the course, and response options ranged on a Likert scale from 1 (Not at all true) to 7 (Very true). All 4 scales (for the four goal types) revealed acceptable or high internal consistency in our sample, with Cronbach's α values as follows: α = .82 (mastery approach); α = .88 (performance approach); α = .73 (mastery avoidance); and α = .88 (performance avoidance).

The Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich et al., 1991). The MSLQ is a well-known measure with several groups of validated scales. Our investigation focuses on the cognitive aspects of creative thinking skills and ideation; we are therefore using the cognitive (learning) strategies scales from the MSLQ, namely rehearsal (e.g., "I make lists of important terms for this course and memorize the lists"), elaboration (e.g., "I try to relate ideas in this subject to those in other courses whenever possible"), and critical thinking (e.g., "When a theory, interpretation, or conclusion is presented in class or in the readings, I try to decide if there is good supporting evidence"). Respondents were asked to rate their level of agreement with each statement on a Likert scale from 1 (Not at all true of me) to 7 (Very true of me), and the Cronbach's α for each scale in our sample was α = .65 (rehearsal); α = .72 (elaboration); α = .88 (critical thinking).

All of the MSLQ measures except one (α = .65 for rehearsal) are within the recommended range of .7 - .95 (Nunnally & Bernstein, 1994). However, in the MSLQ manual, Pintrich et al. (1991) found the Cronbach's α for the Rehearsal scale in their original validation study to be α = .69, (p. 18), calling it "robust" (p.7). We interpret our slightly lower finding (α = .65) as a suggestion that the 4 items in this scale are related but perhaps not as closely as items in the other scales.

Calculated aggregate variables. Additional aggregate variables were calculated from the participant responses to allow for initial large-grain clarification of overall relationships between ideation and our focal constructs. These aggregate variables were mastery total (the mean of mastery approach and mastery avoidance), positive total[2] (the mean of hope, pride, and enjoy), negative activating (the mean of shame, anger, anxiety, and frustration), negative deactivating (the mean of hopeless, disappointed, bored), negative total (the mean of the preceding seven negative emotions), and deep strategies (the mean of elaboration and critical thinking).

Open response: mixed methods approach. In addition to using validated pre-existing questionnaires we invited participants to describe, in their own words, factors that they "believe support or suppress [their] creativity in relation to [their] learning within [their] current program of study at McGill" (research question 4). A qualitative analysis was conducted of learners' perceptions about elements that help or hinder creative thinking in the context of their studies. This open-ended question was placed in the first omnibus questionnaire (phase 1), immediately following the RIBS ideation questions. The rationale for this placement was that the participants' interpretation of "creativity" in the question would be primed by the ideation construct which had been the focus of the immediately preceding questionnaire. In both cases, participants were reminded to think of their current studies while answering these questions.

In the absence of pre-existing theories explaining factors influencing creative thinking among STEM students in higher education, a bottom-up grounded theory approach (Hsieh & Shannon, 2005; Strauss & Corbin, 1994) was used to identify shared concepts in participants' unique responses. Content analysis methods were used with an inductive category development

[2] Only positive activating emotions are measured by the AEAL. For that reason, there are no separate aggregates for positive activating or deactivating emotions, only positive total; all are activating.

framework to conceptualize initial tentative categories, and specific codes were developed through an open coding process identifying emerging common themes in participant responses (Krippendorf, 1980; Mayring, 2000). Each nominal code refers to a qualitatively different theme (Stemler, 2004), and the codes were neither rank-ordered nor mutually exclusive (Jones, Johnson, Butler, & Main, 1983). The length of coding segments varied, consisting of an individual participant's entire response and ranging in length from two to 121 words.[3] This approach initially yielded a total of 10 codes (five suppressing and five supporting creativity), revised to 11 (Table 3) after the first round of interrater agreement testing. The individual codes are discussed in detail in the section on results.

166 complete participant responses[4] to the open-ended question were analyzed (50 male, 116 female, mean age = 19.76, *SD* = 1.48). With the large number of potential coding variations from among 12 codes (the 11 themed categories as well as the possibility of no code), the risk of overestimating agreement due to chance (Cohen, 1960) was low, and consensus estimates of interrater reliability were calculated with percentage agreement. Two independent researchers in addition to the primary investigator coded 40 % of the responses. After round 1 with coder 1, the initial inter-rater agreement was 71%. Discussions about items of non-agreement led to one additional code being split out from the original five supporting codes, and agreement with coder 1 then improved to 84%. Coder 2 used the revised coding scheme (for round 2) and agreement was 82%. Agreement for both coders fell within the range of 75-90% proposed by Stemler

[3] Each segment could potentially be assigned multiple codes if the respondent identified many items that affect creativity. Alternatively, it was possible that a segment not be assigned any codes, in cases where the response did not sufficiently address the specific construct of creativity. An example of a "no code" response is "I'm not entirely happy in my current program"; an example of a "multi-code" response is "Talking with others is the best way to generate ideas since they often arise from different points of view" because it alludes to two separate ideas that support creativity: *talking with others* and *different points of view*.

[4] Although Phase 1 had 171 participants, five responses were excluded for reasons described below under "data screening and analysis".

(2004) as acceptable levels of agreement for this type of coding, suggesting that the final coding scheme allowed the coders to independently make similar interpretations from the spontaneous response data collected from the open-ended prompt (Hallgren, 2012). Subsequently, quantitative analyses were conducted based on the codes.

Data Screening and Analysis

Prior to commencing quantitative analyses**,** responses from the two phases of data collection were merged into one data file in SPSS, using unique participant identification codes to match responses to participants. Data were then screened and cleaned as described below, in order to verify that data were robust to statistical assumptions. The screening sections below are followed by summaries of the quantitative analyses undertaken with the cleaned data.

Missing data and attrition. Using the listwise exclusion function (Peugh & Enders, 2004) for missing data in SPSS, we initially determined that $n = 124$ participants responded completely to all the questionnaires for our four focal constructs, measured in the first two phases of the larger data collection. In order to investigate whether data were missing at random, we conducted an ANOVA to compare the means of the measures in phase 1 (ideation and the four sub-scales to the AGO, namely mastery approach, mastery avoidance, performance approach, and performance avoidance) between those who stayed in the study (i.e., also participated in phase 2) and those who did not. No significant group differences in responses to these measures were found, suggesting that attrition had no effect on the responses.

A chi-square analysis was conducted to determine whether the nominal variables of gender or year of study were independent of attrition. No association was found for year of study, but gender showed a significant association, $\chi 2$ (2, $N = 171$) = 6.236, $p = .013$, with an effect size *Phi* = .189. This small-to-moderate effect size suggests that males were somewhat

more likely to drop out of the study. The gender distribution in phase 1 was $n_{male} = 53$, $n_{female} = 122$ (30% male to 70% female), and in phase 2 $n_{male} = 31$, $n_{female} = 94$ (25% male to 75% female).

These proportions may simply be reflective of the higher levels of volunteerism among women; it is known that studies with volunteer participants (such as the present study) have a higher proportion of female participants. Researchers have consistently found that the strongest predictor of response vs. non-response is gender, with females being more likely to respond across all types of surveys (e.g., Porter & Whitcombe, 2005; Underwood, Kim, & Mathier, 2000). Additionally, Sax, Gilmartin, and Bryant (2003) found that due to increasing overall demands on students, many are unwilling to commit the time to voluntarily complete a questionnaire, although this effect may be somewhat moderated when the topic of the questionnaire is perceived to have relevance to students' lives. While we have no direct evidence of this effect in the present study, it is conceivable that female STEM students perceived a study on creativity, emotions, and goals to be more relevant to their learning experiences than did male students.

Screening for robustness to assumptions. Prior to commencing correlational analyses to seek answers to research question 1, data were visually screened by using boxplots, Q-Q plots, and frequency distributions. For our focal dependent variable (RIBS, measuring ideational behaviour), the initial box plot revealed four outliers. Visual inspection of the data revealed data entry errors for three participants who had not responded to any of the RIBS questions, but whose scores had been erroneously entered as "0". After removal of these three cases, the outcome variable met assumptions of normality, based on non-significant results from both the Kolmogorov-Smirnov ($p = .200$) and Shapiro-Wilk ($p = .362$) tests despite one remaining outlier identified in the box plot. Closer inspection confirmed that the outlier was a participant with a

low score, rather than an error, and with a z-score of -2.71 the case was retained (because it was less than the suggested cut-off of z >=|3.29|; Field, 2013).

In behavioural research, fully normal distributions of data are exceedingly rare (Micceri, 1989), and our data were typical in this sense. Skewness and kurtosis were evaluated, and three variables (mastery approach, shame, and anger) displayed moderate skewness. Z-scores were calculated and six outliers (z >=|3.29|; Field, 2013) were identified among a total of 18 variables, two each in the three skewed variables. Each was replaced with the next closest non-outlying score (Ghosh & Vogt, 2012). Kurtosis has a smaller overall impact on outcomes than skew (Tabachnick & Fidell, 1996), and observed levels of kurtosis were not of concern in our data.

After completing univariate screening as described above, we investigated potential multivariate outliers among the 18 variables in our study by computing the Mahalanobis distance (*MD*; Tabachnick & Fidell, 2013). Two multivariate outliers were identified with *MD* = 45.92 and *MD* = 44.33 respectively. Because these two cases exceeded the critical value ($\chi 2_{crit}$ = 42.31 at *df* = 18 and $p < .001$), they were excluded from further analysis. Finally, we conducted a graphical assessment of multivariate normality (Nor, 2015) which yielded the Chi-square versus Mahalanobis distance plot shown in Figure 6. Based on this relatively straight line, we proceeded with quantitative analyses as summarized below.

Analyses conducted. To answer research question one, bivariate Pearson correlation analyses were conducted with all 17 independent (four goal variables, ten emotion variables, and three learning strategy variables) and aggregate variables (described above) in relation to ideational behaviour (our focal dependent variable). The decision was made to utilize listwise (rather than pairwise) deletion of missing data for two reasons: It is the default procedure in SPSS (Schlomer, Bauman, & Card, 2010), and is also referred to as complete case analysis

(Pigott, 2001). The latter feature allows correlations to be compared across the data set in multivariate analyses (i.e., each correlation is calculated using the same pair of cases). We had determined earlier that although the data were not missing completely at random (MCAR), the gender effect was very small and attributable to forces outside our variables, thus minimizing the bias that can occur from listwise deletion. Additionally, we ran tests with both listwise and pairwise deletion and found that the differences in significant results were negligible between the two methods.

The correlations were conducted as 2-tailed for variables where theory did not suggest reasons to do otherwise (i.e., goal constructs and learning strategies). For emotions, however, prior research (Ashby & Isen, 1999; Fredrickson & Branigan, 2005; Friedman et al., 2003; Isen et al., 1987; Kaufman & Vosburg, 2002; Mitchell & Phillips, 2007; Runco 2014) has consistently found that positive emotions support, and negative emotions suppress, divergent thinking (operationalized here as ideation). Although negative emotions can support some forms of creativity under certain conditions (e.g., Dreisbach & Goschke, 2004), these findings have been associated with the *convergent* phase of creativity where negative moods can sustain perseveration and help bring about closure. The creativity scale used in the present study (RIBS; Runco et al., 2001) is a measure of *divergent* thinking which is consistently thought to be supported by positive emotions and suppressed by negative emotions. Therefore, bivariate correlations between achievement emotions and ideational behaviour were conducted as 1-tailed analyses.

For research question two (whether goals, emotions, or learning strategies influence each other in relation to ideational behaviour), process modelling using PROCESS for SPSS 2.16.1 (Hayes, 2013) was used to explore indirect effects (mediation) between the constructs. In

keeping with the exploratory nature of the present study, and given the lack of convergence in the literature on the directionality of constructs (as discussed above), three groups of analyses were conducted (Figure 7). Group one explored the potential indirect effect of achievement emotions on the relationship between achievement goals and ideational behaviour; group two reversed the constructs and examined the potential indirect effect of achievement goals on the relationship between achievement emotions and ideation; and in group three we explored whether either emotions or goals had an impact on the relationship between learning strategies and ideational behaviour.

For research question three (whether the relationships between our focal independent variables and ideation differed between genders or years of study), we initially explored group differences with ANOVAs and MANOVAs looking for main effects and interaction effects, and subsequently ran moderated moderation models in PROCESS (Hayes, 2013). Using PROCESS and the bootstrap resampling function allowed us to minimize the detrimental effects that a small and unequal sample size (particularly after the total sample was divided into eight cells; that is, two genders by four years) can have on power and the accuracy of inferences based on statistical results (Fritz & Mackinnon, 2007; Preacher & Hayes, 2008).

Finally, responses to research question four (open ended question about factors that suppress or support ideation) were analyzed for content, and the items identified by learners were grouped into themed categories that either support or suppress creativity thinking within the context of the program of study. The categories (11 nominal codes) were then dummy coded (0 = category not mentioned, 1 = category mentioned by the respondent) to allow for further exploratory quantitative analyses including bivariate correlations among the categories, and also

between the categories and other constructs measured in the present study (ideation, goals, affect, and learning strategies).

Results

Research Question One

To determine whether, and to what extent, ideation was related to goals, emotions, and learning strategies, bivariate Pearson's correlations were examined between ideation and 17 relevant questionnaire variables in our study (four measuring goals, ten measuring emotions, and three measuring study strategies), as well as six calculated aggregate variables as described above. For legibility, each of the three constructs (goals, emotions, and study strategies) is reported separately.

Ideation and goals. Both mastery goals (approach and avoidance) were significantly correlated with ideational behaviour. Mastery approach goals revealed a correlation of $r = .242$ ($p = .008$), and mastery avoidance goals were correlated at $r = .230$ ($p = .012$). The aggregate total mastery variable was more strongly correlated with ideation than either of the individual (component) mastery variables at $r = .266$ ($p = .003$). Neither performance approach goals nor performance avoidance goals were significantly correlated with ideational behaviour (Table 4).

Ideation and emotions. Ideational behaviour was positively correlated with total positive activating emotions ($r = .267$, one-tailed $p = .002$) and negatively correlated with total negative emotions ($r = -.193$, one-tailed $p = .018$), negative activating emotions ($r = -.201$, one-tailed $p = .014$), and negative deactivating emotions ($r = -.165$, one-tailed $p = .036$). Aside from shame and boredom which were not significantly correlated with ideation, the other eight measured individual emotions were significantly correlated in the expected directions; that is, all

positive emotions were positively correlated and negative emotions negatively correlated with ideation (see Table 5 for correlations with individual emotions).

Ideation and study strategies. There was no correlation between shallow study strategies (rehearsal) and ideation. However, deep study strategies were significantly and positively correlated with ideation ($r = .482$, $p < .001$). The two components of deep strategies were also individually correlated with ideation: elaboration at $r = .310$, $p = .001$ and critical thinking at $r = .512$, $p < .001$ (Table 6).

Research Question Two

In keeping with the exploratory nature of the study, we investigated whether any of the focal constructs (goals, achievement emotions, and study strategies) have a mediating effect on each other in terms of their joint influence on ideation. Three groups of PROCESS mediation analyses were conducted using Model 4 (Hayes, 2013, 2018; see example of a conceptual diagram of the model in Figure 8). This model was selected because it allows for parallel mediation; we were able to explore the effects of several hypothetical mediators within one model. Additionally, we used bias-corrected bootstrapping which is more robust against small samples and unequal group sizes, providing maximum power for the sample (Fritz & MacKinnon, 2007).

For each analysis, the goal was to explore the extent to which the effect of the mediator(s) M affected the strength of the relationship between the independent variable (X) and the dependent variable (Y). The dependent variable in each of our models was ideational behaviour because the specific aim of research question two was to examine how goals, achievement emotions, and study strategies potentially influence each other in relation to ideation in the context of STEM.

Three groups of analyses were carried out. Group 1 explored the influence of achievement emotions on the relationship between achievement goals and ideation; Group 2 analyzed the effects of achievement goals on the relationship between emotions and ideas; and Group 3 examined the impact of achievement emotions and achievement goals on the relationship between study strategies and ideational behaviour (Figure 9, repeated from Figure 7 for sequential reference).

Group 1. Achievement emotions were explored as aggregate variables, based on valence and activation. The impact of positive activating emotions, negative activating emotions, negative deactivating emotions, and total negative emotions was analyzed independently, and separate tests were run with mastery approach goals and mastery avoidance goals as the independent variables (and ideation as the DV).

The results of the initial analysis of grouped emotion variables suggested that mastery approach goals positively predicted positive activating emotions (hope, pride, and enjoyment). For the "a" path (Hayes, 2013, 2018)[15], $B = .311$, $p < .001$, and SE=.069. The R-squared value for this relationship was .31, indicating that 31% of the variance in positive activating emotions is accounted for by mastery approach goals. The "b" path in this model was also significant, indicating a positive relationship between positive activating emotions and the outcome variable of ideational behaviour ($B = .289$, $p < .01$, SE=.136). While the omnibus test revealed that the overall model (total effect) was significant at $F_{(2, 116)} = 7.31$, $p = .008$ with a coefficient of $B =$ .278, the inclusion of positive activating emotions as a mediator rendered the direct effect non-

[5] All references to "a" path, "b" path, etc, are references to results from PROCESS mediation analyses (Hayes, 2013, 2018), as shown in the conceptual diagram in Figure 8. For legibility, the author's name will not be repeated at every mention of the path.

significant, suggesting mediation. However, the indirect (mediation) path only bordered on significance with an effect coefficient *B* = .090, *SE*=.059, [LLCI -.001, ULCI .232] (Figure 10).

Nonetheless, the effect size for this mediation was significant: R-squared = .036 (or 3.6%), *SE* = .025, [LLCI .003, ULCI .11]. The practical effect of this mediation may be interpreted as small but significant (e.g., Cohen, 1988; Shrout & Bolger, 2002), and the borderline significance of the indirect path may be an artifact of confounding factors within the aggregate variable.

To increase the granularity of the analysis, we then explored the *individual* positive activating emotions of hope, pride, and enjoyment as potential mediators for mastery goals with respect to ideation. With mastery approach as the IV, hope was revealed as a full mediator with significant "a" and "b" paths (*B*=.366, *p* = .000, *SE* = .074 and *B*=.325, *p* = .011, *SE* = .125, respectively) as well as a significant indirect effect (*B*=.119, *SE* = .067, [LLCI .009, ULCI .272]). Consistent with full mediation, the direct effect of mastery approach on ideation was rendered insignificant with the inclusion of hope in the model.

However, neither pride nor enjoyment significantly mediated this relationship. While the direct effects in both models with mastery approach and ideation were significant (pride *B*=.233, *p* = .037, *SE* = .016; enjoyment *B*=.234, *p* = .03, *SE* =. 109), no indirect (mediating) effect was found for these two emotions. This suggests that hope is the specific significant emotion that brings the aggregate positive emotion variable close to significance. Although neither pride nor enjoyment revealed any indirect effects in their respective individual models, hope fully mediated the relationship between mastery approach and ideation (Figure 11).

Next, we considered the influence of *negative* emotions on the relationship between mastery approach goals and ideation. Beginning with the aggregate emotion variables, the three

models were tested with different groups of negative emotions (negative activating: shame, anger, anxiety and frustration; negative deactivating: disappointment, hopelessness, and boredom; and total negative emotions: all of the previous seven emotions combined) as potential mediators in the relationship between mastery approach goals and ideational behaviour.

Aggregate negative activating emotions were not a significant mediator for the effect of mastery approach on ideation, although there was, again, a significant "a" path: B= -.234, p = .001, SE = .072. Note the negative coefficient, indicating an inverse relationship between mastery approach and negative activating emotions. The findings were similar for negative deactivating emotions with respect to their role in the model: the "a" path was again negative and significant (B = -.334, p = .000, SE = .07) but no mediation was evident. Finally, regarding the influence of total negative emotions on the relationship between mastery avoidance and ideation, again only the "a" path of mastery avoidance to negative deactivating emotions was significant (B = -.120, p = .024, SE = .052), but no mediating (significant indirect) effects were found for the influence of grouped negative emotions on the relationship between mastery approach and ideation (Figure 12).

Similarly, each of the individual negative emotions showed a negative (inverse) association with mastery approach through a significant "a" path (except anxiety which only approached significance). The statistics were as follows: shame B = -.206, p = .007, SE = .074; anger B = -.176; p = .042, SE = .056; frustration B = -.389, p = .000, SE = .092; hopelessness B = -.341, p = .000, SE = .084; disappointment B = -.338, p = .000, SE = .087; boredom B = -.323, p = .000, SE = .083, and anxiety B = -.165, p = .09, SE = .097 (Figure 13). Although no mediation by individual negative emotions was found, these "a" paths indicated that higher levels of

mastery approach goals were associated with lower reported levels of all negative emotion variables (aggregate and individual).

Turning now to models (still within Group 1) using mastery *avoidance* goals as the independent variable, we found that they were positively related to positive activating emotions, but to a lesser extent than mastery approach goals. This "a" path had coefficient $B = .123$, $p < .05$, $SE = 017$. The R-squared value for mastery avoidance to positive activating emotions was .05, suggesting that a smaller amount (5%) of variance in positive activating emotions is accounted for by mastery avoidance goals, compared to mastery approach goals (31%). The "b" path in this second mediation model was also significant, ($B = .323$, $p < .05$, SE=.128). The omnibus test showed that the overall model was significant at $F_{(1, 117)} = 6.55$, $p = .012$, but in this analysis both the total effect "c" (B=.184, $p = .012$, $SE = .072$) and direct effect "c'" (B=.145, $p = .048$, $SE = .072$) paths remained significant, which is indicative of partial mediation. In other words, the relationship between mastery avoidance and ideation was *partially* mediated by positive activating emotions. The mediation effect size was again small but significant, R-squared = .022 or (2.2%), $SE = .019$, [LLCI .001, ULCI .081] (Figure 14).

Regarding the effects of individual positive emotions in this model, only the "a" paths were significant for two of the three emotions (hope B =.162, $p = .003$, $SE = .055$, and enjoy B =.154, $p = .01$, $SE = .059$). The inclusion of pride had no effect, and none of the emotions showed significant direct or indirect overall effects in the model. Thus, individual positive emotions did not mediate the relationship between mastery avoidance and ideational behaviour.

Testing the model with mastery avoidance and negative emotions, none of the aggregate negative emotions showed evidence of mediation, nor were individual "a" or "b" paths for individual negative activating emotions statistically significant, although frustration approached

significance in its negative relationship with mastery avoidance (B = -.132, p = .054; SE = .068). For negative deactivating emotions, boredom was significantly and negatively associated with mastery avoidance (B = -.139, p = .024, SE = .061) and hopelessness approached significance (B = -.119, p = .057, SE = .062). Disappointment was not statistically significant in this model, and with no significant b paths from individual negative emotions to ideation, there was no mediation.

To summarize the results regarding positive emotions in Group 1, positive activating emotions have more of an influence on the relationship between mastery approach and ideation than on the relationship between mastery avoidance and ideation. In more fine-grained analyses, hope was the only individual component within positive activating emotions responsible for the mediating effect on mastery approach with respect to ideation. Hope also influenced the model in the relationship between mastery avoidance and ideation but to a lesser extent, and no mediation was found in this model. None of the negative emotions (aggregate variables of activating, deactivating, and total negative emotions, nor individual negative emotions) showed evidence of mediating the relationship between mastery goals and ideational behaviour. However, despite introducing the negative effects of negative achievement emotions in the models, the *direct* relationship between mastery approach and ideation remained positive and significant. In the model with negative activating emotions, the direct effect of mastery approach on ideation was B = .236, p = .039, SE = .113, [LLCI .013, ULCI .459]. Testing negative deactivating emotions as mediators in the same model, the direct effect remained similarly positive at B = .248, p = .033, SE = .113 [LLCI .020, ULCI .468]. When mastery avoidance was the independent variable, its direct effect on ideation remained positive as well, even with the inclusion of negative affect (activating and deactivating) in the model. With

negative activating emotions the direct effect of mastery avoidance on ideation was $B = .162$, $p = .029$, $SE = .073$, and with negative deactivating emotions the direct effect of mastery avoidance on ideation was $B = .169$, $p = .025$, $SE = .074$.

Group 2. In this second group of mediation analyses the potential mediating effects of achievement goals on the relationship between emotions and ideas were examined. We began by analysing the potential mediating effect of mastery approach goals on the relationship between positive activating emotions and ideation. Despite a significant "a" path of $B = .477$, $p = .000$, $SE = .109$, and a significant overall model (F 2,116) = 6.02, $p = .003$, the indirect effect was not significant. There was no mediation but the direct effect was significant ($B = .289$, $p = .036$, $SE = .136$).

Examining the individual positive emotions, however, two (pride and enjoyment) were found to be fully mediated by mastery approach in their influence on ideation. Pride was significantly associated with mastery approach through the "a" path: $B = .295$, $p = .003$, $SE = .096$. In the same model mastery approach significantly influenced ideation through the "b" path: $B = .223$, $p = .037$, $SE = .106$. Similarly, enjoyment was significantly associated with mastery approach ("a" path: $B = .351$, $p = .000$, $SE = .093$) and mastery approach in turn significantly influenced ideation ("b" path: $B = .238$, $p = .03$, $SE = .109$). Both of these models revealed full mediation: pride showed a significant indirect effect of mastery approach of $B = .066$, $SE = .040$, [LLCI .006, UCLI .167], while the statistics for the full mediation by mastery approach on the effect of enjoyment on ideas were $B = .084$, $SE = .048$, [LLCI .010, UCLI .204]. In contrast, the influence of hope on ideation was not mediated by mastery approach, although there was a highly significant relationship between hope and mastery approach ("a" path; $B =$

.470, p = .000, SE = .095) as well as a significant direct effect of hope on ideation ("c'" path; B = .325, p = .011, SE = .125; Figure 15).

Turning now to negative emotions as the independent variable ("X" in Model 4; Hayes, 2013, 2018) and exploring a mediation model with mastery approach goals, we found full mediation with the aggregate variable of total negative emotions through mastery approach: the indirect effect is significant with B = -.107, SE = .062, [LLCI -.268, UCLI -.016]. We also have full mediation with both the aggregate negative activating and deactivating emotions: B = -.083, SE = .052, [LLCI -.219, UCLI -.009] and B = -.116, SE = .063, [LLCI -.276, UCLI -.020], respectively (panels A, B, and C in Figure 16).

Exploring which of the individual negative emotions contributed to the indirect effects observed, we found that the effects of all but two negative emotions (anxiety and anger) on ideation were fully mediated by mastery approach, as follows: frustration, B = -.073, SE = .044, [LLCI -.189, UCLI -.010]; hopeless, B = -.084, SE = .047, [LLCI -.211, UCLI -.016]; disappointed, B = -.083, SE = .048, [LLCI -.210, UCLI -.014]; bored, B = -.098, SE = .051, [LLCI -.230, UCLI -.020]; and shame B = -.079, SE = .051, [LLCI -.223, UCLI -.009] (panels D, E, F, G, and H, respectively, in Figure 16).

Still within Group 2, looking now to the impact of mastery *avoidance* as a potential mediator, we began with the aggregate independent variable of positive activating emotions and its relationship with ideation. Our analysis of the mediation model revealed that positive activating emotions had both direct positive effects on ideation (B = .323, SE = .128, p =.013, [LLCI .069, ULCI .576]) and significant indirect effects through the mediator (B =.056, SE = .035, [LLCI .005, ULCI .151]), referred to as partial mediation (Figure 17).

Testing the individual positive emotion of hope we also found partial mediation: significant direct effect *B* = .345, *SE* = .117, *p* = .004, [LLCI .113, ULCI .577] and indirect effect *B* =.059, *SE* = .035, [LLCI .006, ULCI .146]. However, the "b" path approached but did not reach significance *B* = .126, *p* = .079, *SE* = .072 (Figure 18).

For enjoyment, there was full mediation as only the indirect effect was significant, *B* = .057, *SE* = .035, [LLCI .009, ULCI .152] (Figure 19). For pride, there was no mediation but the direct effect was significant *B* = .258, *SE* = .109, *p* =.01, [LLCI .042, ULCI .474].

Models testing mediation by mastery avoidance of the relationships between either negative *total* emotions (grouped) or negative *activating* emotions (grouped and individual) and ideation returned no significant results, although frustration was close to being significant with its ULCI exactly equal to zero and a significant overall model (*B* = -.235, *SE* =.097, *p* = .017, [LLCI -.426, ULCI -.043]), but no indirect effect.

Aggregate negative *deactivating* emotions, however, were fully mediated by mastery avoidance (*B* = -.057, *SE* = .040, [LLCI -.166, ULCI -.004]) (Figure 20), and closer inspection revealed that the individual effect of boredom was the main reason behind the mediation, with an individually significant indirect effect of *B* =-.055, *SE* = .036, [LLCI -.155, ULCI -.006] (Figure 21). The effect of disappointment was not mediated, nor was the effect of hopeless (although the latter was close with ULCI = .001).

Group 3. In this last group of mediation analyses, our aim was to explore whether either achievement goals or achievement emotions had a mediating effect on the relationship between learning strategies and ideation. We ran several models with deep strategies (elaboration and critical thinking) as the independent variable ("X" in Model 4) and goals and emotions as potential mediators ("M" in Model 4). Rehearsal (a shallow strategy) was not included in the

mediation models because we determined earlier (in research question 1) that it was not significantly correlated with ideation.

Exploring the potential effects of both mastery approach and mastery avoidance on the relationship between deep strategies (jointly as an aggregate variable, and individually through elaboration and critical thinking) and ideation, we found only direct and total effects, no indirect effects (mediation). Similarly, there was no evidence of mediation between deep strategies (jointly) and ideation through any of the aggregate emotion variables, nor the individual emotions. Although a significant "b" path emerged in the model that included hope (B = .340, SE =.170, p = .048, [LLCI .003, ULCI .677]), the indirect effect was not significant.

Testing a model with critical thinking as the IV and all individual emotions as potential mediators, no indirect effects were observed. However, when the model was based on elaboration as the IV, hope emerged as the only significant mediator (indirect effect coefficient B =.098, SE = .062, [LLCI .001, ULCI .247]). The direct effect was also significant (B= .243, SE= .089. p= .007), suggesting that hope partially mediates the relationship between elaboration and ideation (Figure 22).

Table 7 summarizes the combinations of independent variables and mediators that yielded full or partial mediation within each group of analyses, providing a bird's eye view of the results for research question 2 (whether emotions and goals have a mediating effect on each other, or on study strategies, in relation to ideational behaviour).

Research Question Three

Whereas research question 2 examined the mechanisms by which achievement goals, achievement emotions, and learning strategies influence ideation, research question 3 explored when and for whom these mechanisms hold true. Through conditional effects analyses

(specifically moderated moderation) we explored how these relationships and patterns differed by gender and by year of study.

Gender and year of study differences in the data. We first explored how gender and year of study differences relate to our focal variables (ideation, achievement goals, achievement emotions, and learning strategies). ANOVAs were run to examine gender differences on the focal variables. Results revealed significant gender differences in anxiety ($F_{(1, 117)} = 6.27$, $p = .014$) and hopelessness ($F_{(1, 117)} = 4.07$, $p = .046$), whereby these negative emotions were significantly higher among female students. Hope approached significance ($F_{(1, 117)} = 3.37$, $p = .069$), and was lower among female students. Despite the lack of statistically significant differences in the other emotions, it is noteworthy that every individual negative emotion (shame, anger, anxiety, frustration, hopelessness, disappointment, and boredom) was higher on average among female students. Gender differences in each of the aggregate emotion variables of negative activating emotions ($F_{(1,117)} = 2.90$, $p = .091$), negative deactivating emotions ($F_{(1,117)} = 2.89$, $p = .092$), and total negative emotions ($F_{(1,117)} = 3.24$, $p = .075$) approached statistical significance (two-tailed). Additionally, every individual positive emotion (pride and enjoyment, in addition to hope as reported above) was lower among females although not significantly so. Correlations between gender and achievement emotions were previously reported in Table 5 under research question 1. There were no significant gender differences in achievement goals or learning strategies, nor in our focal outcome variable of ideation. Table 8 contains descriptive statistics by gender for each of the focal variables in the study.

ANOVAs by year of study revealed significant between-group differences in three of the achievement goals: mastery approach ($F_{(3, 166)} = 4.44$, $p = .005$); performance approach ($F_{(3, 166)} = 3.59$, $p = .015$); and performance avoidance ($F_{(3, 166)} = 4.22$, $p = .007$). Because performance

goals were not found to be significantly related to our main outcome variable of ideation, these two findings were not analyzed further. There were no significant differences by year of study in ideation, emotions, or study strategies.

Mastery approach goals, however, had been previously found to be significantly related to ideation, and we therefore performed post-hoc analyses[6] to probe where the differences lie between years of study. Mastery approach goals appear to peak in year 0 (Y0[7]) and then decrease through years 1 and 2 (Y1 and Y2), before leveling out in year 3 (Y3; Figure 23). Between Y0 and Y2 the mean difference (decrease) is significant (.663, p = .005), and between Y0 and Y3 the significant decrease is .637 (p = .012). There are also significant changes in mastery approach between Y1 and Y2 (mean decrease = .443, p = .013) and Y1 and Y3 (mean decrease = .417, p = .039).

In Figure 24, we split the figure into panels by gender, showing achievement goals across the years of study separately for males (coded as 0) and females (coded as 1). This visual representation shows that the direction of change in mastery approach from Y2 to Y3 differs between genders such that reported mastery approach goals decrease for males in the last year of study, but increase for females during the same time. Although these differences were not statistically significant, this trend (with interactions more clearly visible in Figure 25 showing mastery goals only, by gender and by year, in the same panel), suggests that our data may contain three-way interactions such that both gender and year of study have a significant impact on the relationship between a given antecedent variable and ideation.

[6] We used Fisher's (1935) Least Significant Differences method for post hoc analyses. These findings should be interpreted with caution since the LSD consists of individual t-tests which may increase the possibility of type 1 error.

[7] In the jurisdiction where the research was conducted, students enter university either through a pre-university college (if local) or from high school (if from outside the province). Y0 refers to the first year for high school entrants, and college entrants start in Y1.

We now move to our focal analyses for research question 3, testing for conditional effects in relationships identified among our variables of interest using Model 3 in PROCESS (Hayes 2018, p. 585; see Figure 26 for a conceptual diagram). In this exploratory series of moderated moderation analyses, gender was the moderator M, year of study was secondary moderator W, and ideation was the outcome variable Y (Figure 27). The independent variable X took on values from our focal constructs -- achievement goals, achievement emotions, and learning strategies -- which also served to provide the organizing structure for reporting results, below.

Achievement goals. Gender and year of study (henceforth referred to as "year") moderated the positive effect that mastery approach goals have on ideation. The overall model was significant $F_{(7, 158)} = 3.10$, $p = .004$; R-squared = .121. Specifically, for female students in years 0 to 2 (F0, F1, F2)[8] and males in years 1 and 2 (M1, M2), the effects were positive and significantly different from zero as follows: F0 ($B = .651$, $SE = .244$, $p = .008$); F1 ($B = .463$, $SE = .145$, $p = .002$); F2 ($B = .275$, $SE = .129$, $p = .034$); M1 ($B = .418$, $SE = .163$, $p = .012$); M2 ($B = .356$, $SE = .146$, $p = .016$) (Figure 28). No significant moderation was found for the mastery avoidance variable, suggesting that there were no significant gender or year differences in how mastery avoidance influences ideation.

Positive achievement emotions. Beginning with the aggregate variable of positive activating emotions, the overall model was significant with $F_{(7, 111)} = 2.68$, $p = .014$; R-squared = .144. We found that the influence of these emotions on ideation was highest in year zero for female students (F0): $B = .654$, $SE = .248$, $p = .010$), and lessened over time. For F1, the effect was significant ($B = .481$, $SE = .191$, $p = .003$), and for F2 it approached significance at $B = .310$,

[8] For the remainder of this section reporting results from research question 3, the shorthand for female students in years 0 – 4 will be F0 – F4, and similarly, for male students, M0-M4.

SE = .170, *p* = .073). There were no significant conditional effects of positive activating emotions on ideation for male students in any year (Figure 29).

For individual positive emotions, the omnibus model for hope was significant ($F_{(7, 111)}$ = 2.72, *p* = .012; R-squared = .146). The conditional effect of hope on ideation was significant for F0 (*B* = .535, *SE* = .248, *p* = .033), F1 (*B* = .468, *SE* = .161, *p* = .005), and F2 (*B* = .401, *SE* = .153, *p* = .010). There were no significant conditional effects of hope on ideation for male students in any year (Figure 30).

The omnibus test for conditional effects of gender and year on the effect of enjoyment on ideation was also significant $F_{(7, 111)}$ = 2.27 *p* = .034; R-squared = .125. Again, there were significant effects for female students, higher in the earlier years, but no significant effects for male students: F0 (*B* = .512, *SE* = .198, *p* = .011) and F1 (*B* = .257, *SE* = .129, *p* = .048; Figure 31). The final positive emotion in the group, pride, was also significant overall ($F_{(7, 111)}$ = 2.39, *p* = .026; R-squared = .131), and like the previous positive emotions reported, the effect was highest for F0 (*B* = .560, *SE* = .224, *p* = .014), decreased for F1 (*B* = .423, *SE* = .145, *p* = .004), and decreased again for F2 (*B* = .286, *SE* = .136, *p* = .017; Figure 32). No other significant conditional effects were found for the individual positive achievement emotions.

Negative achievement emotions. To orient the results in this group of analyses, we again began with the aggregate variable, negative activating emotions. The overall model testing for conditional effects of gender and year on the effect of negative activating emotions on ideation was significant; $F_{(7, 111)}$ = 2.44, *p* = .023; R-squared = .133. In this model, the three-way interaction term bordered on significance $F_{(1, 111)}$ = 3.32, *p* = .07, and the R-squared change as a result of the three-way interaction between negative activating emotions, gender, and year was .026.

In contrast to the positive emotions reported above, the relationship between negative activating emotions and ideation was inverse; that is, higher negative achievement emotions were associated with lower ideational behaviour. Also contrasting with patterns revealed among the positive achievement emotions, the significant effects of the aggregate negative emotion variable appeared in the later years (F2: B = -.542, SE = .187, p = .005) and were strongest in the last year of study (F3: B = -.840, SE = .299, p = .006) for female students. No significant conditional effects were observed with male students in any year (Figure 33).

Looking next at the negative activating emotions individually, the omnibus model for shame just reached significance $F_{(7, 111)} = 2.09$, p = .051, R-squared = .116. The three-way interaction effect approached significance $F_{(1, 111)} = 3.12$, p = .077, and R-squared increase due to the interaction was .025. Results for female students in higher years indicated significant conditional negative effects of shame on ideation: for F2, B = -.371, SE = .164, p = .026 and for F3, a strong negative effect of B = -.686, SE = .270, p = .012 (Figure 34).

A similar pattern was revealed among conditional effects in the relationship between anxiety and ideation. The model was significant ($F_{(7, 111)} = .2.47$, p = .022, R-squared .137), and significant negative effects of anxiety on ideation were found in the last two years for female students: F2 (B = -.302, SE = .136, p = .028) and F3 (B = -.562, SE = .215, p = .010; Figure 35). Frustration also showed significant negative effects on ideation for female students. The overall model was significant ($F_{(7,111)} = 2.14$, p = .05, R-squared = .119). The conditional effect of frustration on ideation was significant for F1 (B = -.247, SE = .116, p = .035) and F2 (B = -.348, SE = .143, p = .017), and approached significance for F3 (B = -.450, SE = .236, p = .06; Figure 36).

It bears pointing out that for each of these significant conditional effects of negative activating emotions on ideation, the negative effects get stronger towards higher years, while the positive effects of positive emotions on ideation are strongest in the early years and decrease in intensity for each year.

No conditional effects of anger on ideational behaviour as a function of gender and year were found, and none of the models testing conditional effects of the negative deactivating emotions (hopeless, disappointed, bored) on ideation as a function of gender and year revealed significant effects.

Learning strategies. The last group of analyses for research question 3 examined conditional patterns by gender or year on the effect of learning strategies on ideation. No effects were found for rehearsal, but the model for elaboration was significant ($F_{(7,111)} = 2.87$, $p = .009$, R-squared = .153). The relationship with ideation was positive, significant for female students in years 0 to three, and decreasing in strength from year to year as follows: F0 ($B = .391$, $SE = .169$, $p = .022$), F1 ($B = .337$, $SE = .106$, $p = .002$), and F2 ($B = .282$, $SE = .113$, $p = .014$; Figure 37).

Finally, we tested the conditional effects of critical thinking on ideation as a function of gender and year, and found a highly significant model with $F_{(7, 111)} = 6.64$, $p = .000$, R-squared = .30. Both genders and all years revealed significant (F0, F1, F2, M0, M1, and M2) or approaching significant (F3, M3) results as follows: F0 ($B = .382$, $SE = .115$, $p = .001$), F1 ($B = .332$, $SE = .074$, $p = .000$), F2 ($B = .282$, $SE = .079$, $p = .001$), F3 ($B = .232$, $SE = .124$, $p = .065$), M0 ($B = .595$, $SE = .224$, $p = .009$), M1 ($B = .520$, $SE = .136$, $p = .000$), M2 ($B = .446$, $SE = .133$, $p = .001$), and M3 ($B = .371$, $SE = .219$, $p = .093$; Figure 38).

Research Question Four

To better understand STEM students' own perceptions of factors affecting their creative thinking within their program of study, responses to open-ended questions were analyzed in the mixed methods section of the present study. Results from 166 respondents included a total of 247 creativity-related utterances (from among a total of 5,706 words), of which 104 (42%) were related to factors that were perceived to support creativity and 143 (58%) were related to factors that were perceived to suppress creativity (Table 9). There were six categories of "creativity support" responses or codes (faculty, inquiry, flexibility, discourse, external, and interest) and five categories of "creativity suppress" responses (personal, rigidity, workload, class size, and evaluation).

The category with the highest frequency of responses overall was rigidity, with 62 responses, or 25% of the overall total. This category relates to the perceived rigidity of a program or course that is taught in a linear, "one-correct-known-answer" format that relies on extensive memorization of previously known facts (e.g., *"All the science courses I've taken encourage simply memorizing and regurgitating which suppresses creativity"*). The second highest overall category of responses was evaluation, with 39 responses (or 16% of the total). This category relates to the negative perceived effect of competition, fear of failure, and grade focus (particularly through multiple-choice exams) on creativity: *"I am studying very hard just to get good grades, not to improve my thinking"; "multiple choice exams do not allow creativity"; "the need to strategize in order to obtain a good grade kills creativity (example of strategizing: needing to learn X by heart because it will be on the exam and there's no time to play with X and discover it at a leisurely pace)".* The third largest perceived negative ("suppress") effect was the impact of a heavy workload and pressing deadlines (21 responses, 8.5% of total; e.g., *"Difficulty of subject matter and time constraints hinder creativity"; "a*

heavy course load with other classes I need to spend more time on suppress my creativity because I am so busy"). These three categories accounted for 85% of the "suppress" responses, and almost 50% of the total codes assigned to responses in this question. The other categories on the negative "suppress" side related to personal reasons (such as mental health, anxiety, or fatigue; 15 responses or 6% of the total; e.g., *"I struggle to be average here and I feel under-qualified"; "Fatigue and stress: suppress"*) and class size (specifically mentioned by six people or 2% of the total; e.g., *"the larger classes in first and second year courses impede creative work"*).

On the positive side, the category most often mentioned as being supportive of creativity with the highest frequency of responses was inquiry, with 32 responses (13% of the total, or 31% of all the positive responses). This category included responses where students mentioned opportunities to devise and test their own hypotheses and/or conduct their own research, problem solving and curiosity, project-based work, and generally having options in the choice and format of assessments (e.g., " *[. . .] made me think of ways to achieve certain results on my own and have given me the tools I needed in order to do so*"; "*options/flexibility for assignments"; "Lab work, research and the ability to think outside the box and have the space to think and experiment independent[ly] strongly supports my creativity in my program"*. The second most common positive response was under the category of flexibility, with 21 responses or 8.5% of the total. This category relates to the flexibility afforded by multiple perspectives whether through flexibility of the system (e.g., to take interdisciplinary or elective courses), open-mindedness of those around you (faculty, administrators, or peers), or connections made to other topics and areas of study (e.g., *"Being able to relate math to other courses is supportive for creativity"; "my multicultural background makes me be able to look at problems from different*

angles"; "[My interdisciplinary program] helped to support my creativity by providing me with exposure to different disciplines and allowing me to consider a problem through various lenses.")

There is some conceptual overlap between the above two categories of inquiry and flexibility. The distinguishing aspect in our coding was whether the utterance related to an aspect *internal* to the student (their own work, thinking, or personal choices within the course) which was coded as inquiry, or *external* to the student (exposure to other fields, connections to related but distinct ideas for example through the professor's lecture, or open-minded perspectives afforded by other readings) which was coded as flexibility.

The next most common response on the "support" side was related to inspiring faculty or teaching assistants (17 responses, 7% of the total; e.g.*; "Professors are researchers so they inspire and constantly remind us of looking for ideas and getting involved"; "Availability of professors and TAs -Professors talking about their field/lab work"; "the enthusiasm / encouragement of the professor"*). These top three positive categories accounted for 67% of the positive responses, or 28.5% of the overall total. Close behind faculty in frequency was discourse, with 16 responses, or 6.5% of the overall total. This category relates to social interaction such as discussions (in class or elsewhere), group work, and opportunities to share ideas with peers (e.g.,*"[. . .] open up discussions in class and introduce subject matter that isn't in the textbook to make us think"; "Being a part of a lab helps me grow my creativity"; "Tutorials, problem sessions and moments of casual interaction [. . .] support creativity"; "Being around people that are as motivated as you to learn and come up with ideas motivates me and supports my creativity"*). Finally, the importance of interest or enjoyment as supportive of creativity was mentioned by 12 respondents (5% of the total codes; e.g., *"Interest in the*

material, motivation: support"; "Support: [. . .] taking classes I enjoy"), and external supportive factors such as extracurricular activities, family, or nature were mentioned by six respondents (2.5% of the total; e.g., *"the nature around me"; "friends and family"*).

Correlation analyses. Using dummy codes for these 11 categorical variables (0 = category not mentioned; 1 = category mentioned by the respondent) we ran two-tailed bivariate Pearson's correlation analyses to explore connections between the themes mentioned in spontaneous responses and the other constructs measured in the present study (ideation, achievement goals, achievement emotions, and study strategies), as well as gender and year of study. Because of the large number of variables, the correlation tables are divided by construct. The first one displays ideational behaviour, gender, and year in relation to the 11 categories (Table 10).

Ideation, gender, and year of study. Ideation was found to be significantly and positively correlated with inquiry (r = .165, p =.034) and flexibility (r = .186, p =.017). These results indicate that students who responded that learning through inquiry in flexible settings is supportive of their creativity also scored significantly higher on the ideation measure. Two other category variables approached significance: external with r =.130, p =.095, and personal with r = -.140, p = .073. Note that the personal category is negatively correlated with ideation, suggesting that students who identified personal reasons (such as mental health challenges and stress) as suppressors of creativity tended to score lower on the ideation scale.

There were no significant correlations between gender and the categories, but year showed significant correlations with three of the creativity-suppressing categories: rigidity (r = .187, p =.016), suggesting that students in higher years were more likely to identify program rigidity as a hindrance to creativity; class size (r = -.163, p =.036), with the negative correlation

coefficient signifying that those in lower years were more likely to identify large classes as a suppressor of creativity; and evaluation (r = .183, p =.018), implying that the theme of grade focus, multiple-choice assessments, and/or competitiveness of the program was more likely to be identified by students in higher years as a hindrance to creativity.

Achievement goals. The next set of correlation analyses was between the response categories and achievement goal orientations (mastery approach, mastery avoidance, performance approach, and performance avoidance; Table 11). Neither of the mastery goals was significantly correlated at α=.05 with the response categories, nor was performance approach. However, performance *avoidance* showed a significant correlation with the workload category (r = .177, p = .022) suggesting that students with performance avoidance goals found that their STEM workload was a hindrance to their creativity within the program. Performance avoidance was also correlated with the flexibility category but negatively (r = -.157, p = .043), indicating that students with performance avoidance goals were significantly less likely to identify themes around flexibility and open-minded perspectives as being supportive of their creativity. By contrast, students with mastery approach goals tended to be more likely to identify flexibility themes as being supportive of creativity, with r = .147 approaching significance at p = .058.

Achievement emotions. Next, we analyzed correlations between the response categories and affect. The first analysis was between the categories and the aggregate variables of positive activating emotions, negative activating emotions, and negative deactivating emotions (Table 12). Two categories were significantly correlated with aggregate emotions, namely workload (suppress) and flexibility (support). Specifically, workload was significantly correlated with both negative activating emotions (r = .332, p =.000) and negative deactivating emotions (r = .226, p = .015). On the support side, flexibility was positively correlated with positive activating

emotions (r = .276, p = .003) and negatively correlated with both negative activating (r = -.215, p = .021) and negative deactivating (r = -.244, p = .008) emotions. Examining the emotions individually (Table 13), we found several correlations between individual emotions and supportive as well as suppressive categories, in addition to four correlations trending towards significance. The suppressive personal category (mental health, stress) approached significance with shame (r = .163, p = .080) and surprisingly showed a positive correlation with enjoyment (r = .198; p =.033). The rigidity category, less surprisingly, approached a significant inverse relationship with enjoyment (r = -.164, p = .079). The workload category approached significance with anger (r = .173, p = .063) and revealed strong correlations with shame (r = .376, p = .000), anxiety (r = .356, p = .000), frustration (r = .202, p = .030), hopelessness (r = .272, p = .003), and disappointment (r = .276, p = .003). On the supportive side, the flexibility category was correlated with every emotion measured, except anxiety. While boredom was marginally significant (r = -.174, p = .062), all others revealed significant correlations with flexibility as follows: hope (r = .213, p = .021), pride (r = .236, p = .011), enjoyment (r = .276, p = .003), shame (r = .-196, p = .035), anger (r = -.183, p = .049), frustration (r = -.218, p = .019), hopelessness (r = -.243, p = .009), and disappointment (r = -.211, p = .023). The correlations with positive emotions and the category of flexibility are all positive, indicating that students who reported more positive achievement emotions were more likely to identify some form of flexibility (whether multiple perspectives, open mindedness, an interdisciplinary approach, or the flexibility to take elective courses outside one's major) as supportive of their creativity in relation to their learning. Conversely, each of the significant negative emotions was negatively correlated with the flexibility category, suggesting that students who reported higher levels of

negative achievement emotions were less likely to identify flexibility as a theme that supports their creativity in the program.

Learning strategies. Finally, we ran correlation analyses with the response categories and learning strategies (Table 14). Rehearsal was negatively correlated with the evaluation category (r = -.204, p = .028) which suggests that students with shallow study strategies were less likely to flag multiple choice exams (a common utterance in the evaluation category) as a detriment to their creativity in the program. Deep strategies, on the other hand, were shown to be significantly and positively related to inquiry (r = .224, p = .016). More fine-grained analysis revealed that critical thinking was responsible for this relationship: Critical thinking measured individually was positively correlated with inquiry (r = .207, p = .026) while the other component of deep strategies, elaboration, showed no significant correlation on its own.

ANCOVA. Given our earlier findings that both gender and year were related to ideational behaviour, we ran an ANCOVA to determine the effect on ideation from responses to the various categories after controlling for year and gender differences (Tabachnik & Fidell, 2013). We recall that ideation was found to be significantly correlated with the creativity-supporting categories of inquiry (r = .165, p =.034) and flexibility (r = .186, p =.017), and approached significance with external (r = .130, p =.095); while the suppressive personal category also approached significance (r = -.140, p = .073). The results of the ANCOVA indicated that when controlling for gender and year of study, the inquiry ($F_{(1, 152)}$ = 4.37, p = .038, partial η2 =.028) and flexibility ($F_{(1, 152)}$ = 5.07, p = .036, partial η2 =.028) categories were still statistically significantly related to ideational behaviour. The external category approached significance at $F_{(1, 152)}$ = 3.77, p = .054, partial η2 =.024, but the personal category was no longer significant when controlling for gender and year.

Discussion

The vital importance of affect and motivation to learner success and wellbeing has become a core topic in educational research, and recent decades have seen the maturing of these lines of inquiry. Many influential theories have been developed, revised, and extended to account for the various ways achievement emotions and achievement goals are believed to influence learning trajectories and outcomes in various educational settings (e.g., Ames and Archer, 1988; Boekaerts, 2007; Efklides, 2014; Elliot et al., 1999; Linnenbrink & Pintrich, 2002; Pekrun, 1992; Pekrun et al., 2009). At the same time, the field of creativity research has broadened, ebbing and flowing through various themes via research keywords that have included not only innovation and divergent thinking, but also education, idea generation, and positive affect (Williams, Runco, & Berlow, 2016). However, research at the juncture of learning (conceptualized as building expertise) and creative thinking (i.e., using learned expertise adaptively) has been scarce.

The aim of the present study was to contribute to filling this gap in relation to STEM students, and to do so we devised a research plan that began with an exploration of correlations between common educational psychology constructs and creativity measures (research question one: Are achievement emotions, achievement goals, or learning strategies related to ideational behaviour?). Findings from this initial exploration then informed the models used to test the mechanisms underlying how these constructs interact to influence ideation (research question two: Do emotions and goals have a mediating effect on each other, or on learning strategies, in relation to ideational behaviour?). Next, we wanted to probe when and for whom relationships between the educational psychology constructs and ideation were particularly salient (research question three: Do these relationships and patterns vary by gender or year of study?). Finally, we

were interested in the lived experiences of STEM students with respect to perceived barriers and facilitators to creative thinking within their programs, and invited students to respond to an open-ended question (research question four: what do STEM students perceive to be the biggest factors supporting or suppressing creative thinking in their field of study?). Main findings will be discussed in the order of the research questions.

Research Question One: The Correlations

Findings from the correlation analysis of the data from our STEM sample were generally consistent with the links and directions found in the existing broader literature on creativity. To the extent that mastery goals are viewed as manifestations of intrinsic motivation, prior research (e.g., Amabile, 1983; Ryan & Deci, 2000; Sternberg & Lubart, 1999) fully supports our findings that mastery goals (both mastery approach and mastery avoidance) were significantly and positively correlated with ideational behaviour.

There did not appear to be a linear relationship between performance goals (performance approach or performance avoidance) and ideation. This finding may be a reflection of the extrinsic nature of the motivation behind performance goals; i.e., the desire to do well (performance approach) or avoid doing poorly (performance avoidance) in comparison to others (Elliot & Harackiewicz, 1996; Harackiewicz et al., 2002). This finding (of no correlation) is largely consistent with prior research that demonstrates that extrinsic motivation is not supportive of ideation, in contrast to intrinsic motivation which supports ideation (Csikszentmihalyi, 2000; Ryan, 1993). In our STEM sample, this finding may also validate the idea that extrinsically motivated learners do not engage as deeply with the material (Elliot & Harackiewicz, 1996; Pintrich & Schunk, 1996), and thus may not build their expertise to a level where they could transcend routine (algorithmic) knowledge and become flexible and fluid (in

the manner of adaptive experts) through their deeper understanding of the material (Bransford et al., 2000; Hatano & Inagaki, 1986; Schwartz, Bransford, & Sears, 2005).

For the emotion data all correlations were consistent with prior research in their relation to ideation. All positive emotions measured (hope, pride, and enjoyment) were positively correlated with ideational behaviour. Amabile et al. (2005) found strong links between positive emotions and creativity during all the phases of a creative act (before, during, and after), and Csikszentmihalyi (2000) also believed that enjoyment supports the experience of creative flow. Although enjoyment and pride were also significantly correlated with ideation, the strongest link among the positive emotions and ideation was hope. One explanation for this finding is that ideation, and creativity in general, are forward-looking in nature, and Runco (2014) has characterized the RIBS measure used in our study (Runco et al., 2001) as a measure of creative *potential* rather than current creative achievement. Similarly, hope has been classified as a forward-looking emotion, with an anticipatory "prospective outcome" object focus (Pekrun, Elliot, & Maier, 2006).

Among the negative emotions, five (anger, anxiety, frustration, hopelessness, and disappointment) of the seven individual emotions measured revealed significant negative correlations with ideation. Compared to the findings on performance goals discussed above, this is an interesting finding: While performance goals had *no effect* on ideation, negative emotions in STEM students seemed to actively *suppress* creative thinking. These results are also consistent with prior research suggesting that divergent thinking (which the ideation scale purports to measure; Runco et al., 2001) requires positive emotions (Ashby & Isen, 1999; Fredrickson & Branigan, 2005; Friedman et al., 2003; Isen et al., 1987; Kaufman & Vosburg, 2002; Mitchell & Phillips, 2007; Runco 2014). Indeed, negative moods have consistently been found to suppress

broad, flexible, and heuristic (i.e., divergent) thinking (Dreisbach & Goschke, 2004; Isen & Daubman, 1984; Isen & Means, 1983; Isen et al., 1982).

Two individual negative emotions, shame (activating) and boredom (deactivating), had no correlation with ideation. The lack of connection between boredom and ideation in STEM students can be understood through the lack of intrinsic motivation among bored students (see above for discussion of the link between intrinsic motivation and creativity). For shame, however, the mechanism is more difficult to understand and will require further research. One might expect, for example, that shame in achievement settings could lead to fear of failure which in turn would direct students to avoid the risk-taking inherent in ideational behaviour. However, surprisingly, no such connection was found and this area would benefit from further investigation.

Finally, also in line with prior research, deep learning strategies (elaboration and critical thinking) were significantly and positively correlated with ideation, but rehearsal (a shallow strategy) was not found to be related to ideational behaviour. The strong relationship between creative and critical thinking is well supported by in the literature (e.g., Baker, Rudd, & Pomeroy, 2001; Basadur, 1995; Nijstad, De Dreu, Rietzschel, & Baas, 2010), and deep learning strategies can allow learners to activate and use prior knowledge creatively when solving problems (Pintrich et al., 1991). Similarly, Mumford et al. (1996) showed that the process through which learned material is encoded has a direct impact on how accessible (for fluid, flexible creativity) the material is when retrieved later.

Importantly for the present study, the significance and directions of the correlations revealed in research question one suggest that the broader trends and findings in the creativity literature seem to be relevant to this specific population (STEM undergraduate students), thus

extending the creativity literature while at the same time providing a theoretical foundation for our subsequent investigations through the other three research questions.

Research Question Two: The "How" Question

Multiple exploratory mediation models were analyzed to explore how our focal constructs (affect, goals, and strategies) interacted in relation to ideational behaviour. While some researchers historically have suggested that achievement goals precede and predict academic emotions (e.g., Pekrun et al., 2006), others have argued that the directionality of the constructs is open to context-dependent interpretation, and that emotions that arise during learning have the potential to recursively influence pre-existing achievement goals (e.g., Linnenbrink & Pintrich, 2002). As we saw earlier, Amabile et al. (2005) noted that while positive emotions are present for the entire arc of a creative act (starting before and continuing during and after the activity), the context within which the creativity takes place (e.g., a particular classroom setting, etc.) has the potential to impact (i.e., mediate) the relationship between emotions and creativity.

Our exploration suggested that both directions may have merit. Positive activating emotions were found to fully mediate the relationship between mastery goals and ideas, while negative emotions neither contributed to nor detracted significantly from that relationship. Analysis of the discrete emotions within the aggregate variable of positive activating emotions revealed that it was specifically hope that accounted for this effect: Neither pride nor enjoyment had any bearing on the relationship. According to Pekrun et al. (2006), hope is an emotion that is linked to prospective future outcomes, and therefore logically tied to goals which are by definition focused on the future (Elliot & Fryer, 2008). In contrast, pride and enjoyment are classified as retrospective and current emotions respectively; that is, relating to activities that

have already happened or are currently ongoing. Further highlighting the close connections between hope and goals, Snyder (2002) defined hope as "the perceived capability to derive pathways to desired goals, and motivate oneself via agency thinking to use those pathways" (p. 249).

Hope was also found to be a partial mediator for the relationship between mastery avoidance and ideation. However, findings relating to the mastery avoidance variable will not be discussed at length. Mastery avoidance was included in the larger study from which the present data were culled, but our discussion is based on the trichotomous achievement goal framework as proposed by Elliot et al. (1999), which includes mastery approach, performance approach, and performance avoidance goals, but not mastery avoidance. Although some researchers have found mastery avoidance to be a valid construct that is distinct and separable from mastery approach (e.g., Baranik, Stanley, Bynum, & Lance, 2010), others have suggested that the paucity of empirical studies measuring mastery avoidance goals, combined with mixed results from them, limit the generalizability of conclusions drawn based on this construct and call for extreme caution in interpreting research using this variable (Hullemann, Schrager, Bodmann, & Harackiewicz, 2010).

In a second group of analyses we reversed the conceptual direction between achievement goals and achievement emotions (by testing models where goals mediated the effect of emotions on ideation) and found that mastery approach goals fully mediated the effects of all three negative deactivating emotions (hopelessness, disappointment, and boredom) and two of the negative activating emotions (frustration and shame, but not anger or anxiety) on ideation. In pondering the interpretations and practical meaning of these significant indirect effects, it is helpful to remember how the models were constructed. Negative emotions have a negative

effect on mastery approach goals, which in turn have a positive effect on ideation. Their joint (indirect) effect on ideation comes from the product of these two effects, and for all five negative emotions listed above, the indirect effect is such that any direct effect becomes insignificant (full mediation). Perhaps learners who adopt mastery approach goals are less prone to the direct negative effects that those negative emotions would exert on ideation whereby mastery goals could be viewed as having a protective effect. We were not able to find prior research on this, and it would be an interesting avenue for future research.

Positive emotions were found to have only direct effects on ideation in this model; i.e., mastery goals did not mediate the relationship between positive emotions and ideation. However, we recall that the opposite was true – hope fully mediated the relationship between mastery approach and ideation. Additionally, we found that deep learning strategies (specifically, elaboration), had a direct relationship with ideation, and also an indirect one (partial mediation) through hope.

To summarize, results for question 2 showed that the influence of hope was present in multiple paths leading to higher creativity--not only directly, but also indirectly as the mediator of several other relationships (mastery approach, mastery avoidance, and elaboration, with respect to ideation). The literature is replete with references to the substantial and unique contribution hope makes to academic achievement in various fields of study, over and above other known predictors such as intelligence, previous achievement, or personality (Curry, Snyder, Cook, Ruby, & Rehm, 1997; Day, Hanson, Maltby, Proctor, & Wood, 2010; Feldman & Kubota, 2015; Rand, Martin, & Shea, 2011; Snyder, 2002; Teahan, 1958). However, very few researchers have studied the importance of hope for creative thinking, and some of that work has come under the umbrella of the larger construct of positive psychology (e.g., Seligman &

Csikzentmihalyi, 2000). Additionally, hope has been studied in organizational settings where it has been linked with overall positive affect and creativity among employees (Rego, Souza, Marques, & Cunha, 2012a, 2012b, 2014). The lack of previous research on the importance of hope as it pertains to creativity or adaptive expertise among STEM students suggests another appealing avenue for future research.

Research Question Three: The "When" and "For Whom" Question

Female STEM students scored lower on all three positive emotions, and higher on all seven negative emotions than male students. While not all of these differences were statistically significant, anxiety and hopelessness were significantly higher among female students, and the difference in hope (lower among females) approached significance. There is a widely held cultural belief that women tend to experience and self-report emotions with more intensity (Brody & Hall, 2008; Simon & Nath, 2004), but in our sample this only held true for negative emotions. A better-fitting theoretical explanation might be Kemper's (1978) power-status theory of emotions, also referred to as the "structural approach" (Kemper, 1990; Simon & Nath, 2004), whereby individuals with more perceived power and status experience more positive emotions, and those with less power and status experience more negative emotions. Stereotypes abound in STEM fields (Carli, Alawa, Lee, Zhao, & Kim, 2016; Keller, 2010; Reuben, Sapienza, & Zingales, 2014), and the combined impact of stereotype threat and gender bias (Beasley & Fischer, 2012; Moss-Racusin, Dovidio, Brescoll, Graham, & Handelsman, 2012; Von Hippel, Issa, Ma, & Stokes, 2010) in STEM undergraduate programs can shape perceptions of unequal power and status. This may be a contributing factor to the gender differences in achievement emotions found in our sample. We found no significant gender differences in the other three focal constructs (achievement goals, learning strategies, or ideational behaviour).

Regarding year of study, the only construct that showed significant changes based on year alone was mastery approach, which tended to decrease across the years, peaking at the beginning of STEM undergraduate students' studies. However, the main focus of the present study is not on gender or year of study differences per se, but rather on conditional effects. The moderated moderation model (taking into account both gender and year of study) indicated that mastery approach was significantly related to ideation for females in the first three years of study, and for males only in the second year, when mastery approach was also at its highest level for male students.

In the present study, we found significant conditional effects of emotions on ideation, conditioned on both gender and year of study. While none of the emotions reported by male students appeared to significantly influence their level of ideation (during any year of study), hope, enjoyment, and pride, as well as shame, anxiety, and frustration had differentially significant influences on ideation among female STEM students. The directions of the influence of positive versus negative emotions on ideation in female students were as expected; i.e., hope, enjoyment, and pride were positively correlated with ideation (Fredrickson, 2001; Hirt, Devers, & McRea 2008; Isen et al., 1987; Runco, 2014) and shame, anxiety, and frustration were negatively correlated with ideation (Dreisbach & Goschke, 2004; Isen & Daubman, 1984).

However, what was not expected (perhaps because no studies have explored this aspect, to the best of our knowledge), was that positive emotions exerted their positive influence on ideation among female students in the *early* years of study, and negative emotions had a significant negative influence in the *later* years. Additionally, the strength (slope) of each of the significant positive effects was highest during the first year of study and decreased for each year after that. In a type of mirror image, the strength of each of the significant negative effects of

negative emotions on ideation for female students *increased* for each subsequent year. The strongest negative influence of an emotion on ideation was shame, followed by anxiety, in the final year of study among female STEM undergraduate students. Looking at the aggregate variable of negative activating emotions (which we recall includes not only shame and anxiety but also anger and frustration), their joint negative effect on ideational behaviour in the last year among female undergraduate STEM students was stronger still. Combined with the findings that all the positive emotions had the strongest impact on ideation in the very first year of study, these results impel us to conduct more research into why this pattern exists among female STEM students, and what the implications may be for female graduates and early-career scientists.

For interpreting these findings, it is important to keep in mind that it was not the reported *levels* of emotions, as such, that are increasing or decreasing significantly over the years of study; in fact we found that they were relatively stable, especially for female students. (Male students seemed to have a spike in negative emotions during the first year, but because the sample in this group was quite small, we are wary of drawing any conclusions on this alone.) Instead, what these conditional effects tell us is that the *intensity* of the link between the emotions and ideational behaviour varies by gender and by year.

The final construct for which we explored conditional effects by gender and year was learning strategies, and we found that the pattern for elaboration (a deep strategy) was similar to that of positive emotions; i.e., elaboration had a significant positive relationship with ideation in the early years of study for female (but not male) students, decreased in strength for each of the first three years of study, and showed no relationship in the last year. We recall from the previous section that the influence of elaboration on ideation was mediated by hope; therefore combining that information with the current finding suggests that the effect of the interplay

between deep learning strategies and hope may be particularly relevant for female students in the early years of STEM studies.

The conditional effects so far have been significant almost exclusively for female students (the lone exception was mastery approach goals for males in the second year), and it may be a reasonable assumption that this could be related to the comparatively smaller participation rate of males in the present study. However, the last individual variable tested, critical thinking, revealed conditional effects on ideation for *all* students (male and female) in *all* years. This was a marked departure from the other conditional patterns seen thus far and can perhaps best be interpreted as an extension of the literature that connects critical thinking and creative thinking. There are mixed points of view within this line of inquiry: Some researchers separate creative and critical thinking into independent dimensions (e.g., Ennis, 1993; Halpern, 2014; Kaufman, Plucker, & Baer, 2008; Runco & Garrett, 2012; Wechsler et al., 2018), while others have found the constructs to be to be related and mutually supportive (e.g., Chang, Li, Chen, & Chiu, 2014; Nijstad et al., 2010; Paul, 1990; Raths, Wasserman, Jonas, & Rothstein, 1966). Glassner and Schwarz (2007) assessed their interplay empirically, and Basadur (1994, 1995) submitted that innovation requires the integration of both critical and creative thinking. More recently, researchers have proposed a dual process theory of creative and critical thinking (e.g., Sowden, Pringle, & Gabora, 2015), leaning on Guilford's (1956) early Structure of Intellect delineation of divergent and convergent thinking. Based on the inconsistent results in the literature and the global imperative of creative and critical thinking, this area merits more research to help clarify the way forward, as reflected by the recent launch of the research project "Fostering and assessing students' creative and critical thinking skills in higher education" by the

Centre for Educational Research and Innovation at the Organisation for Economic Co-operation and Development (OECD, 2018).

Research Question Four: The Lived Experiences Question

In this open-ended exploration of students' own views on what helps and hinders their creativity within their program of study, it seemed easier for students to identify barriers: Well over half of the comments were about aspects that were perceived to suppress creativity. Nonetheless, many supportive factors were identified as well, and the overall picture that emerged was one of thoughtful learners who were well aware of conditions that would help them increase creativity within their programs. The most frequently identified barrier, constituting a quarter of all the responses (positive as well as negative), was a category that included instructional or program rigidity, memorizing, and a general climate of a single correct method or answer being presented, followed by the evaluation category where students identified multiple choice testing and constant comparative evaluation pressures as hindrances. These two negative categories (rigidity and evaluation) together accounted for almost three quarters of all the items that learners identified as hurting their creativity. On the positive side, the categories found most helpful for creative thinking were inquiry and flexibility, which together accounted for over half the responses regarding factors supportive of creative thinking.

Two main themes thus emerged on the negative (rigidity and evaluation) and positive (flexibility and inquiry) sides. Juxtaposing the themes (rigidity versus flexibility; evaluation of rote learning versus inquiry learning) paints a picture that bears more than a passing resemblance to the paradigm shift that has been underway in education for several decades (e.g., American Psychological Association, 1997). If the goal of traditional pedagogy was to transmit conventional knowledge linearly from expert to novice and assess recall, newer more flexible

models of education aim to support "discovery, being inquisitive, being a problem finder and a problem solver, being a thinker, and [. . .] producing knowledge that is meaningful to yourself and others" through inquiry (Aulls & Shore, 2008, p. 23).

Participant responses generated spontaneously (i.e., without guiding prompts or restrictions) seem to point to inquiry learning also being creative learning, because students who identified inquiry and flexibility as supportive of their creativity also scored significantly higher on the ideation measure. In the achievement goal domain, we learned that respondents who were concerned with not performing as well as their classmates (i.e., those with performance avoidance goals) were significantly more likely to identify a heavy workload as a hindrance to creativity, and significantly less likely to spontaneously mention flexibility as supportive. In contrast, those with mastery approach goals (which we have seen are strongly linked with creativity) tended to mention flexibility as a creativity support. This category included responses that related to open-mindedness (of self, peers, or faculty) and general openness. Although the influence of openness as a personality trait on creativity was not tested in the present study, responses from participants suggest that it is a trait which they value as being supportive of creativity. Research by Prabhu, Stutton, and Sauser (2008) showed that openness and multiple perspectives (flexibility) are closely related and help to intrinsically sustain engagement and task interest. This category, overall, is in line with other previous research suggesting that environments that provide a sense of control and autonomy (in this case, through flexibility to make decisions related to one's learning) are positively related to flow (Csikszentmihalyi, 1990; Kowal & Fortier, 1999), intrinsic motivation (which in turn is known to support creativity; e.g., Amabile, 1983; Ryan & Deci, 2000) and cognitive flexibility (Deci & Ryan, 1987).

Our findings relating to flexibility are also fully in line with the Control-Value Theory of achievement emotions, because choice and flexibility in tasks are theorized to enhance perceived control and thereby influence the emotions experienced (e.g., Pekrun & Stephens, 2010). In fact, the flexibility category was significantly related to nine of the ten reported emotions (all except anxiety). All the directions were as expected, i.e., flexibility was positively related to positive emotions, and negatively related to negative emotions. Earlier, we saw that the flexibility category was also linked to higher ideational behaviour, and these findings therefore provide further support for the connections in the literature between the valence of emotions and divergent thinking; i.e., positive emotions support, negative emotions suppress (e.g., Dreisbach & Goschke, 2004; Fredrickson, 2001; Hirt et al., 2008; Isen et al., 1987; Runco, 2014). These results suggest a possible future direction of extending current theories through investigating the role of flexibility in greater detail. Flexible learning environments could be the mediator through which positive emotions translate to more creative thinking.

An unexpected finding was that there were no correlations between any of the achievement emotions and the inquiry category. However, in reflecting on our coding decision criteria between the two categories of inquiry and flexibility (which are similar in that they both relate to non-prescriptive ways of learning), we recall that the differentiating principle between the two was that inquiry relates to learners' *own* thinking and choices about coursework (e.g., "… come up with a good answer *in the way you want*"; "working on your *own projects*, testing your *own hypotheses*"; italics added) whereas the flexibility category relates to factors external to the self (e.g., "*I can take many different courses* across the Faculty of Science, [it] helped to support my creativity by providing me with *exposure to different disciplines* and *allowing me* to consider a problem through various lenses"; "…the various *services offered* to get a different

perspective on the material taught in class"; "*acceptance* of different logical answers", "*open-mindedness*"; italics added). We propose that the emotions relating to the (external) flexibility category may relate to feeling adaptively supported within the classroom or program environment, thus tapping into social (external) factors, achievement emotions and agency (e.g., Amabile, 1983; Bandura, 1989; Goetz, Pekrun, Hall, & Haag, 2008). By contrast, students simply focusing on their own work, mulling over hypotheses, or thinking about varied ways to pursue their own learning (as reflected in the inquiry category) are not--in that very moment--relating to the outside world, and that may be a reason why no detectable significant relationships between the inquiry category and achievement emotions (by definition social in nature; e.g., Goetz et al., 2008) were found.

On the creativity-suppressive side, students who reported that their heavy workload and lack of time were hindrances to their creativity were also more likely to experience significantly higher levels of overall negative emotions, both activating and deactivating. Specifically, levels reported of shame, anxiety, and frustration, and to a lesser extent (approaching significance) anger, were higher for this group. Disappointment and hopelessness were also felt significantly more acutely by those who identified heavy workload as a hindrance to creativity.

Our final findings in this qualitative section of our exploratory investigation lend further support to a pattern we also discovered in the quantitative data; namely, the close relationship between creative thinking and critical thinking (e.g., Basadur, 1994, 1995; Chang et al., 2015; Nijstad et al., 2010; Sowden et al., 2015). We recall that the quantitative data (in research question 3) revealed that critical thinking as a deep learning strategy was significantly and positively related to ideational behaviour (divergent thinking; Runco et al., 2001) for both male and female students, in each of the four years of study. Now, in question four, participants who

spontaneously identified inquiry as a supportive factor of creativity also scored significantly higher in critical thinking. Combined with our previous qualitative finding that linked inquiry with ideation (creative thinking), we have evidence suggesting a possible intervening role for inquiry in supporting both creative and critical thinking.

We conclude this discussion of the qualitative part of the present study by proposing that two response categories (of contextual factors supporting creative ideation among undergraduate STEM students) emerged as potential intervening influences at the nexus between established constructs in educational psychology research and creative thinking. Our study uncovered evidence suggesting that a flexible learning environment (the first category) may be pivotal to the functioning of the mechanisms between achievement emotions and creative thinking. Similarly, an inquiry-based learning environment (the second category) seems to play a vital role as a fulcrum between creative and critical thinking. These proposed relationships are depicted in Figure 39 as the ACE (affect, cognition, and environment) model of ideation, and suggest a compelling area for future research.

Practical Implications

The findings in this dissertation have both practical and theoretical implications. The latter will be discussed in a subsequent section (as contributions), while this section is devoted to educational and practical implications.

There seems to exist an implicit belief that students who are high achievers in STEM undergraduate programs (as measured by exam grades) are the students who will go on to build successful careers in science, technology, engineering, or other fields where innovation and adaptive expertise are foundational. That belief may be part of the reason for the prevalence in educational psychology research of studies measuring the effects of emotions, motivation, and

learning strategies, as well as their interactions, on *achievement* outcomes, with much less emphasis on creative outcomes. However, experienced faculty already know what a supplemental analysis[9] in our study corroborated; namely, that it is not always the most academically successful students who are the most creative. Research has also shown that it is not graduates with the highest grades who display the greatest potential for innovation (Mayhew, Simonoff, Baumol, Wiesenfeld, & Klein, 2012), and innovation giants like Google have long ago stopped asking for grades as part of their hiring process (Bryant, 2013). This suggests that adaptive expertise may not correlate with traditionally measured achievement outcomes which has implications for how we teach and assess learning and growth in higher education—that is, if we want to promote adaptive expertise over routine expertise.

Based on our findings, support in the form of practical workshops and other professional development opportunities should be given to faculty in STEM programs to gradually increase the use of teaching practices that develop and support creative thinking and adaptive expertise, rather than routine (rote) expertise among students. Such practices include flexibility and a focus on inquiry teaching (Aulls & Shore, 2008), which the present study revealed as a fertile environment, if not a springboard, for both creative and critical thinking. Faculty training would be helpful in providing practical tools to help instructors in higher education become more effective "meddler[s] in the middle" (McWilliam, 2009; McWilliam & Haukka, 2008) and assist faculty in using research as a core part of the curriculum (Shore, Pinker, & Bates, 1990), rather than something they engage in when they are not teaching. Extensive student research experience, together with exposure to interdisciplinary research and varied career possibilities, contribute to building a diverse and inclusive STEM learning community (Gross, Iverson,

[9] Midterm exam grades had been collected for STEM students as part of the larger study from which our data were culled, and we conducted a Pearson's bivariate correlation analysis between scores in ideational behaviour and midterm exam grades. No statistical correlation was found between the two variables.

Willett, & Manduca, 2015). Assembled, edited, and curated lists of classroom practices that support creativity are numerous and helpful (e.g., Gajda, Beghetto, & Karwowski, 2017, p. 251; Sawyer, 2011, p. 400), and research on fostering critical thinking has produced some useful suggestions (e.g., Basadur, Ellspermann, & Evans, 1994; Heijltjes, Gog, & Paas, 2014; OECD, 2018)--but practical support in translating these lists and suggestions into actual classroom practices in higher education would probably have more impact on learning outcomes.

In addition to implications for faculty, our research results also have implications at the student level. In the interests of fostering adaptive and creative skills, learners should be directly supported in developing and maintaining the deep learning strategies (Bliss & Mueller, 1987) that our research revealed as foundational to ideational behaviour. Furthermore, workshops, mentoring, and counselling regarding the role of achievement emotions in ideation may be particularly useful for female STEM students, given our findings about the differential impact of achievement emotions on ideation among female participants in the study. However, we should keep in mind (as will be discussed under limitations) that the small representation of males in our study may have contributed to the female-centric findings with this variable, and male students should not automatically be excluded from counseling or other support available. Additionally, findings about heavy workloads being linked to stronger negative emotions--and viewed as creativity-suppressing--imply the need for strategic support for managing heavy workloads, and also perhaps for cross-faculty and cross-program co-ordination to help distribute workloads more evenly and manageably. These strategies would support not only student mental health and general learning outcomes, but also creativity, as implied by one participant's wry observation: *"Who has the time to think creatively when you're just trying to survive?"*

Our findings also provide support for the idea of offering workshops on the topic of gender bias and stereotypes in STEM at the beginning of each year; perhaps even making these a required part of the program. The growing body of evidence of systematic and structural bias against female STEM students (and later, women in STEM careers if they make it that far; e.g., Canadian Association of University Teachers, 2016; Clark Blickenstaff, 2005; Simon, Aulls, Dedic, Hubbard, & Hall, 2015; Williams, 2015) needs to be better known, not only by female students but by everyone involved in STEM. Many people might be surprised to learn about the research evidence and would be more likely to become allies in the fight for gender equity if the extent and enduring effects of bias were more broadly known.

Given the prominent impact of hope on ideation (repeatedly found embedded in various mechanisms in the present study), the support of this vital achievement emotion should receive particular attention through structured counseling, advising, peer support groups, seminars, and mentorship, as well as the development of meaningful and supportive relationships with faculty (or a combination of these activities). Good relationships with faculty have been shown to significantly influence innovation outcomes across disciplines (Mayhew et al., 2012).

Mastery approach achievement goals were found to support creative thinking, which has implications for classroom assessment practices (again, if indeed the goal is to support creative ideation and the building of adaptive, rather than merely routine, expertise). Senko, Hama, and Belmonte (2013) found that mastery goals were closely related to interest-based studying which was not always strategic (i.e., planned to maximize exam scores), and may partly explain why there was no correlation between creative thinking (ideation) and midterm grades in our study. Senko et al. (2013) further claimed that performance goals were more conducive to exam success through their promotion of more vigilant, cue-seeking study behaviours. We argue that this is an

example of how exam grades are disproportionately driving research into learning, and exams often assess rote learning rather than thinking skills. To be more supportive of creative thinking in higher education, assessment should encourage the abilities of students to find (or create) their own problems and answer their own questions, as well as building their own cases within learning (e.g., Aulls & Shore, 2008; Mayhew et al., 2012). These are not new suggestions (constructivist pedagogy has been on this track for the better part of a century; e.g., Bruner, 1961; Dewey, 1938; Piaget, 1977; Savery & Duffy, 1995; Vygotsky, 1978), but our findings seem to imply that their implementation in undergraduate STEM classrooms may be lacking, and more support for faculty and learners is required.

Limitations

There are a number of aspects that limit the generalizability of the findings in the present study. Chief among these is the small sample size, particularly for male students. While this is typical of studies that rely on volunteers (Porter & Whitcombe, 2005; Underwood et al., 2000), it suggests an elevated risk for type 2 error—particularly with the even smaller sub-samples and unequal group sizes in certain cells of our moderated moderation analyses (Knudson & Lindsey, 2014). To minimize the possibility of this error, we used bootstrapping to test for indirect and conditional effects (Hayes & Scharkow, 2013) but the possibility remains that some non-zero relationships have gone undetected (Maxwell, 2004). On the other hand, given widespread concerns about the leaky pipeline for female scientists and attrition among female STEM students (e.g., Clark Blickenstaff, 2005; Simon et al., 2015), gaining more information specific to female students is of particular value for better supporting them in undergraduate STEM programs.

The analyses were cross-sectional, which precludes claims about directionality among the constructs. Due to the design of the bigger study of which our data were a previously unexplored subset, responses were collected online at two time points and the temporal distance varied. The second time point was planned to occur within two weeks of the participants' midterm exam dates, and for some participants the exam may have been very close to the first collection, while several weeks may have passed for others. Because the link to the questionnaires for achievement emotions and learning strategies was sent by email and completed by participants online, we do not know whether they were actively studying--or *thinking* about studying--while completing the questionnaire. The emotions were not measured by experience sampling, and responses may therefore have tapped into trait-like habitual emotions or beliefs about studying (Robinson & Clore, 2002), rather than actual "in the moment" transient state emotions. The wording in the learning strategy questionnaire asked about habitual (trait) rather than immediate (state) strategies. Habitual emotions and behaviours are considered to be more stable over time within individuals, and inter-person differences are more noticeable in habitual traits than the intra-person variations found in state emotions (Hertzog & Nesselroade, 1987), providing the rationale for investigating relationships among focal constructs with variables that had been measured at an earlier time. The present study was exploratory in nature, aimed at finding relationships and patterns in a previously unstudied sample, with previously uncombined constructs. While we cannot claim causality, we have uncovered new relationships, patterns, and potential mediators (e.g., flexibility and inquiry) which can later be tested in a longitudinal study with appropriate temporal separation of data collection times. A longitudinal design would then allow for inferences about antecedents and causally based predictions about outcomes.

A final limitation is the self-report nature of the questionnaires. However, although self-reports may risk memory distortions and social desirability bias (Pekrun & Bühner, 2014), they are nonetheless considered authentic and ecologically valid compared to experimental studies in a lab setting. Similarly, significant correlations have been found between self-reported creativity and results from the Torrance Tests of Creative Thinking (Kaufman, 2006; Park, Lee, & Hahn, 2002), lending further credibility to self-report results in the present study.

Future studies could incorporate in their research design measures of emotions in real time through experience sampling, as well as verifying physiological responses and calibrating them with self-reports. Combining this with tests for divergent thinking in authentic settings would allow multiple data points to inform findings and balance participant perceptions with data from objective channels. The next section will discuss other potential future directions.

Future Directions

Given the exploratory nature of the present study, numerous potential future directions have emerged as a result of patterns and relationships discovered through our analyses, as well as through limitations of the original study design. Many were already discussed, and some will be assembled here under three subheadings (achievement goals, achievement emotions, and a proposed new model) referencing the constructs or models the most closely relate to.

Achievement Goals

In the domain of achievement goals, we found multiple links between creative thinking and mastery goals, but no relationship to performance goals. A possible future direction would be to examine whether mastery approach goals are uniquely related to adaptive expertise, while performance approach goals (which have been found to negatively predict critical thinking; Ranellucci et al., 2015) may be more related to routine expertise and traditionally measured

academic achievement. We also saw hints in our study that mastery goals may help lessen the impact of negative emotions on ideation, and this is a question worthy of further study.

Achievement Emotions

Several findings point to interesting new avenues of research into the roles of achievement emotions in creativity and adaptive expertise. The role of hope, in particular, appeared in multiple analyses as significantly (directly and indirectly) related to ideation. This area could therefore be a particularly rich source for a more fine-grained understanding of the role of specific achievement emotions as they relate to creative thinking and innovation among STEM students--both at the undergraduate level (as in the current study) and beyond, into post-graduate studies and STEM careers. There may be important gender differences within this emotion at different levels of study and career that could, if explored, open new avenues to support female scientists (and potentially male scientists too, if we were to obtain a large enough sample to determine its benefits) at different positions along the pipeline.

This research could be broadened to investigate our dual findings that positive emotions had the strongest impact on female students' ideational behaviour in the first year and subsequently decreased, while negative emotions increased in importance in relation to ideation, with the strongest relationship in the last year of the program. The present study was cross sectional, so the respondents from year 1 are not the same students as at year 4. To remedy this, a longitudinal cohort study could be undertaken to investigate whether attitudes and the effects of emotions on ideation change through the years of study: This may have a significant impact on female graduates' propensity to innovate and use their learned expertise adaptively and creatively post-graduation. As stated above, it would be valuable to conduct the study with a

larger number of male participants to help determine whether these are uniquely female phenomena within STEM.

Proposed New Model of Ideation

Our study uncovered evidence suggesting that flexibility within the learning environment may underlie the functioning of the mechanisms between achievement emotions and creative thinking. Similarly, an inquiry-oriented learning environment appears to play a vital role at the nexus of critical and creative thinking. These proposed relationships were depicted earlier in Figure 39 and suggest a compelling area for future research. One possible direction would be to examine the mediating roles of inquiry learning and flexible settings, with the aim of determining their respective roles in (i.e., whether they mediate, or otherwise enable) the connections between creative thinking on one hand, and critical thinking (for inquiry) and achievement emotions (for flexibility) on the other. A part of this study could also focus on the differential impacts of internal (individual) versus external (social) factors in supporting creative thinking. The research in the area of flexibility could also consider in more detail the impact of the control-value theory of achievement emotions in education (Pekrun et al., 2002) in relation to ideation in STEM. Since nine of ten emotions measured for the present study were significantly correlated with the flexibility category, it would be interesting to extend those findings through examining learner perceptions of control and value and explore whether this might further clarify the links between emotions and creative thinking.

Any significant findings from this future research could then be used to help design the kinds of STEM learning environments that are more likely to support ideational flexibility and adaptive expertise. A study of this nature would also further contribute to the literature on the connections between creative and critical thinking.

Finally, although a secondary discovery that was not part of the original research plan, our finding that midterm grades and ideational behaviour were not statistically correlated raises some interesting questions, particularly as grades and ideation share similar antecedents (approach goals, positive emotions, and deep learning strategies). Another possible future direction could thus be looking for answers to where and why grades and ideation diverge, despite sharing similar antecedents.

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Tables

Table 2

Descriptive Statistics for All Study Variables

	Min	Max	Mean	SD	Skew	Kurtosis	Cr. α
Gender[1]	0	1	.70	.46	-.88	-1.29	
Year of Study	0	3	1.44	.95	.23	-.85	
Age	18	29	19.73	1.48	2.27	10.96	
Ideation	1.57	7	4.61	1.10	-.09	-.19	.93
Achievement Emotions							
Hope	1	5	3.12	.83	-.32	.24	.78
Pride	1	4.67	2.63	.87	.18	-.32	.79
Enjoyment	1	5	2.54	.88	.47	.51	.88
Shame	1	4	1.61	.79	1.51	1.79	.81
Anger	1	4.33	1.69	.88	1.47	1.37	.92
Anxiety	1	5	3.29	.99	-.22	-.29	.89
Frustration	1	5	2.69	1.00	.51	-.28	.84
Hopelessness	1	5	2.14	.91	.98	.60	.76
Disappointment	1	5	2.21	.93	.60	-.28	.83
Boredom	1	5	2.86	.90	.09	-.34	.86
Achievement Goals							
Mast Approach	3.33	7	6.00	.95	-1.00	.42	.82
Mast Avoid	1	7	5.00	1.37	-.32	-.63	.73
Perf Approach	1	7	5.51	1.45	-.82	-.19	.88
Perf Avoid	1	7	5.19	1.58	-.60	-.44	.88
Learning Strategies							
Rehearsal	1	7	4.40	1.31	-.36	-.15	.65
Elaboration	1	7	4.61	1.18	-.22	-.20	.72
Critical Thinking	1	7	3.61	1.49	.32	-.45	.88

[1] Gender was dummy coded as 0 = male and 1 = female

Table 3

Open Response Codes, Descriptions, and Sample Responses of Factors that Support and Suppress Creative Thinking

Codes Supporting	**Description**	**Sample response**
P1. Faculty	Engaging, passionate professors and TAs	"the enthusiasm and encouragement of the professor" "professors talking about their field and lab work" "professors [who] introduce subject matter that isn't in the textbook to make us think" *(this would also be coded P3)*
P2. Inquiry **relates to their **own** thinking and choices in their **own** course work **	Opportunities for students to conduct research, hypothesizing, problem solving, curiosity, open assignments, lab (work), projects	"encourage students to ask their own questions and think of possible answers and a way to test their hypotheses" "options for assignments in courses" "research and the ability to think outside the box and have the space to think and experiment independently strongly supports my creativity in my program"
P3. Flexibility **relates to factors **external** to the self**	Multiple perspectives, broad topics, open-mindedness, flexibility of system (e.g., electives)	"many possible answers, supported by flexible grading" "being able to relate math to other courses" "…alluding to implications of a certain idea in relation to other ideas previously discussed"
P4. Discourse	Interaction, discussions, group work, peers, lab (community), sharing ideas	"the […] I did with my teammate last semester supported our creativity." "events that bring together students for speakers, or just to share ideas" "[…] open up discussions in class"
P5. External	Extracurricular activities, nature, family	"the nature around me" "there is always lots happening at […] that supports creativity"
P6. Interest	Interest, positive emotions	"interest in the material"
Codes Suppressing	**Description**	**Sample response**
N1. Personal	Fatigue, mental health, negative emotions	"previous concussions, depression, negative outlook on school" "inability to manage stress" "anxiety suppresses passion and creativity"
N2. Rigidity	Rigidity of program, extensive memorizing,	"there isn't any opportunity for creativity [. . .] as it's mostly just memorize and regurgitate or

	one known correct answer only, pure facts	calculations" "the strict, mundane set of procedures I often follow" "the entire program is just designed to shove knowledge down students' throats"
N3. Workload	Workload (too much); time (not enough); difficulty of material; deadlines	"workload [. . .] suppresses passion and creativity" "not enough time to just sit down and think about things" "who has the effort to think creatively when you're just trying to survive?"
N4. Class Size		"most courses are big and do not allow…" "huge lectures suppress creativity"
N5. Evaluation	Exams, tests (esp. multiple choice), evaluation, grade focus, competition, performance, fear of failure	"exams that are all multiple choice suppress creativity" "the desire to do well [. . .] prevents me from […] exploring" "the fear of failure and the importance put on grades" "constant comparison to other students" "knowing you are evaluated means you must sometimes be strategic"

Table 4

Correlations Between Ideation and Goals

Variable	1	2	3	4	5	6	7	8
1. Ideation	1							
2. Mastery Approach	.242**	1						
3. Mastery Avoidance	.230*	.550***	1					
4. Mastery Both	.266*	. 831***	.921***	1				
5. Perform Approach	.137	.102	.172 †	.162 †	1			
6. Perform Avoidance	.082	-.051	.450***	.276**	.503***	1		
7. Gender[1]	-.032	.001	-.049	-.032	.012	.153	1	
8. Year[2]	.114	-.229*	-.084	-.163 †	-.060	-.018	.013	1

*$p < .05$, **$p < .01$, ***$p < .001$, †approaching significance at $p < .1$

Notes:

1. Gender coded as 0 - male, 1- female
2. Years coded 0-3

Table 5

Correlations Between Ideation and Achievement Emotion Variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Ideation	1												
2. Hope	.308***	1											
3. Pride	.227**	.693***	1										
4. Enjoy	.173*	.620***	.664***	1									
5. Shame	-.080	-.416***	-.326***	-.154*	1								
6. Anger	-.160*	-.408***	-.223**	-.342***	.581***	1							
7. Anxiety	-.185*	-.310***	-.174*	-.155*	.526***	.462***	1						
8. Frustrated	-.219**	-.451***	-.301***	-.419***	.556***	.783***	.518***	1					
9. Hopeless	-.183*	-.554***	-.354***	-.391***	.639***	.729***	553***	.778***	1				
10. Disapp	-.158*	-.560***	-.420***	-.453***	.629***	.676***	.555***	.807***	.767***	1			
11. Bored	-.080	-.424***	-.317***	-.586***	.146	.401***	.155**	.548***	.458***	.529***	1		
12. Gender	-.032	-.167†	-.030	-.045	.096	.042	.226*	.132	.183*	.113	.100	1	
13. Year	.114	-.076	-.162†	-.177†	-.115	-.161†	-.142	-.051	-.153†	-.032	.048	.013	1

*$p < .05$, **$p < .01$, ***$p < .001$, †approaching significance at $p < .1$

Notes:
1. Gender coded as 0 - male, 1- female
2. Years coded 0-3
3. Correlations between emotion and ideation are one-tailed based on theory; correlations between emotion and gender, as well as emotion and year, are two-tailed in the absence of theory suggesting otherwise.

Table 6

Correlations Between Ideation and Study Strategies

Variable	1	2	3	4	5	6	7	8
1. Ideation	1							
2. Rehearsal	-.061	1						
3. Elaboration	.310***	.258**	1					
4. Critical Thinking	.512***	.090	.529***	1				
5. Shallow Strategies (rehearsal)	-.061	1	.258**	.090	1			
6. Deep Strategies (elaboration + critical thinking)	.482***	.188*	.842***	.904***	.188*	1		
7. Gender	-.032	.813	.124	-.112	.096	-.009	1	
8. Year	.114	-.022	.073	.018	-.022	.049	.013	1

* $p < .05$, ** $p < .01$, *** $p < .001$, † approaching significance at $p < .1$

Notes

1. Gender coded as 0 - male, 1 - female
2. Years coded 0-3

Table 7

Summary of Full and Partial Mediation of Relationships between IVs and Ideation (DV)

	IV	**Mediator**	
Group 1	MAP	*Pos-Activating*	(●)
	MAP	Hope	●
	MAV	Hope	(◒)
Group 2	Pride	MAP	●
	Enjoyment	MAP	●
	Neg-Total	MAP	●
	Neg-Activating	MAP	●
	Frustration	MAP	●
	Shame	MAP	●
	Neg-Deactivating	MAP	●
	Hopeless	MAP	●
	Disappointed	MAP	●
	Bored	MAP	●
	Pos-Activating	MAV	◒
	Hope	MAV	(◒)
	Enjoy	MAV	●
	Neg-Deactivating	MAV	●
	Bored	MAV	●
Group 3	Elaboration	Hope	◒

●Full mediation; ◒ Partial mediation; ( ) approaching significance ($p < .1$)

Table 8

Descriptive Statistics by Gender for Focal Variables

	Mean		Min		Max		SD	
	Male	Female	Male	Female	Male	Female	Male	Female
Ideation	4.78	4.53	2.43	1.57	6.71	7.00	1.21	1.05
Achievement Emotions, Aggregate								
Positive (all are activating)	2.88	2.72	1.00	1.11	4.33	4.89	.78	.75
Negative Activating	2.12	2.39	1.00	1.08	4.33	4.42	.74	.75
Negative Deactivating	2.20	2.47	1.33	1.00	5.00	4.33	.89	.73
Negative Total	2.16	2.43	1.28	1.08	4.67	4.29	.79	.69
Achievement Emotions, Individual								
Hope	3.35	3.04	1.00	1.00	5.00	5.00	.93	.77
Pride	2.68	2.62	1.00	1.00	4.33	4.67	.87	.87
Enjoyment	2.60	2.51	1.00	1.00	4.00	5.00	.81	.91
Shame	1.48	1.66	1.00	1.00	4.00	4.00	.70	.81
Anger	1.62	1.71	1.00	1.00	4.33	4.33	.89	.88
Anxiety	2.91	3.42	1.00	1.00	5.00	5.00	1.02	.95
Frustration	2.47	2.77	1.00	1.00	5.00	5.00	1.00	.99
Hopelessness	1.86	2.24	1.00	1.00	5.00	4.67	1.01	.86
Disappointment	2.03	2.27	1.00	1.00	5.00	4.33	.97	.92
Boredom	2.71	2.91	1.33	1.00	5.00	4.67	.98	.86
Achievement Goals								
Mastery Approach	5.98	6.17	3.33	3.67	7.00	7.00	1.09	.86
Mastery Avoid	5.06	4.97	1.67	1.00	7.00	7.00	1.41	1.36
Performance Approach	5.32	5.59	1.00	1.67	7.00	7.00	1.60	1.39
Performance Avoid	4.69	5.29	1.00	1.33	7.00	7.00	1.83	1.45
Learning Strategies								
Rehearsal	4.19	4.47	1.00	1.00	6.75	7.00	1.39	1.27
Elaboration	4.36	4.69	1.00	2.00	6.33	7.00	1.32	1.12
Critical Thinking	3.88	3.51	1.00	7.00	1.00	7.00	1.57	1.45

Table 9

Frequencies of Open-ended Responses by Code

Code	Description	f	%
P1. Faculty	Engaging, passionate professors and TAs	17	7
P2. Inquiry	Opportunities for students to conduct research, hypothesizing, problem solving, curiosity, open assignments, lab (work), projects	32	13
P3. Flexibility	Multiple perspectives, broad topics, open-mindedness, flexibility of system (e.g., electives)	21	8.5
P4. Discourse	Interaction, discussions, group work, peers, lab (community), sharing ideas	16	6.5
P5. External	Extracurricular activities, nature, family	6	2.5
P6. Interest	Interest, positive emotions	12	5
	Total Positive (Supports)	**104**	**42**
N1. Personal	Fatigue, mental health, negative emotions	15	6
N2. Rigidity	Rigidity of program, extensive memorizing, one known correct answer only, pure facts	62	25
N3. Workload	Volume of work, time (not enough of it), difficulty of material, deadlines	21	8.5
N4. Class Size	Large classes	6	2
N5. Evaluation	Exams, tests (esp. multiple choice), evaluation, grade focus, competition, performance, fear of failure	39	16
	Total Negative (Suppresses)	**143**	**58**
	Total codes	**247**	**100**

Table 10

Correlations Between Ideation, Gender, Year of Study, and Response Categories

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Ideation	1	-.095	.052	-.140†	-.008	-.122	-.007	-.093	.048	.165*	.186*	.056	.130†	-.026
2. Gender		1	.026	.024	.069	-.027	.057	-.008	.005	.040	-.027	.125	.057	-.020
3. Year			1	-.019	.187*	-.031	-.163*	.183*	.026	-.025	-.012	.015	.077	.062
4. Stress				1	-.167*	.133	-.061	.073	-.106	-,004	.004	.039	.052	-.007
5. Rigid					1	-.083	-.155*	-.008	-.108	.082	-.008	-.095	-.155*	.062
6. Workload						1	-.074	-.083	.170*	-.148†	-.090	-.001	-.074	.174*
7. Class Size							1	-.031	-.065	-.098	-.074	.046	-.037	-.054
8. Evaluation								1	-.093	-.105	-.040	.012	.121	.010
9. Faculty									1	-.024	.170*	.159*	-.065	.136†
10. Inquiry										1	.031	.037	-.098	-.026
11. Flexibility											1	.060	.023	.104
12. Discourse												1	.046	-.012
13. External													1	-.054
14. Interest														1

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$, †approaching significance at $p < .1$

Table 11

Correlations Between Achievement Goal Orientations and Response Categories

Response Category	Mastery Approach	Mastery Avoidance	Performance Approach	Performance Avoidance
1. Stress	.004	-.042	.009	.120
2. Rigid	.002	-.024	-.005	-.049
3. Workload	.005	.075	.106	.177*
4. Class Size	.083	-.045	.035	-.095
5. Evaluation	-.110	-.042	.067	.053
6. Faculty	.068	.038	-.024	-.055
7. Inquiry	.124	.097	-.002	.000
8. Flexibility	.147†	-.057	-.027	-.157*
9. Discourse	.026	.009	-.064	-.063
10. External	-.021	-.013	.035	.077
11. Interest	.137	.054	.050	.041

*$p < .05$, **$p < .01$, ***$p < .001$, †approaching significance at $p < .1$

Table 12

Correlations Between Aggregate Achievement Emotions and Response Categories

Response Category	Positive Activating	Negative Activating	Negative Deactivating	Negative Total
1. Personal	.027	.145	.102	.129
2. Rigid	-.068	-.039	.028	-.005
3. Workload	-.118	.332***	.226*	.291**
4. Class Size	.001	-.109	-.027	-.070
5. Evaluation	.036	-.084	-.164	-.132
6. Faculty	.039	-.100	-.084	-.097
7. Inquiry	.128	-.007	-.083	-.049
8. Flexibility	.276**	-.215*	-.244**	-.241**
9. Discourse	-.055	-.063	-.076	-.073
10. External	.104	-.097	-.074	-.089
11. Interest	.038	.139	.090	.116

*$p < .05$, **$p < .01$, ***$p < .001$, †approaching significance at $p < .1$

Table 13

Correlations Between Individual Achievement Emotion Variables and Response Categories

Response Category	Hope	Pride	Enjoy	Shame	Anger	Anxiety	Frustr	Hopeless	Disapp	Bored
1. Personal	-.145	.005	.198*	.163†	.092	.107	.124	.114	.170	-.028
2. Rigid	-.005	-.004	-.164†	-.040	-.076	-.010	-.011	-.001	-.012	.087
3. Workload	-.146	-.150	-.020	.376***	.173†	.356***	.202*	.272**	.276**	.026
4. Class Size	-.064	.031	.031	-.063	-.089	-.073	-.128	-.043	-.041	.016
5. Evaluation	.050	.006	.039	-.020	-.078	-.107	-.064	-.152	-.094	-.181
6. Faculty	.167	-.104	.047	-.094	-.164	-.031	-.057	-.039	-.087	-.091
7. Inquiry	.052	.149	.133	-.009	.001	.082	-.095	-.041	-.032	-.144
8. Flexibility	.213*	.236*	.276**	-.196*	-.183*	-.116	-.218*	-.243**	-.211*	-.174†
9. Discourse	.002	-.118	-.026	.002	-.133	-.032	-.045	-.087	.017	-.131
10. External	.068	.095	.108	-.504	-.038	-.143	-.074	-.062	-.055	-.073
11. Interest	.086	.003	.014	.027	.140	.162	.096	.112	.125.	-.009

*$p < .05$, ** $p < .01$, *** $p < .001$, †approaching significance at $p < .1$

Table 14

Correlations Between Learning Strategies and Response Categories

Response Category	Rehearsal (Shallow Strategies)	Deep Strategies	Elaboration	Critical Thinking
1. Personal	.043	.118	.047	.149
2. Rigid	-.007	.018	.073	-.030
3. Workload	-.043	-.062	-.058	-.051
4. Class Size	.048	.001	.006	-.003
5. Evaluation	-.204*	.069	.045	.073
6. Faculty	-.140	-.081	-.023	-.109
7. Inquiry	.158	.207*	.129	.224*
8. Flexibility	.039	.058	.061	.042
9. Discourse	-.118	-.147	-.131	-.127
10. External	.010	.107	.087	.099
11. Interest	-.081	.047	.032	.049

*$p < .05$, **$p < .01$, ***$p < .001$, †approaching significance at $p < .1$

Figures

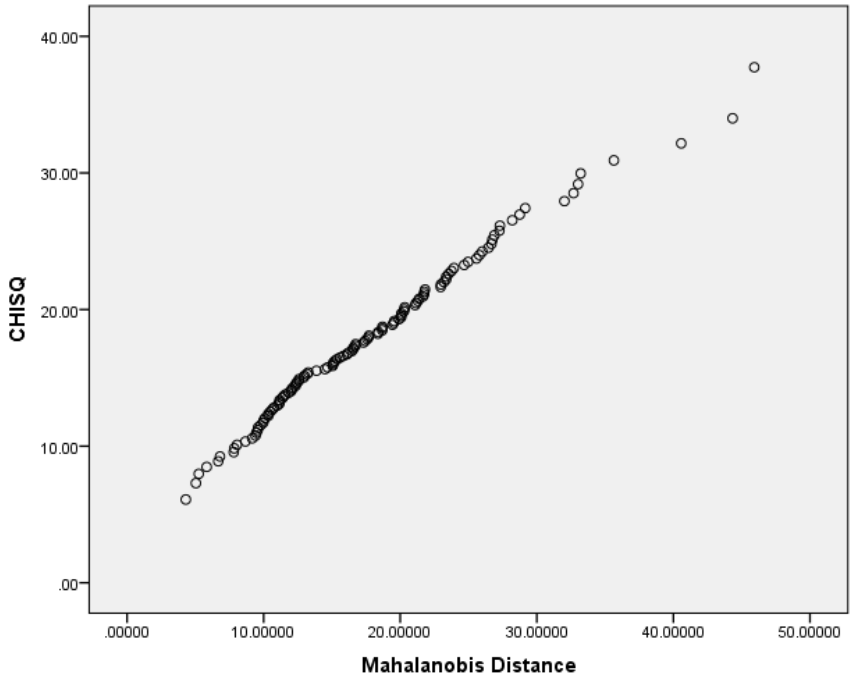


Figure 6. Chi-square versus Mahalanobis distance plot.

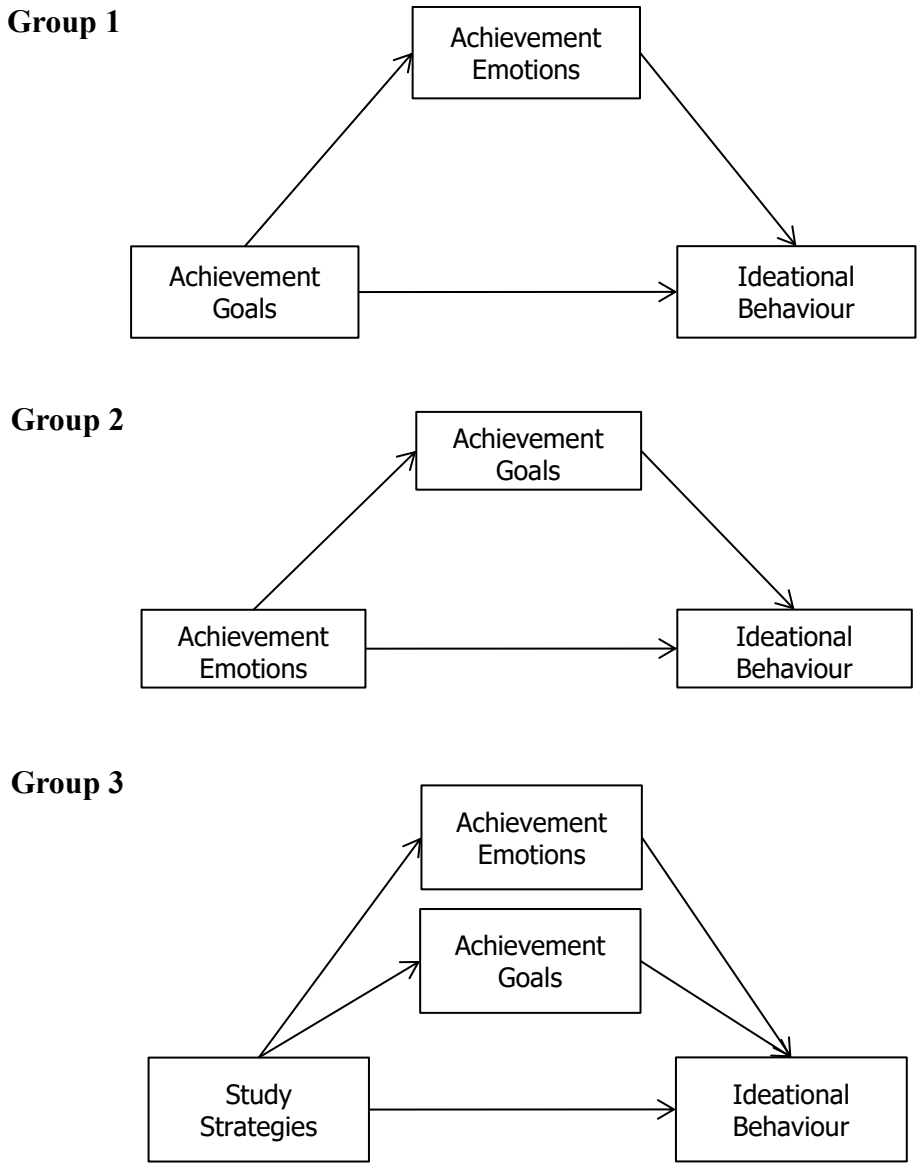


Figure 7. Groups of mediation analyses for research question 2.

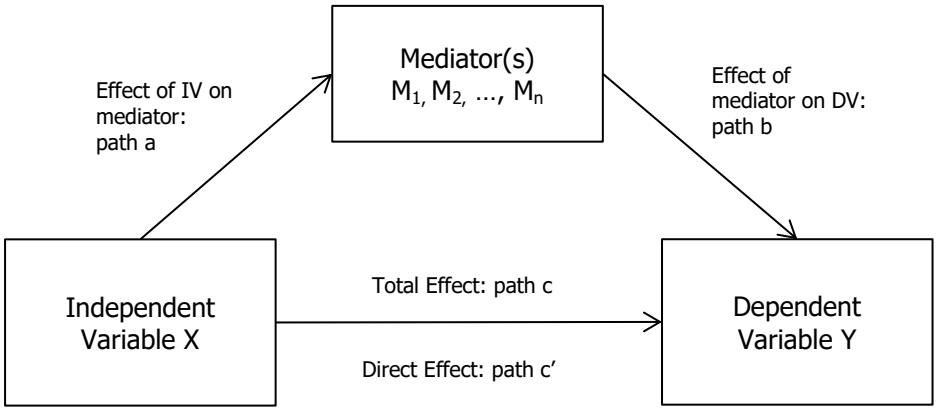


Figure 8. Conceptual diagram of PROCESS mediation using Model 4 (Hayes, 2013, 2018).

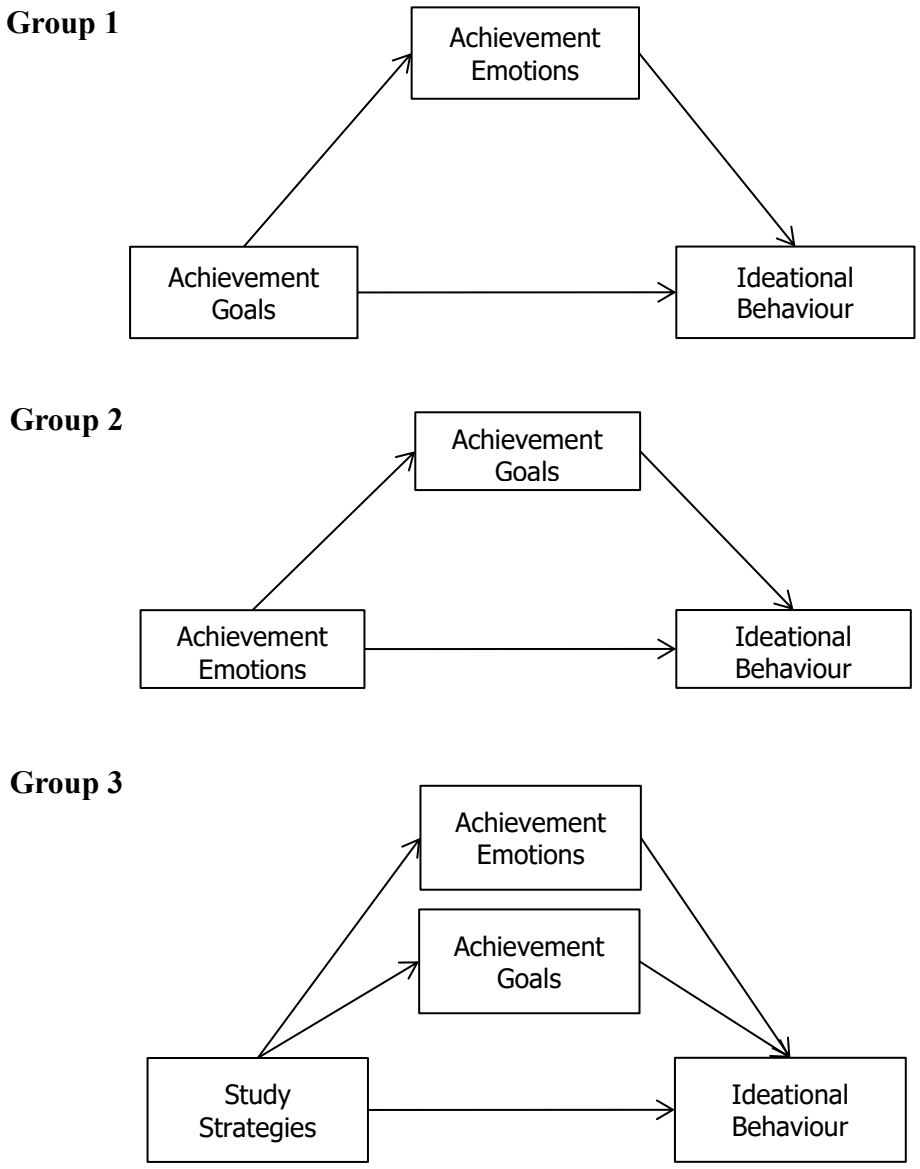


Figure 9. Groups of mediation analyses for research question 2 (repeat).

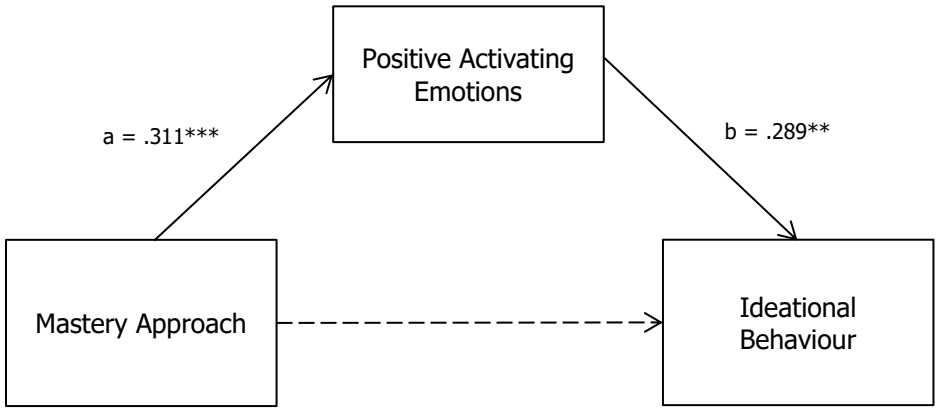


Figure 10. Indirect effect of positive activating emotions on the relationship between mastery approach goals and ideational behaviour.

* < .05 , ** < .01, *** < .001, † approaching significance

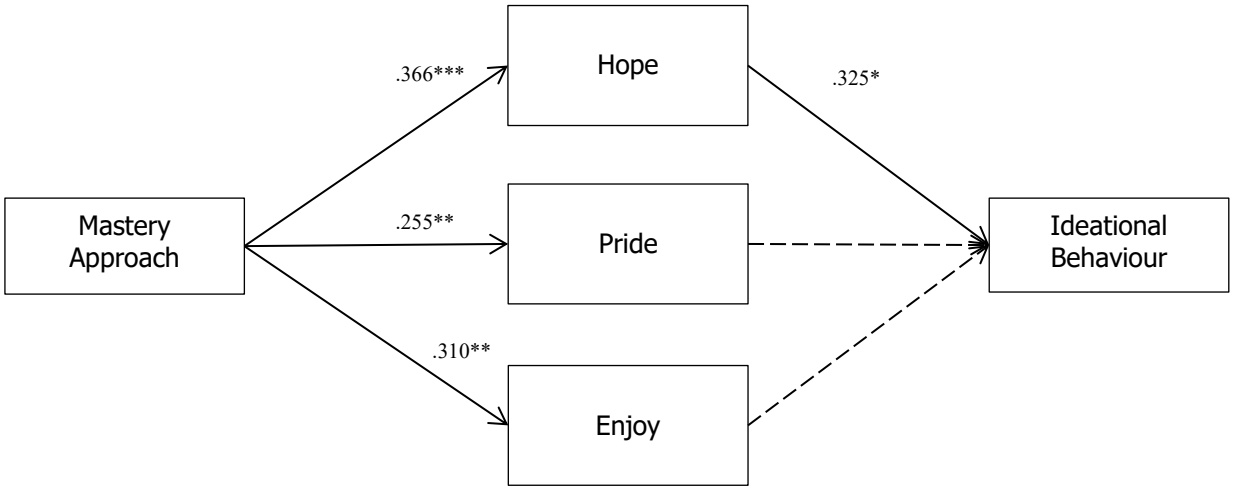


Figure 11. Process model for the indirect effects of individual positive emotions on the relationship between mastery approach goals and ideation.

* < .05 , ** < .01, *** < .001, †approaching significance < .1

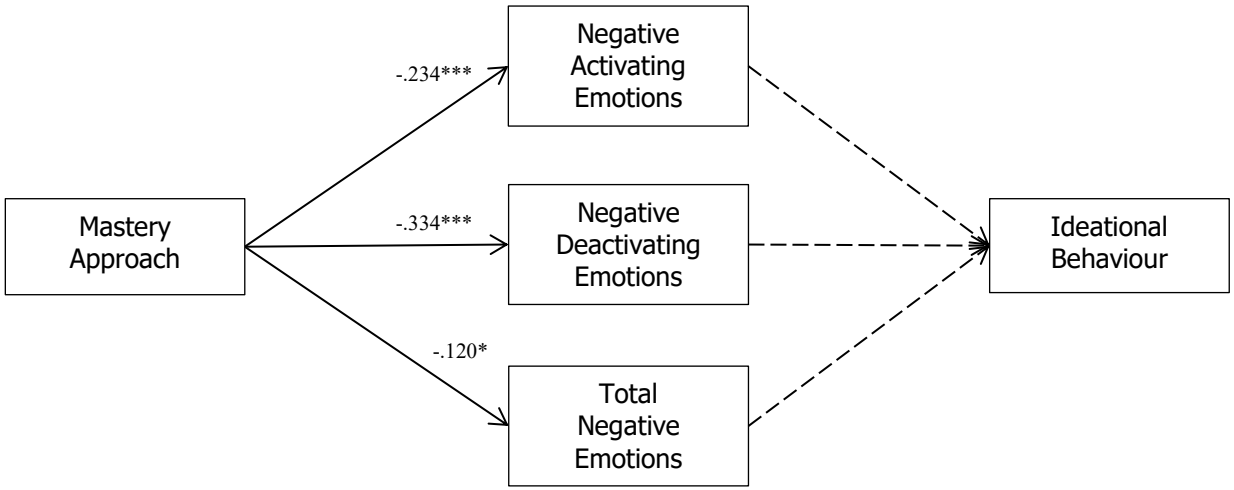


Figure 12. Effects of aggregate negative emotions on the relationship between mastery approach goals and ideational behaviour. No mediation.

* < .05 , ** < .01, *** < .001, † approaching significance

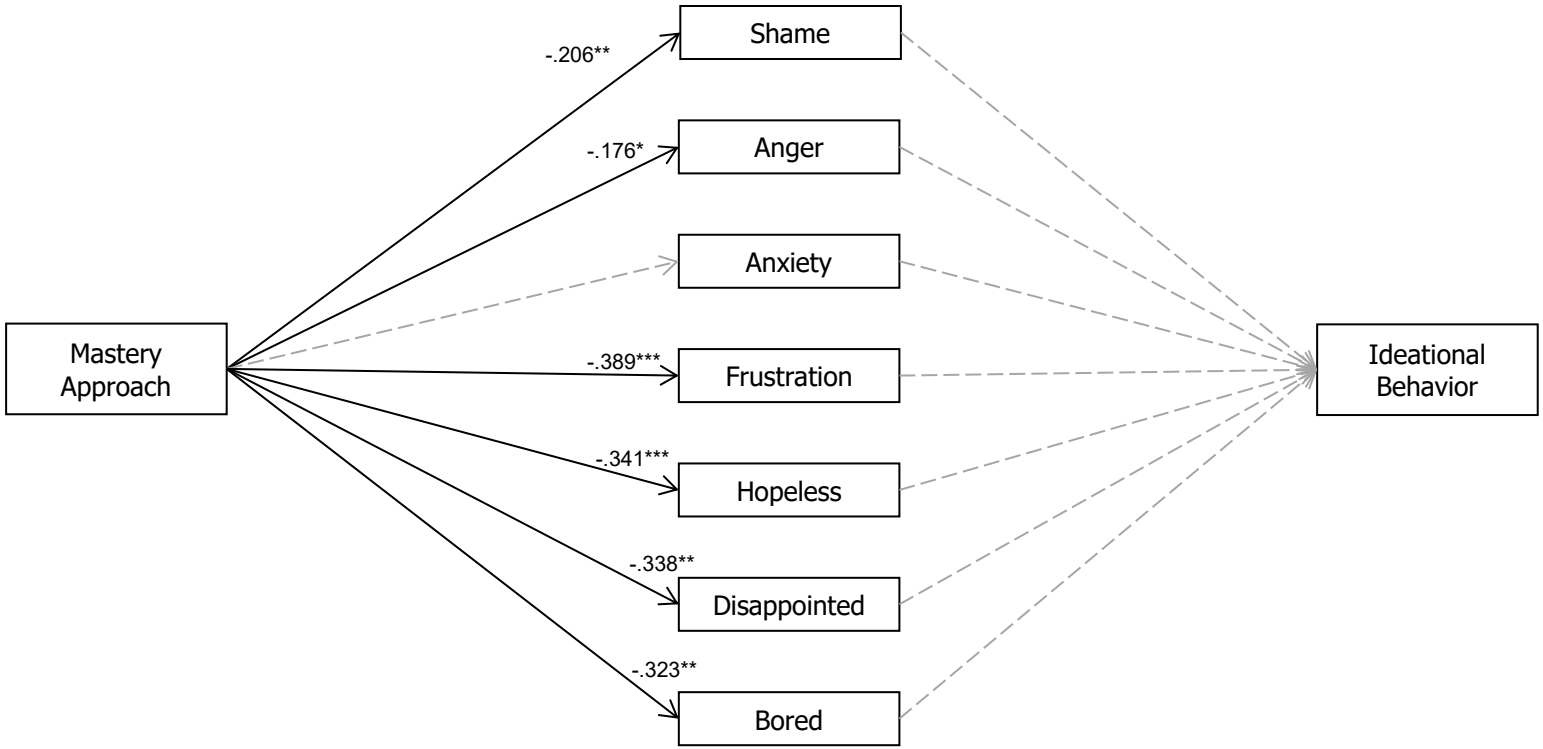


Figure 13. Process model for the indirect effects of individual negative emotions on the relationship between mastery approach goals and ideation. No mediation.

* < .05 , ** < .01, *** < .001, † approaching significance

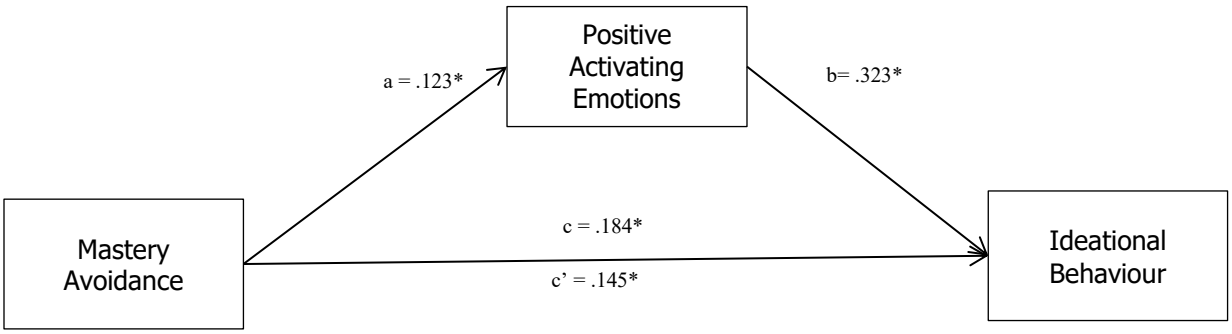


Figure 14. Direct and indirect effects (partial mediation) of positive emotions on the relationship between mastery avoidance goals and ideational behaviour.

* < .05 , ** < .01, *** < .001, † approaching significance

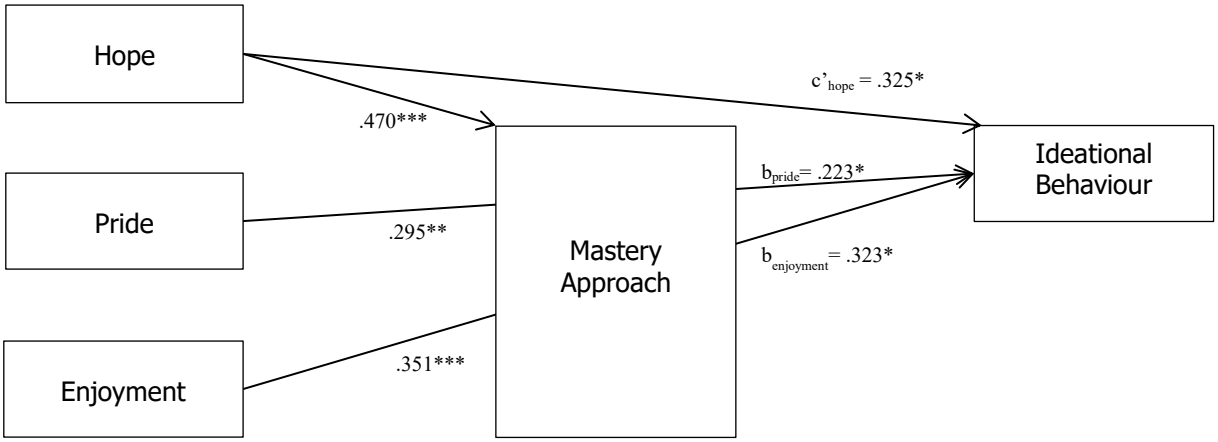


Figure 15. Mastery approach goals (in group 2 analyses) mediate the effect of pride and enjoyment on ideation; hope exerts a direct effect.

* < .05 , ** < .01, *** < .001, †approaching significance

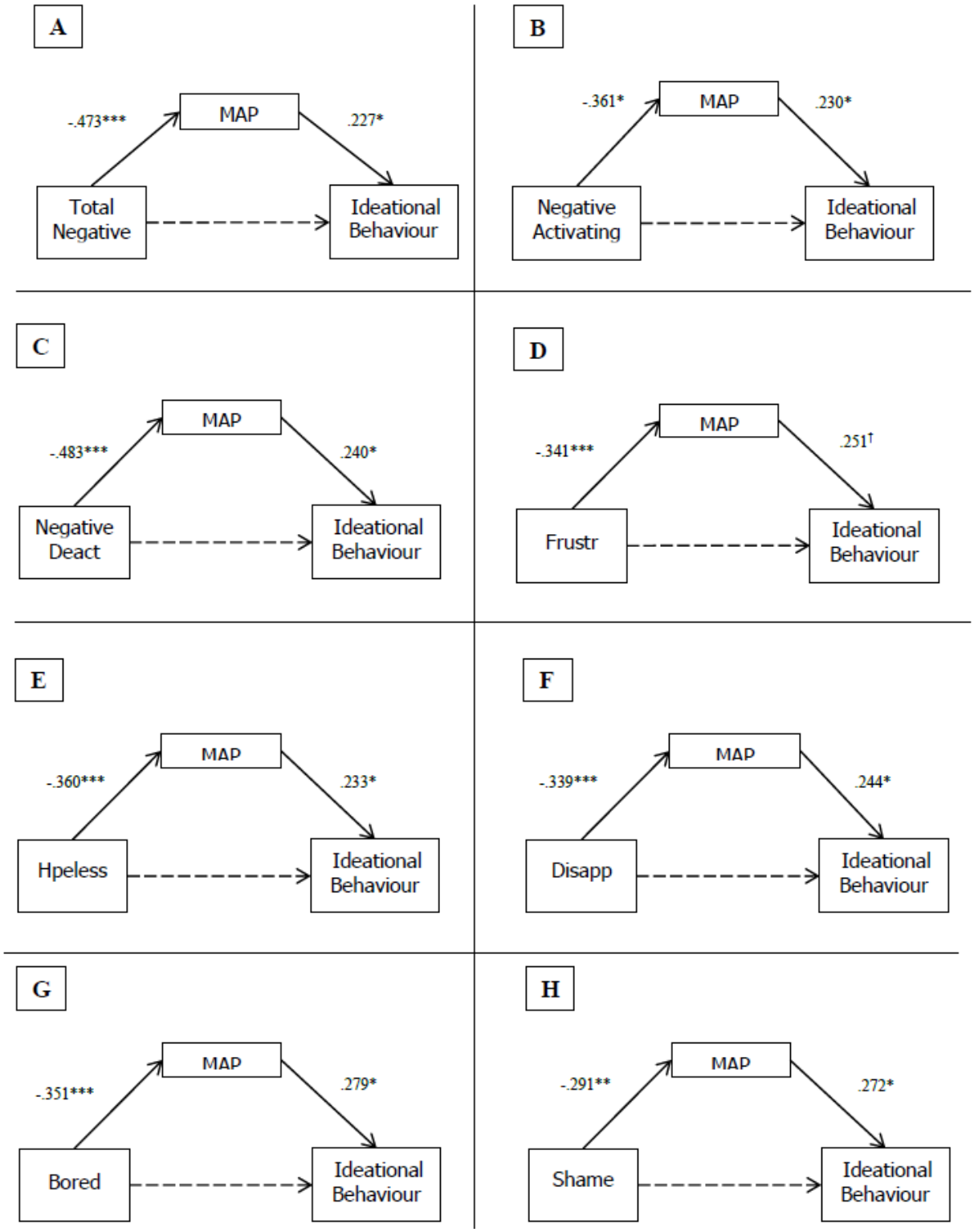


Figure 16. Full mediation by mastery approach goals on the influence of negative emotions (aggregate and individual) on ideation.

* < .05 , ** < .01, *** < .001, † approaching significance at $p = .052$

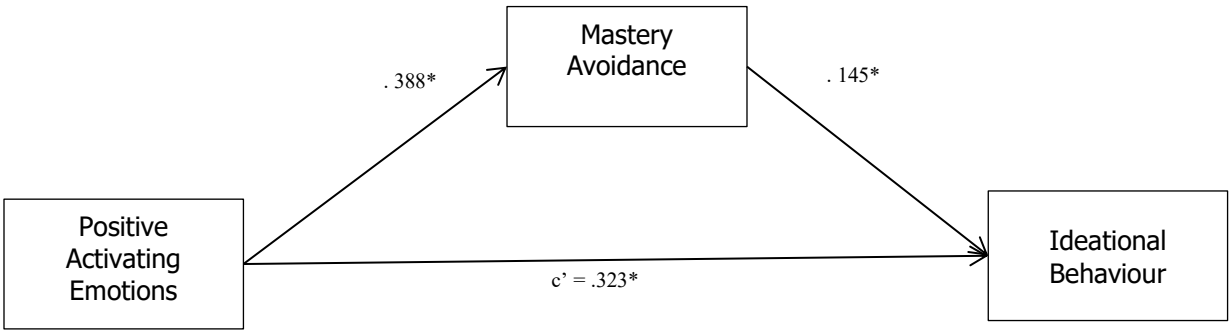


Figure 17. Direct and indirect effects (partial mediation) of positive activating emotions and ideational behaviour through mastery avoidance.

* < .05 , ** < .01, *** < .001, † approaching significance

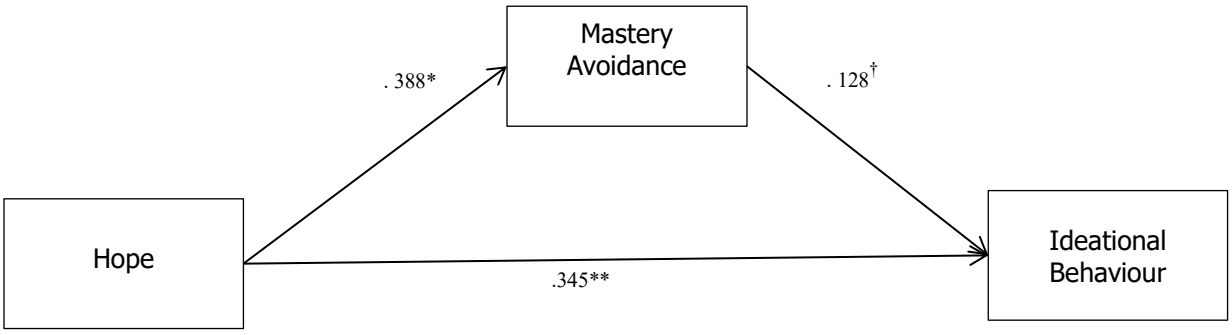


Figure 18. Direct and indirect effects (partial mediation) of hope on ideation through mastery avoidance.

* < .05 , ** < .01, *** < .001, † approaching significance at .079

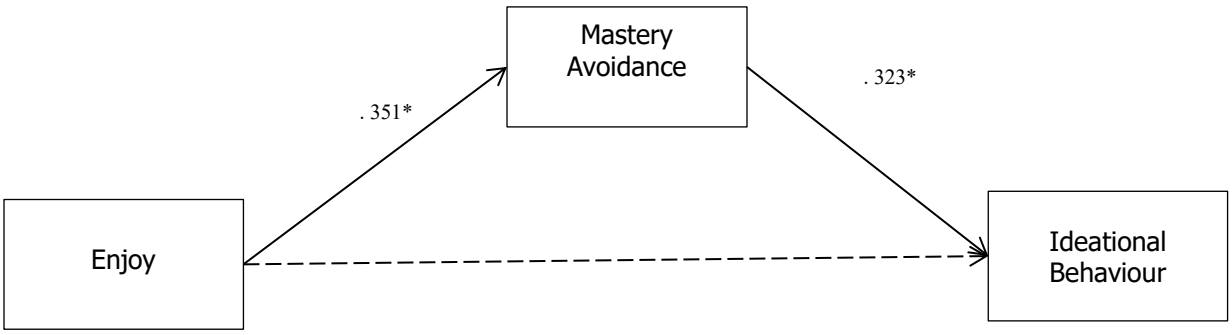


Figure 19. Indirect effect (mediation) of enjoyment on ideation through mastery avoidance.

* < .05 , ** < .01, *** < .001

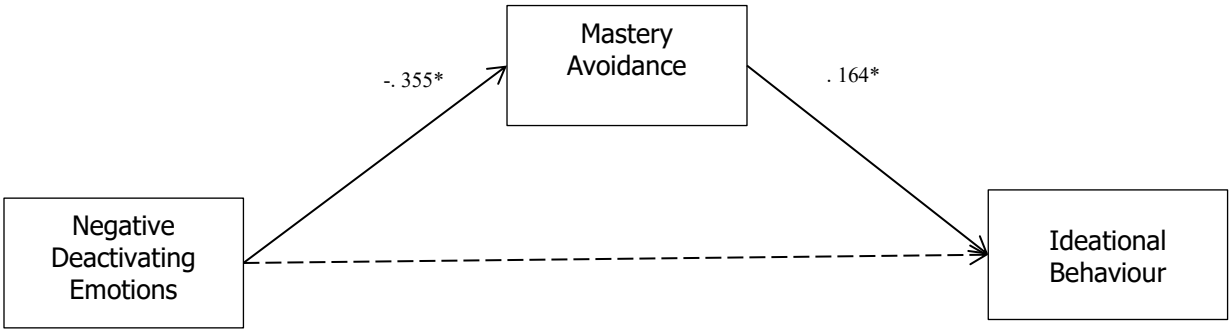


Figure 20. Indirect effects (mediation) of negative deactivating emotions on ideation through mastery avoidance.

* < .05 , ** < .01, *** < .001

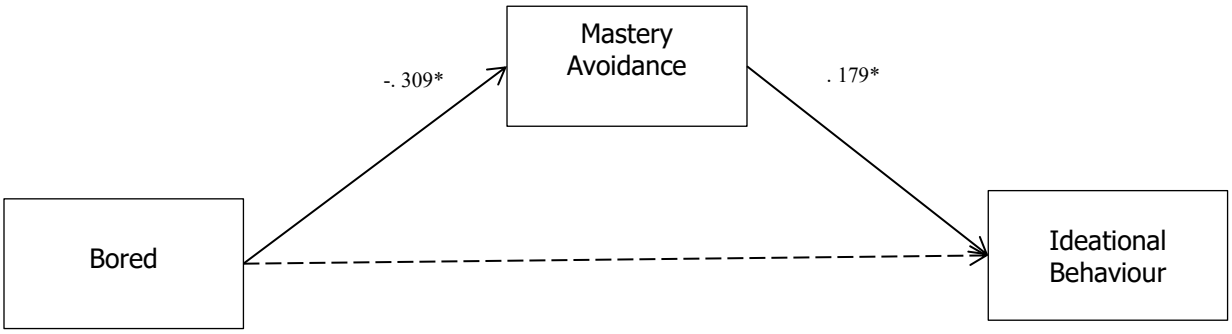


Figure 21. Indirect effect (mediation) of boredom on ideation through mastery avoidance.

* < .05 , ** < .01, *** < .001

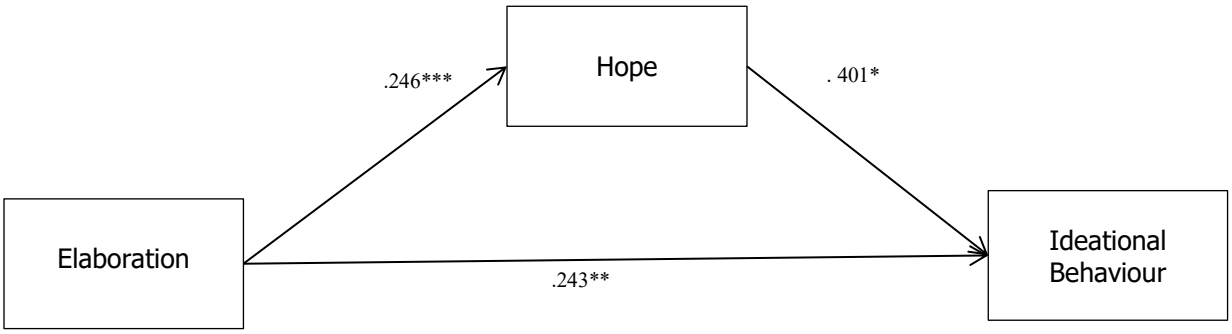


Figure 22. Direct and indirect effects of elaboration on ideation through hope.

* < .05 , ** < .01, *** < .001

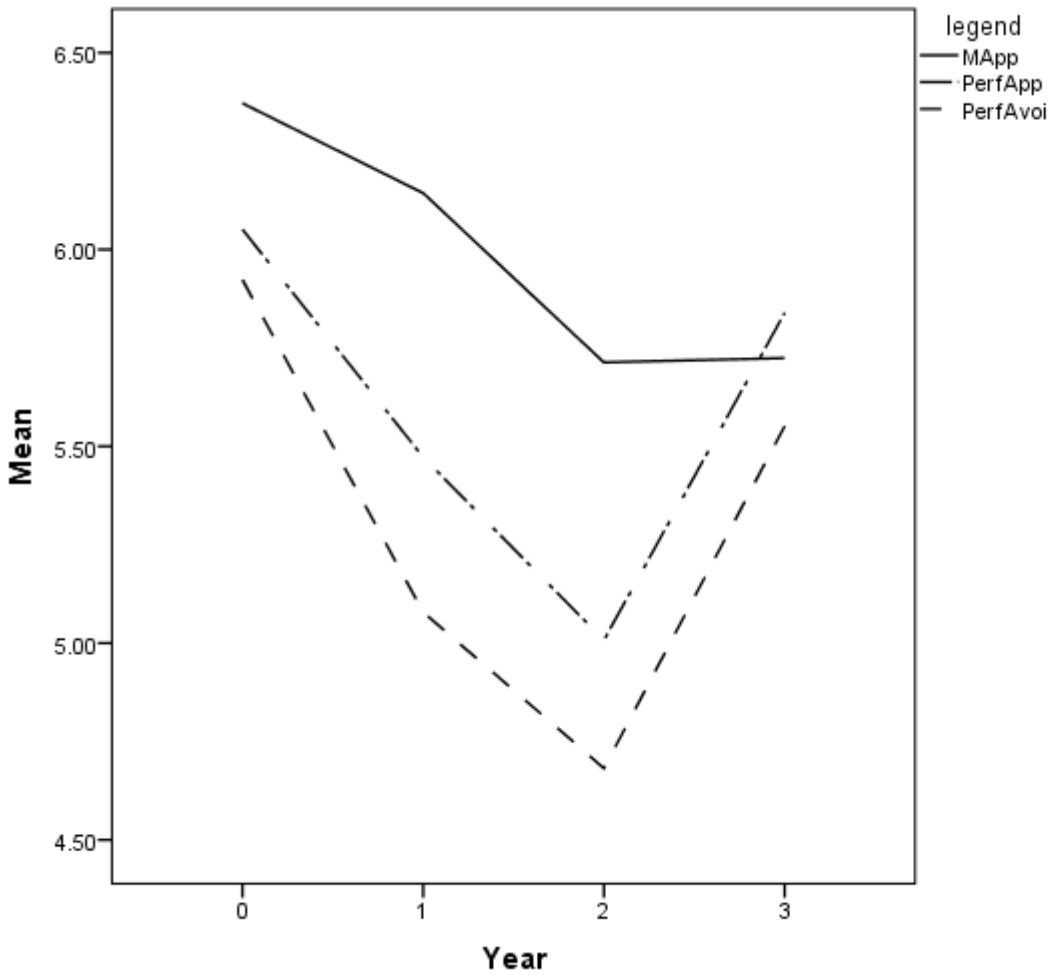


Figure 23. Changes in mastery approach, performance approach, and performance avoidance goals by year of study.

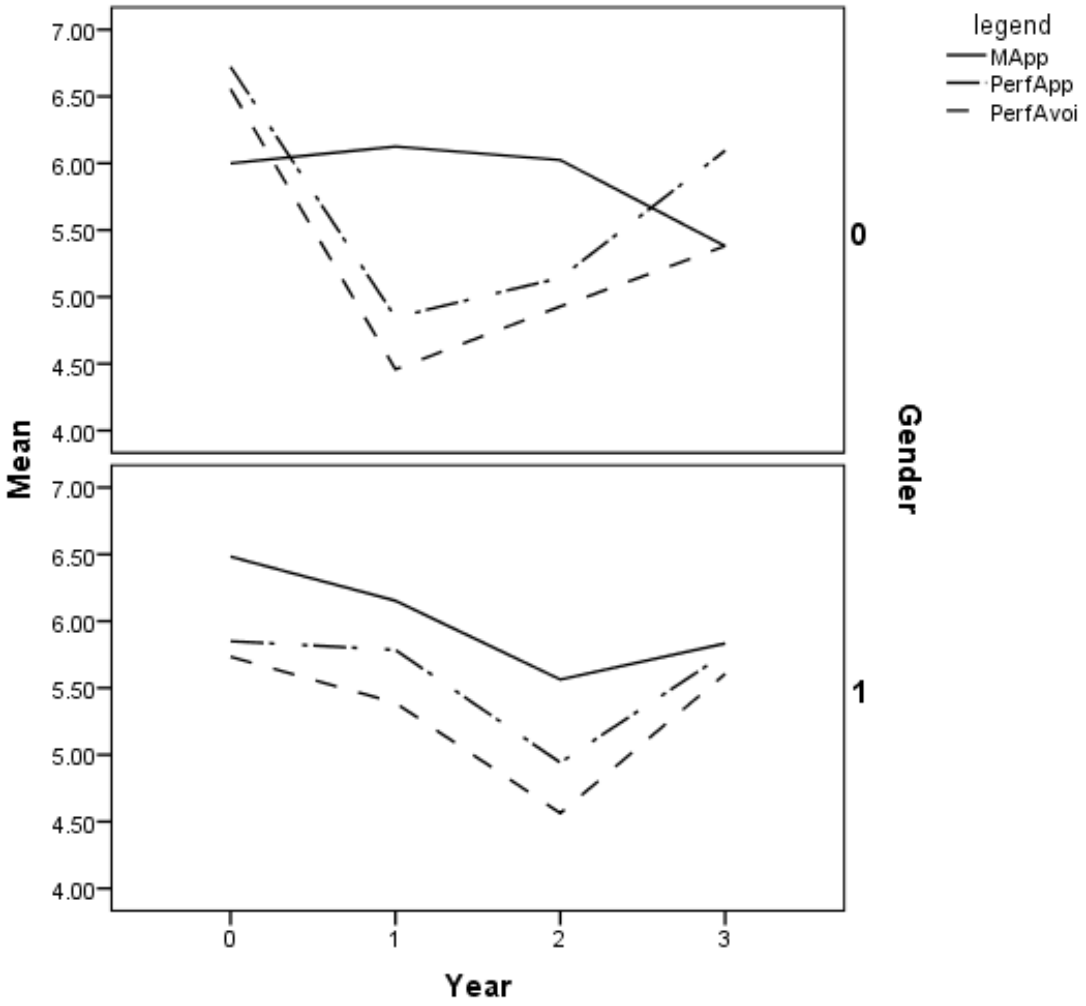


Figure 24. Changes in mastery approach, performance approach, and performance avoidance goals by year of study and by gender.

Gender: 0 = males, 1 = females

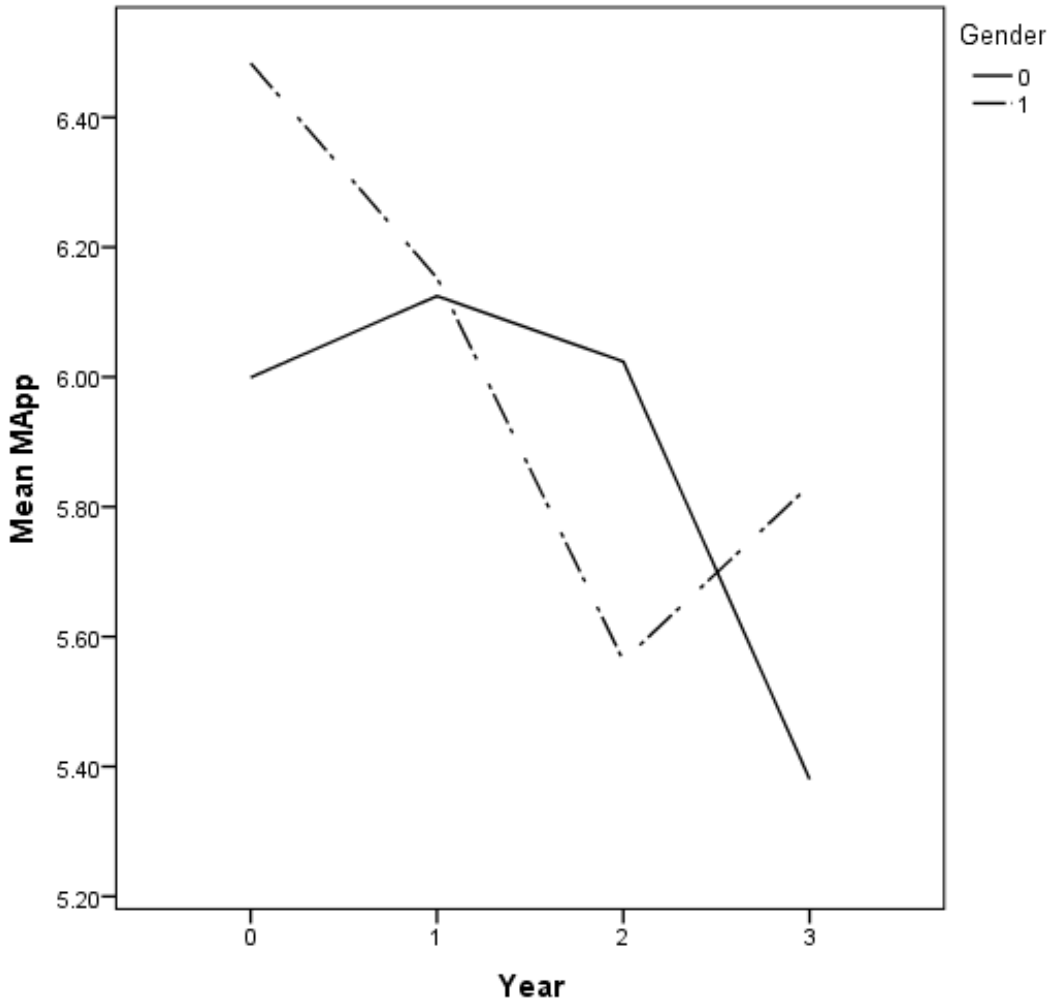


Figure 25. Changes in mastery approach goals by year of study and by gender.

Gender: 0 = males, 1 = females

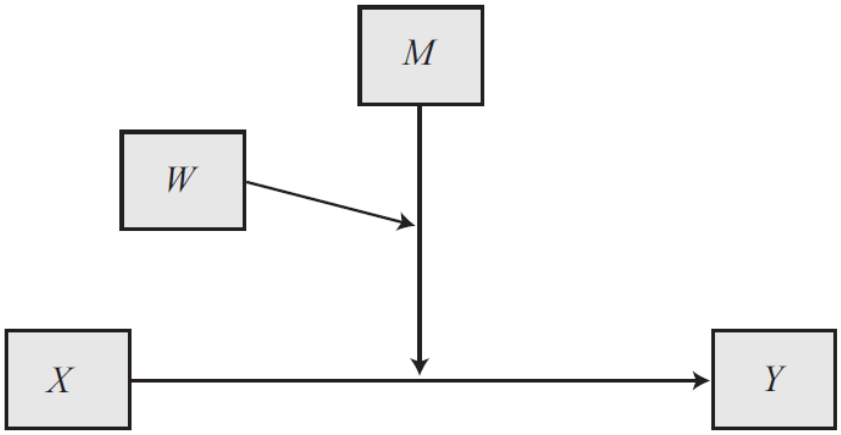


Figure 26. Conceptual template of Model 3. Hayes (2018, p. 585)

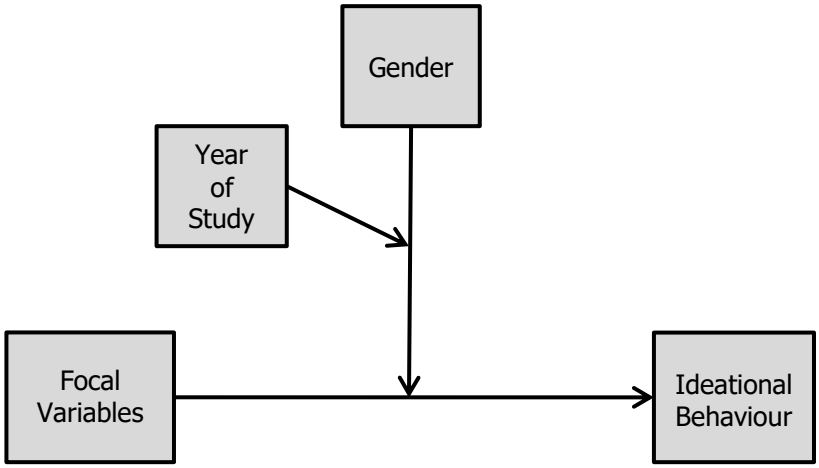


Figure 27. Model 3 in the context of the present study.

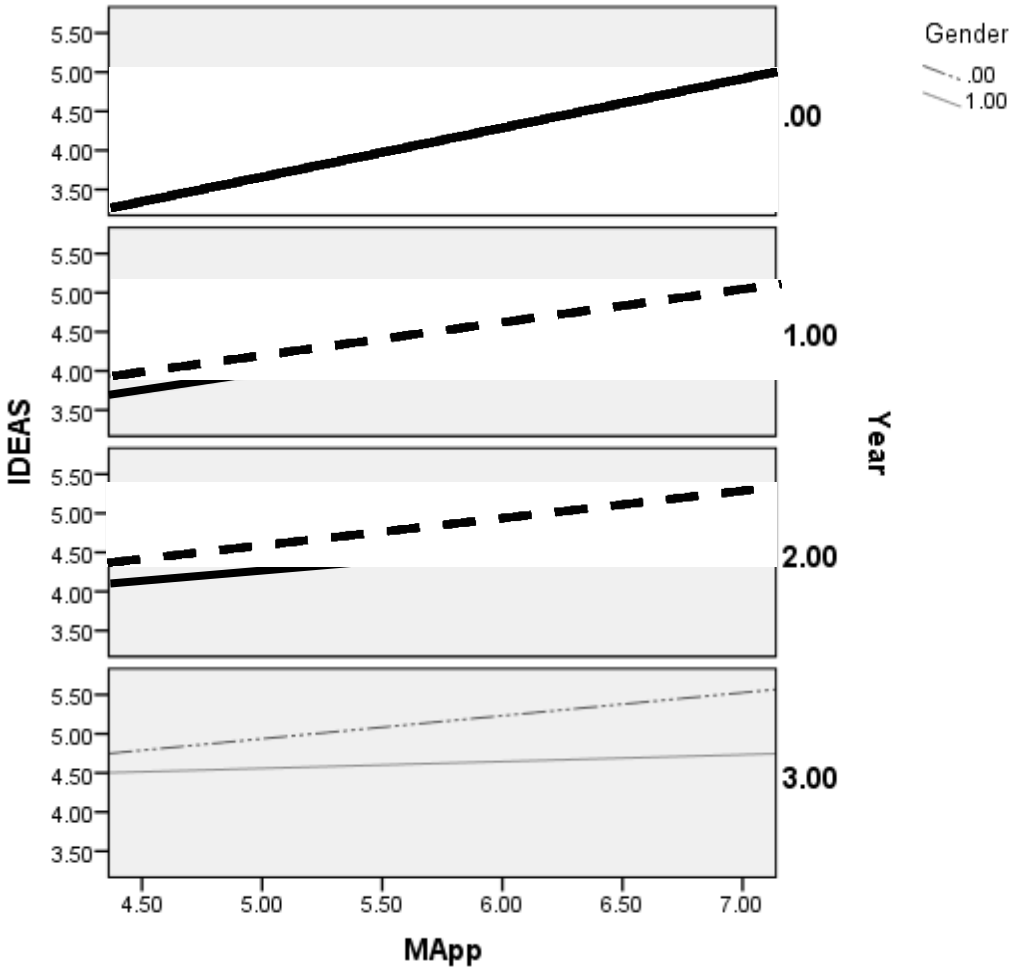


Figure 28. The conditional effect of mastery approach goals on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F0**, F1**, F2*, M1*, and M2*)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

Gender: 0 = male, 1= female

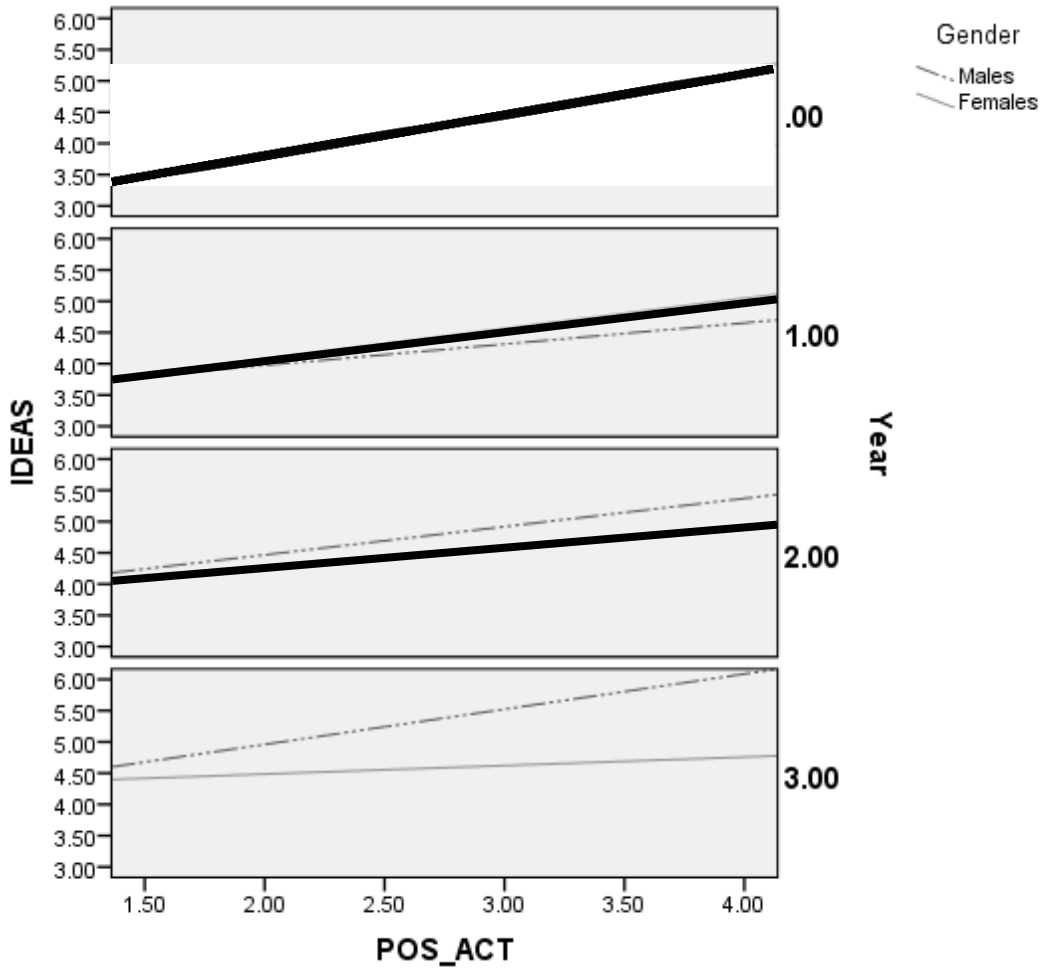


Figure 29. The conditional effect of positive activating emotions on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects (**F0**, F1**, F2**†) are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

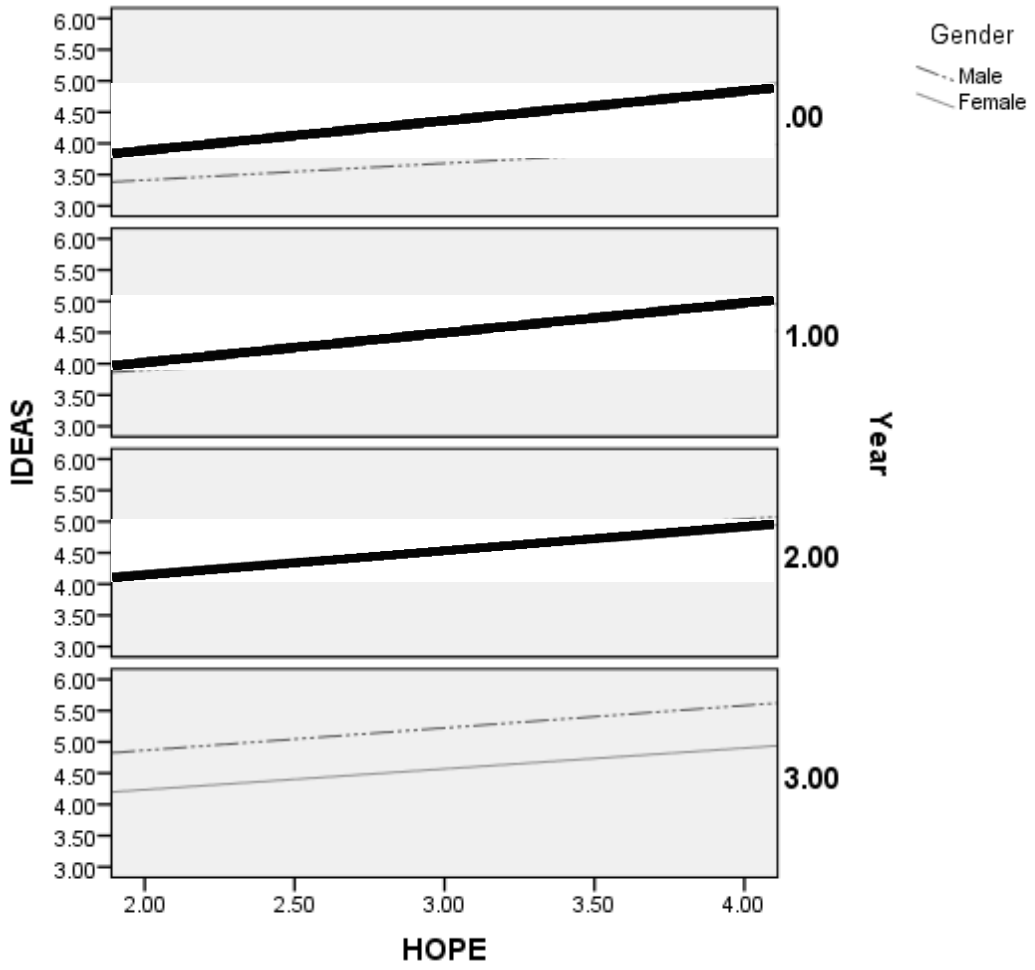


Figure 30. The conditional effect of hope on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F0*, F1**, F2**)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

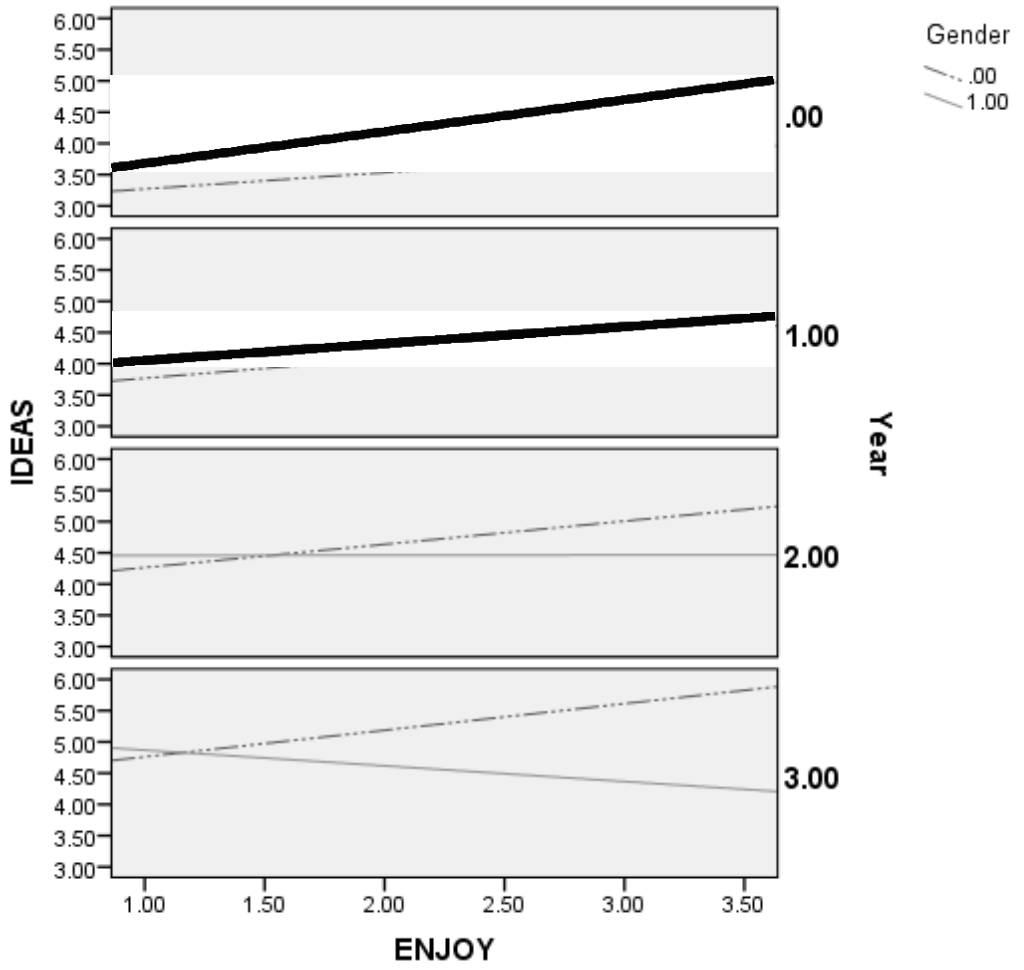


Figure 31. The conditional effect of enjoyment on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F0*, F1*)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

Gender: 0 = male, 1= female

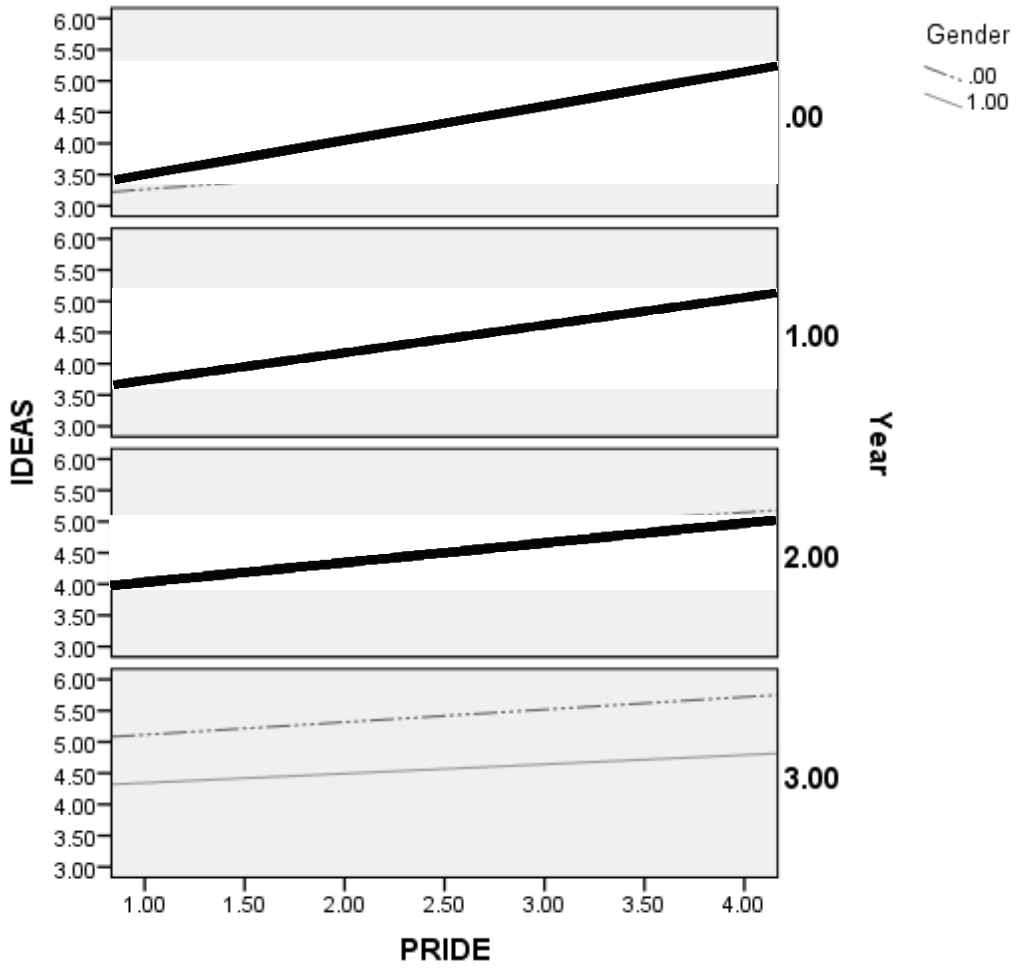


Figure 32. The conditional effect of pride on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F0*, F1**, F2 *)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

Gender: 0 = male, 1= female

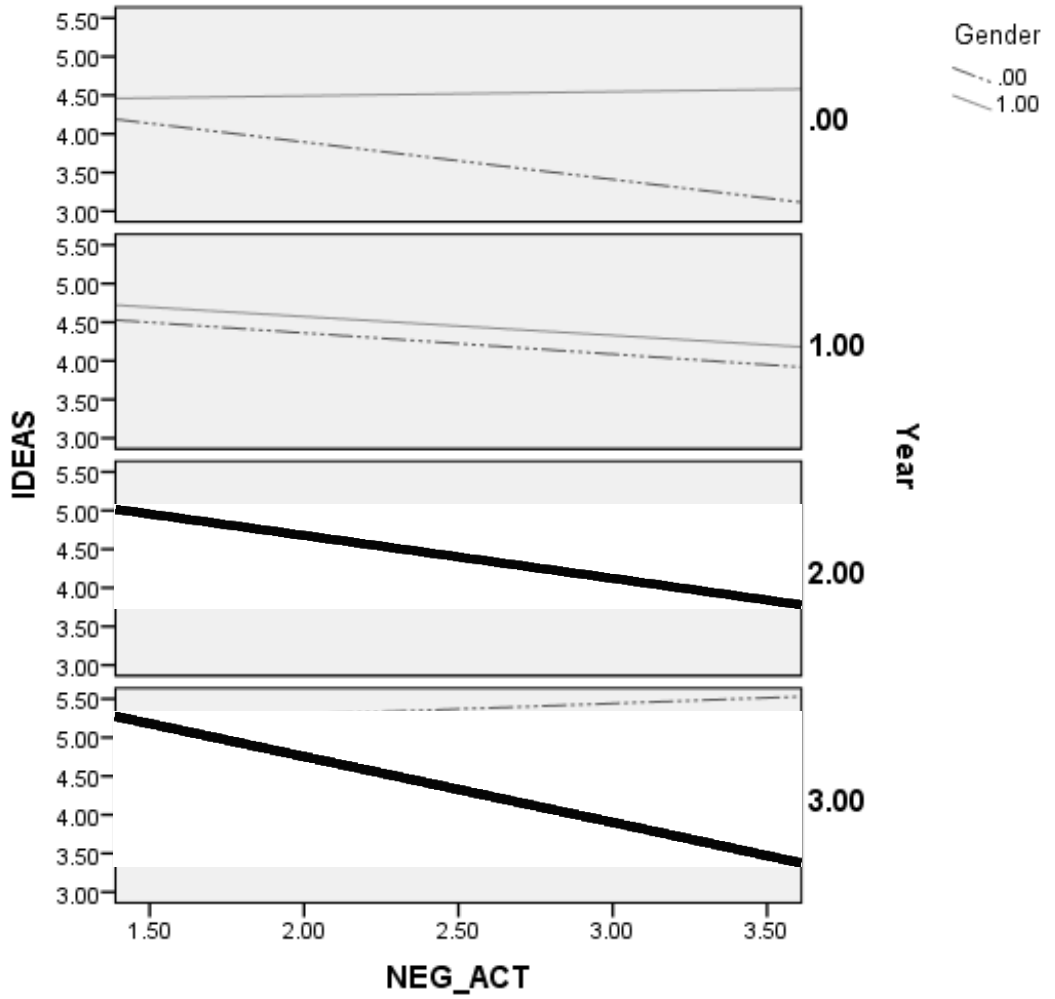


Figure 33. The conditional effect of aggregate negative activating emotions on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F2**, F3**)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

Gender: 0 = male, 1= female

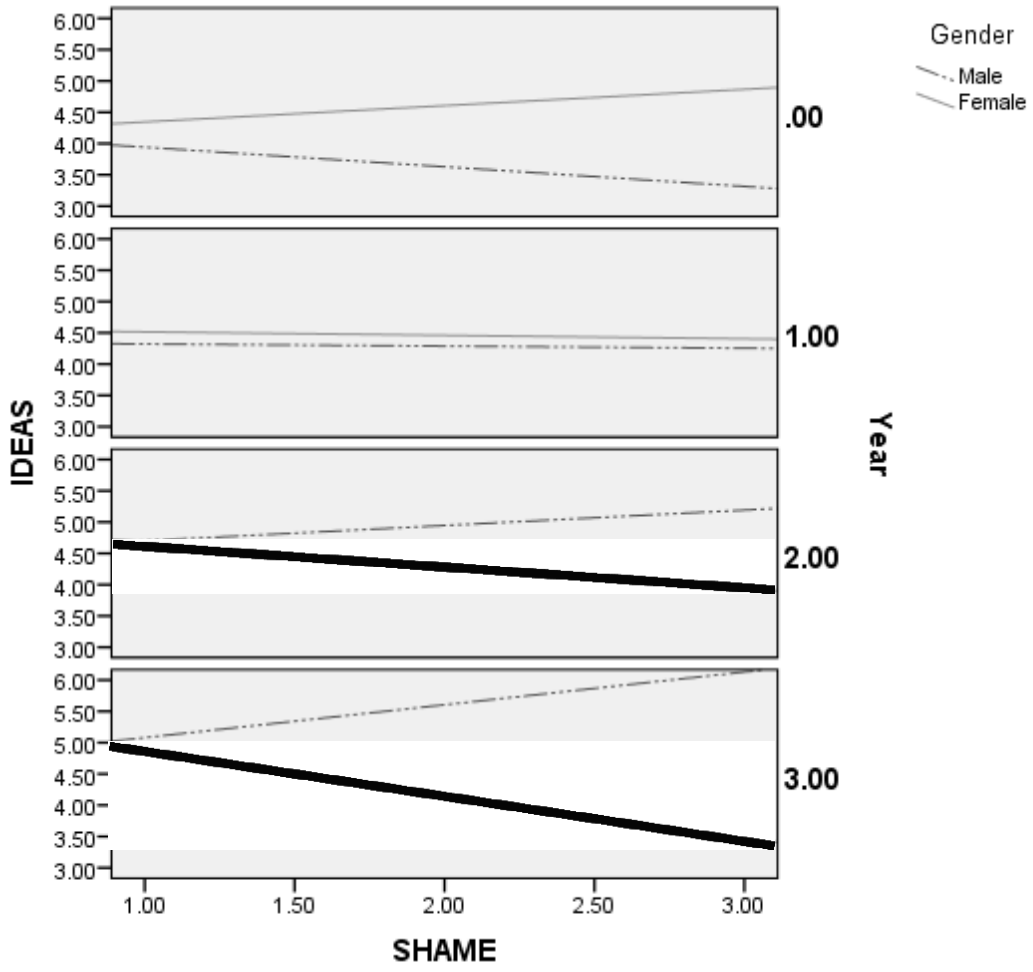


Figure 34. The conditional effect of shame on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F2**, F3**)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

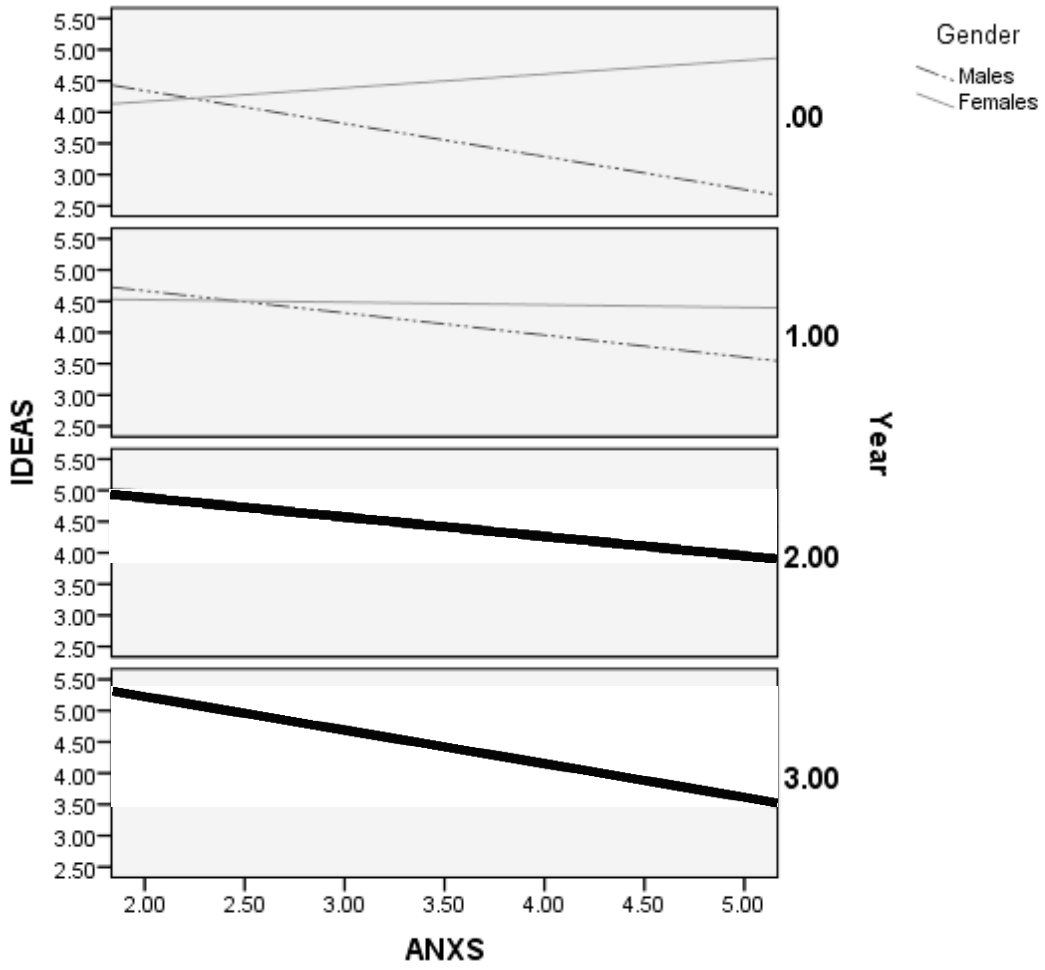


Figure 35. The conditional effect of anxiety on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F2*, F3**)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

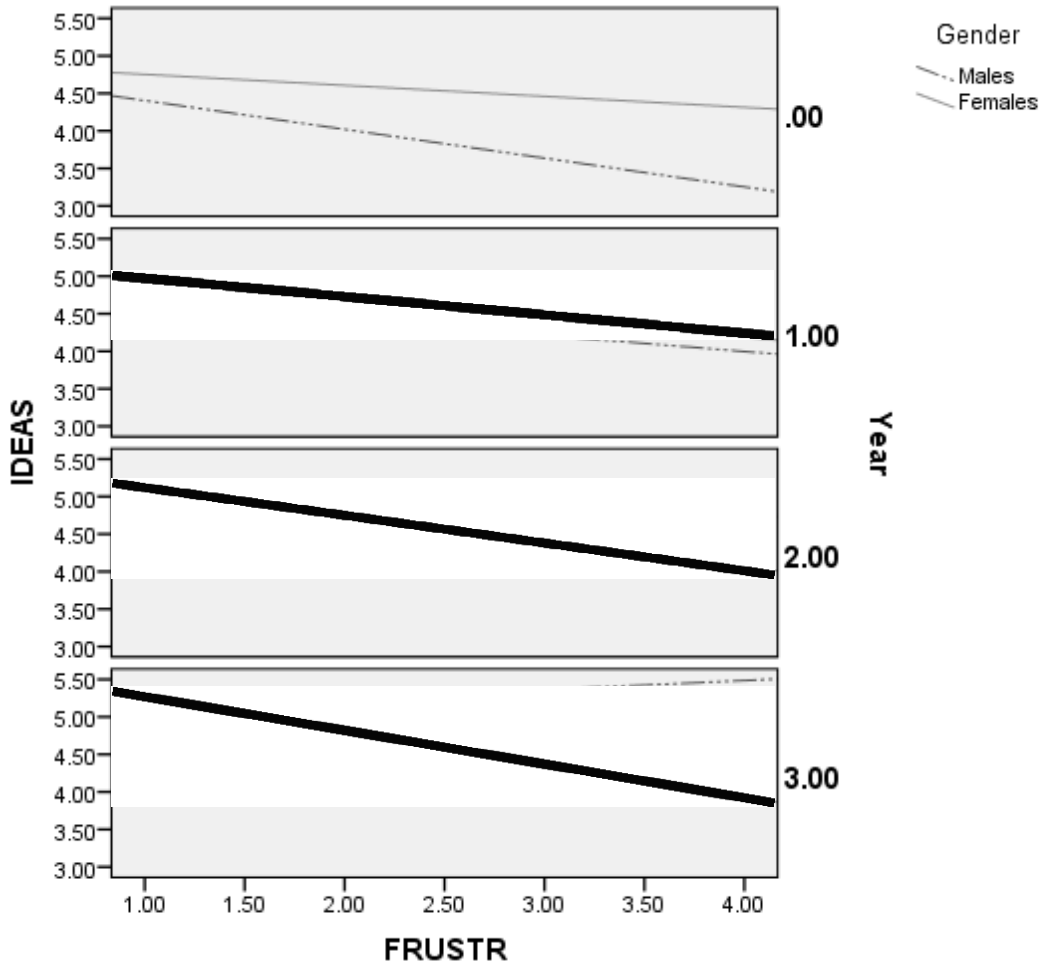


Figure 36. The conditional effect of frustration on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F1*, F2*, F3†)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

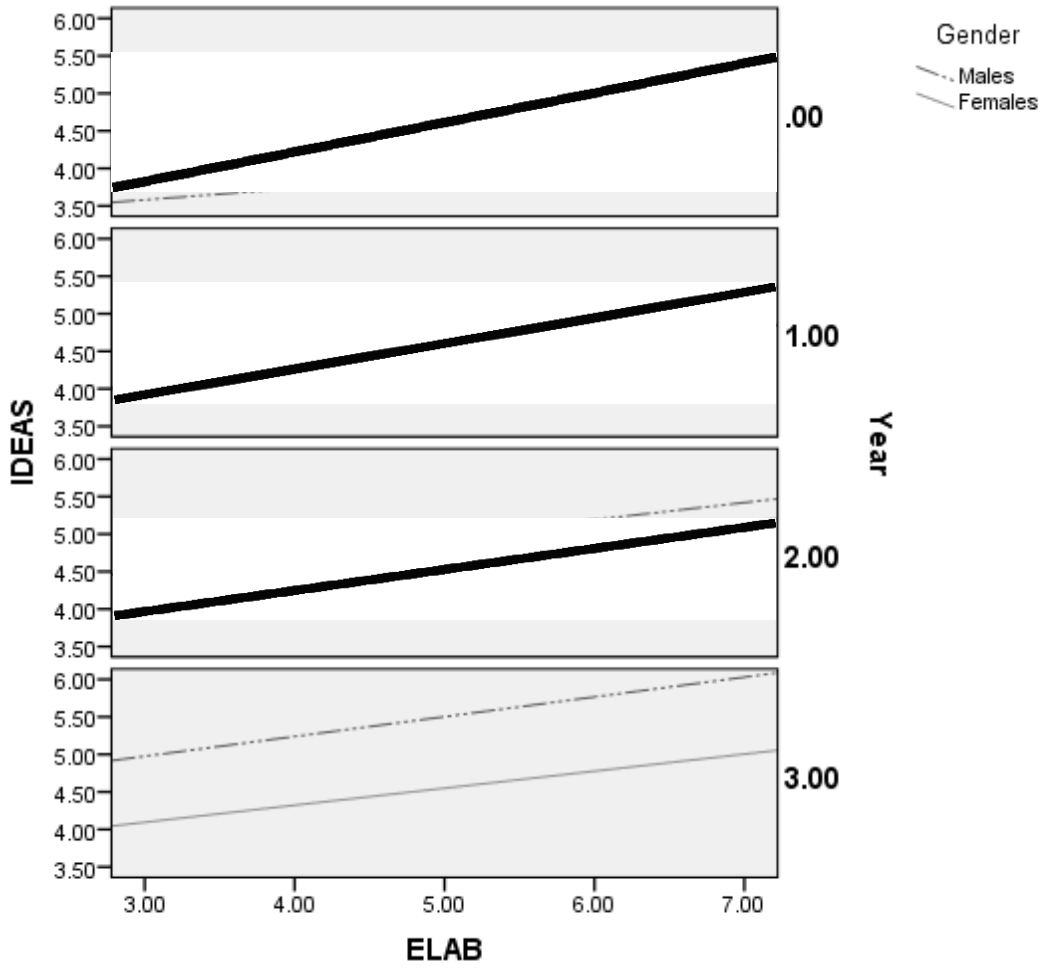


Figure 37. The conditional effect of elaboration on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F0*, F1**, F2*)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1

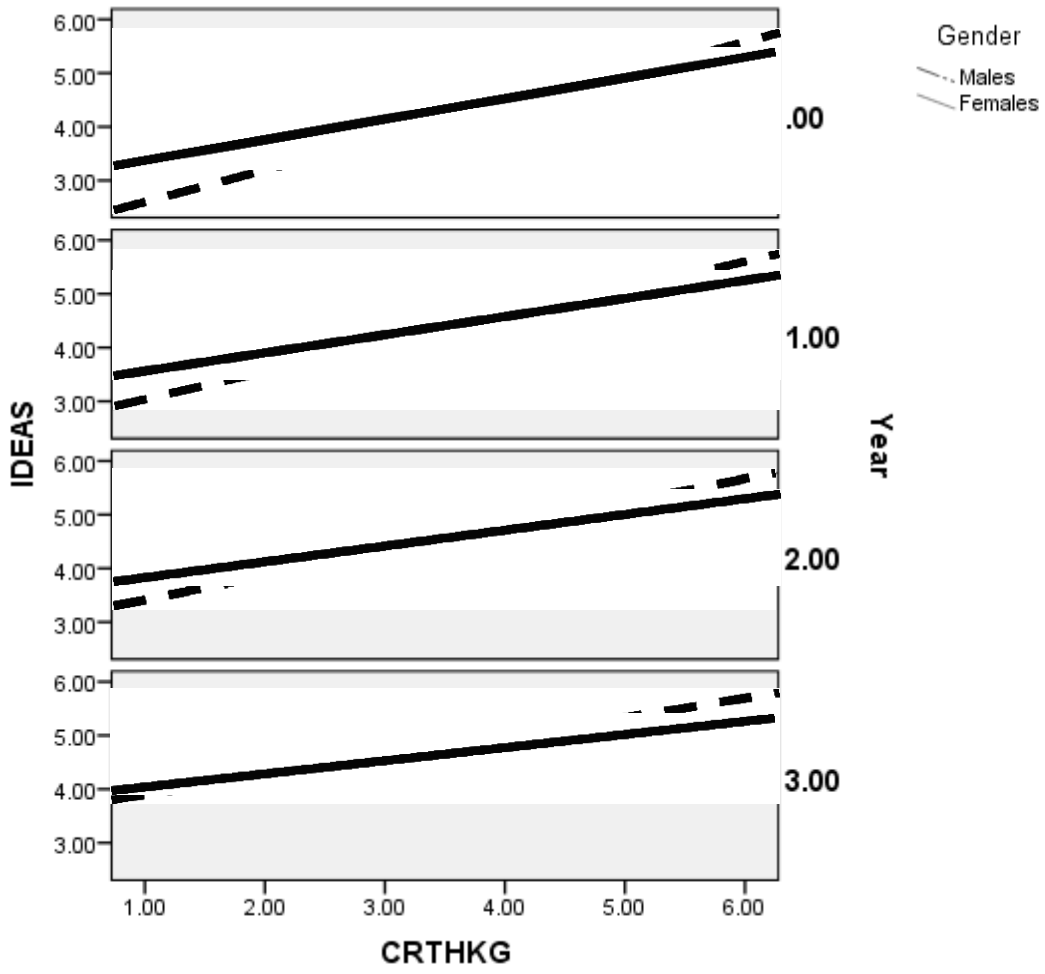
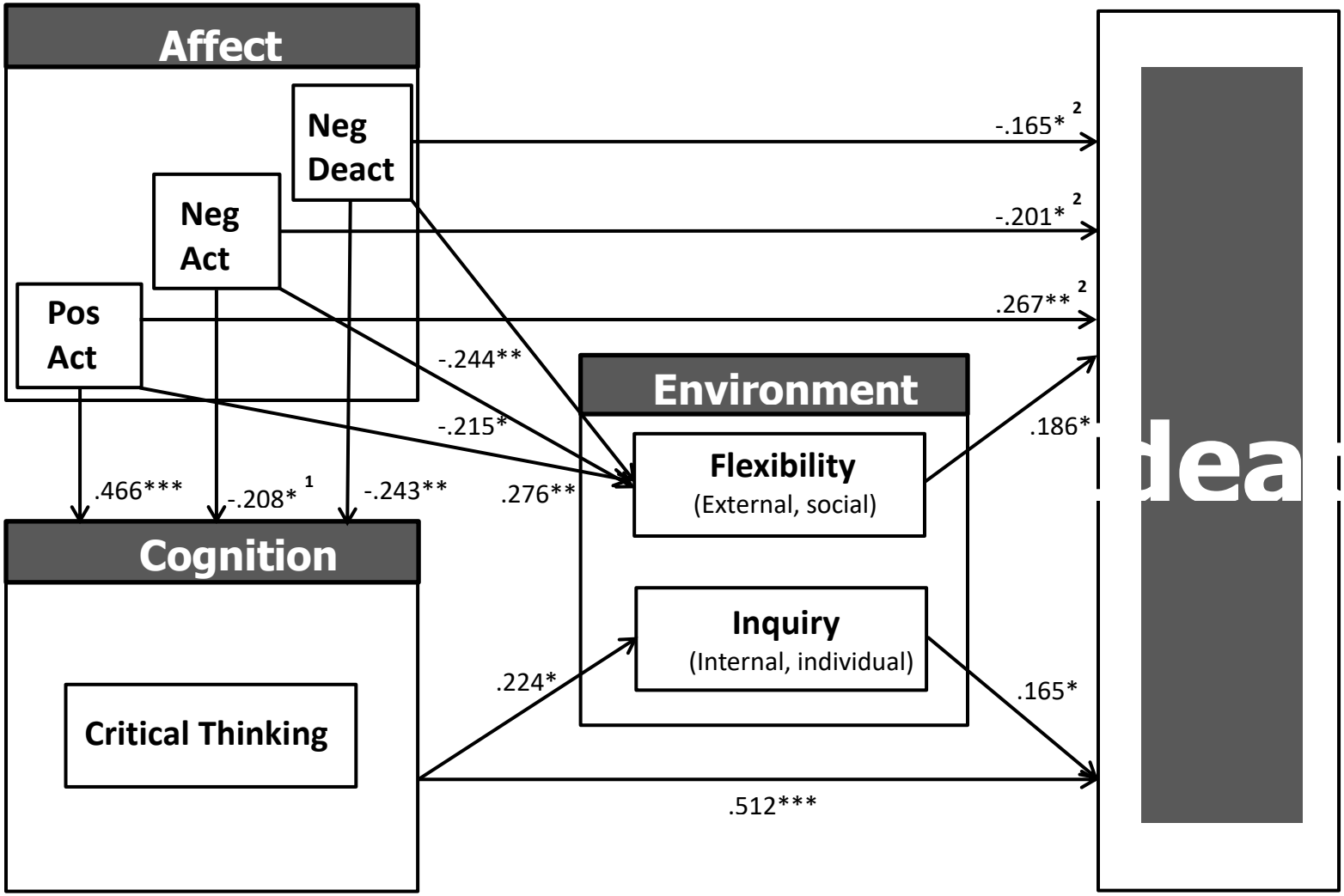


Figure 38. The conditional effect of critical thinking on ideational behaviour as a function of gender and year of study from a moderated moderation model. Significant effects **(F0***, F1***, F2***, F3†, M0**, M1***, M2***, M3†)** are highlighted with thicker lines.

* < .05 , ** < .01, *** < .001, † approaching significance < .1



* $p < .05$, ** $p < .01$, *** $p < .001$, † approaching significance at $p < .1$

1 Frustration is the only sig of the negative activating emotions. The other two affect measures are aggregate variables

2 Direct correlations between affect and ideation are 1-tailed, all others are 2-tailed

Figure 39. Proposed ACE model (affect, cognition, and environment) of ideation with bivariate Pearson correlations.

Appendix B

Self-report instruments used in the present study.

Instrument name; author	**Instructions to participants; Scale**	**Questionnaire items*** * Please note that items were not presented in order to participants when authors recommended otherwise
Runco Ideational Behaviour Scale (RIBS); Runco, Plucker, & Lim, 2001	"In the context of your program of study at McGill, please rate the following items based on how you feel you behave in relation to new ideas. Your rating should be on a 7-point scale where 1= not at all true of me to 7= very true of me." Likert, 1-7	1. I have many wild ideas. 2. I think about ideas more often than most people. 3. I often get excited by my own new ideas. 4. I come up with a lot of ideas or solutions to problems. 5. I come up with an idea or solution other people have never thought of. 6. I like to play around with ideas for the fun of it. 7. It is important to be able to think of bizarre and wild possibilities. 8. I would rate myself highly in being able to come up with ideas. 9. I have always been an active thinker—I have lots of ideas. 10. I enjoy having leeway in the things I do and room to make up my own mind. 11. I would take a college course which was based on original ideas. 12. I am able to think about things intensely for many hours. 13. I try to exercise my mind by thinking things through. 14. I am able to think up answers to problems that haven't already been figured out. 15. I am good at combining ideas in ways that others have not tried. 16. Friends ask me to help them think of ideas and solutions. 17. I have ideas about new inventions or about how to improve things.
Achievement Emotions Adjective List (AEAL)	"We are interested in the emotions you experience when studying for the course you selected at the beginning of the study. Please rate how intensely	Bored, anxious, hopeful, resigned, frustrated, dull, worried, happy, irritated, monotonous, excited, disappointed, nervous, joyful, proud, dissatisfied, ashamed, optimistic, angry, confident,

Raccanello, Brondino, Crane, & Pasini, 2016	you feel the following emotions while studying for this course." Likert, 1-5 1. Not at all 2. Very little 3. Moderate 4. Strong 5. Very strong	humiliated, discontent, hopeless, furious, masterful, embarrassed, annoyed, self-satisfied, helpless, mad
Achievement Goal Orientation Scale (AGO); Elliot & Murayama, 2009	"Please keep in mind the course you chose when answering the following questions. We are interested in the goals you have for the course you selected. Please indicate how true the following statements are of you." Likert, 1-7 1 Not at all true -7 Very true	***Mastery Approach:*** 1. My aim is to completely master the material presented in class. 2. My goal is to learn as much as possible. 3. I am striving to understand the content as thoroughly as possible. ***Performance Approach:*** 1. My goal is to perform better than the other students. 2. I am striving to do well compared to other students. 3. My aim is to perform well relative to other students. ***Mastery Avoidance:*** 1. My aim is to avoid learning less than I possibly could. 2. My goal is to avoid learning less than it is possible to learn. 3. I am striving to avoid an incomplete understanding of the course material. ***Performance Avoidance:*** 1. I am striving to avoid performing worse than others. 2. My aim is to avoid doing worse than other students. 3. My goal is to avoid performing poorly compared to others.

Motivated Strategies for Learning Questionnaire (MSLQ); Pintrich, Smith, Garcia, & McKeachie, 1991	"The following questions ask about your learning strategies and study skills for this class. **There are no right or wrong answers. Answer the questions about how you study in this class as accurately as possible.** If you think the statement is very true of you, select (7); if a statement is not at all true of you, select (1). If the statement is more or less true of you, find the number between (1) and (7) that best describes you" Likert, 1-7	***Rehearsal:*** 1. When I study for this class, I practice saying the material to myself over and over. 2. When studying for this class, I read my class notes and the course readings over and over again. 3. I memorize key words to remind me of important concepts in this class. 4. I make lists of important terms for this course and memorize the lists. ***Elaboration:*** 1. When I study for this class, I pull together information from different sources, such as lectures, readings, and discussions. 2. I try to relate ideas in this subject to those in other courses whenever possible. 3. When reading for this class, I try to relate the material to what I already know. 4. When I study for this course, I write brief summaries of the main ideas from the readings and the concepts from the lectures. 5. I try to understand the material in this class by making connections between the readings and the concepts from the lectures. 6. I try to apply ideas from course readings in other class activities such as lecture and discussion. ***Critical thinking:*** 1. I often find myself questioning things I hear or read in this course to decide if I find them convincing. 2. When a theory, interpretation, or conclusion is presented in class or in the readings, I try to decide if there is good supporting evidence. 3. I treat the course material as a starting point and try to develop my own ideas about it.

	4. I try to play around with ideas of my own related to what I am learning in this course. 5. Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.

Chapter 5:

General Conclusions

Amid ubiquitous calls for more creative and adaptable university graduates, there is a need to examine in greater detail the factors and mechanisms that foster applied creative thinking--the kind of creative thinking that is based on acquired knowledge and can lead to innovation in a domain. Although grades and performance outcomes have traditionally been a primary focus for many faculty members, leaders, and policy makers in higher education, the discussion needs to be broadened to also include approaches that allow university students to build their knowledge in ways that make it accessible and adaptive for creative, innovative applications. Based on the relative view of expertise that is built along a continuum of learning, rather than existing as an absolute state (Chi, 2006), we explored elements that influence whether acquired expertise is likely to remain routine or become adaptive (Hatano & Inagaki, 1986).

The present investigation aimed to bridge the research traditions in educational psychology relating to achievement emotions, goals, and learning strategies on one hand, and creative thinking on the other. To that end, we explored relationships between affect, goals, learning strategies, and ideation in STEM students. We further examined whether gender or year of study impacted the patterns and mechanisms through which the constructs influence each other, and finally asked learners about their perceptions of factors supporting or suppressing creative thinking within their domain.

Four research questions were asked, and the first simply explored correlations between the constructs to determine whether findings and relationships suggested in the broader creativity literature also hold true regarding ideation in our STEM sample. Based on our results that mastery approach goals, positive emotions, and deep strategies support ideation, and negative

emotions generally suppress it, we continued with research question two which focused on the roles of possible mediating variables. Findings suggested that achievement emotions and goals can influence each other in recursive ways, and that hope and mastery approach goals were important on many levels in supporting ideation. The third question explored gender and year of study differences, and we found new evidence that positive emotions are particularly relevant for ideation early in the program for female students. Negative emotions tend to take on increasing importance (as far as their inverse relationship with ideation) later in the program for females. Critical thinking was revealed as having a significant positive relationship with ideation for both genders in all years of study. The fourth and final question asked learners for their own perceptions about factors influencing their creativity within their program, and responses revealed that flexible inquiry settings were perceived to support whereas rigid and highly evaluatory settings were perceived to suppress ideation.

Our findings were synthesized into a proposed new ACE (affect, cognition, and environment) model for ideation, providing a suggested framework for how learner-specific factors interact with the learning environment to support applied creative thinking.

Implications for Teaching and Learning

The results from this dissertation provide evidence of the significant influences of achievement emotions and goals, as well as learning strategies, on creative ideation. The dissertation further delineates the kinds of learning environments that are perceived to support creativity, and conversely outlines the typical characteristics of undergraduate STEM education that are seen as barriers to creativity. Based on the findings, faculty who are interested in supporting creative thinking in the domain--in addition to pure content knowledge--can design the learning experience to be flexible, calling on their students to be actively involved through

inquiry. Numerous possible interventions for both faculty and learners were outlined in terms of workshops, professional development, counseling, advising, peer support groups, seminars, and mentorship. Overall, the findings are a reminder that educational research should consider creativity and innovation skills as an educational outcome worthy of research, alongside the traditional focus on grades as a measure of achievement.

Contributions to Science

This dissertation explored how existing constructs in educational psychology (achievement goals, achievement emotions, learning strategies) relate to ideational behaviour (creative thinking) in undergraduate STEM studies. As such, it extends the body of literature in each of the four areas mentioned and advances our understanding of how to help learners build adaptive (versus routine) expertise. Despite limitations that reduce the generalizability of our findings (discussed in a previous section), several interesting contributions to science emerge from this dissertation. Firstly, no previous review of the literature has compared the bodies of literature on adaptive expertise and creative thinking as a way of framing applied creative thinking as an educational outcome. The present work further included a first review of how theories of achievement emotions and goals could be expected to support applied creative thinking.

The empirical work in the present dissertation contributes original knowledge by providing support for the validity of using the Runco Ideational Behaviour Scale (Runco, Plucker, & Lim, 2001) in STEM settings. It also adds to the literature on creative thinking and goals among STEM students by delineating the positive effects of mastery achievement goals on creative thinking, while finding no evidence of a relationship between performance goals and ideation--raising the possibility of performance goals being more closely linked with routine

expertise while mastery goals support adaptive expertise. Our secondary analyses further revealed that traditional measures of academic achievement (grades) are not reliable measures for the potential for creative thinking or innovation. This finding is an interesting contribution since although grades and creative thinking share many supportive factors (positive emotions, mastery goals, and deep learning strategies) the two measures were not correlated and seem to tap into other, as yet unexplored, variables.

Next, our findings broaden our understanding of how achievement emotions in the stressful and competitive STEM field can affect creative thinking. While there already exists a general consensus in the creativity field that positive emotions support creativity and negative emotions usually detract from it, prior to this dissertation not much work had been done examining the effects of achievement emotions on creative thinking within the specific context of STEM programs. The findings in the present study afford us a better understanding of the discrete positive and negative emotions that support creative thinking and conversely, those that suppress it. A major new finding is the differential impact of specific positive versus negative achievement emotions on ideation among female students, and how those impacts may change through the duration of the program, thus contributing to the important (and growing) literature on gender differences in STEM fields. Additionally, in the domain of achievement emotions, the present research has allowed us to learn more about the critical role of hope in creative thinking.

Furthermore, we have provided additional evidence to extend and reinforce the literature on the links between creative (divergent) and critical (convergent) thinking. This evidence comes from two distinct sources within our mixed methods study design: a) our quantitative finding that critical thinking was significantly and positively related to ideation for all students in

all years of study, and b) the analysis of spontaneous student responses in the qualitative section that allowed us to link creative thinking (ideation) with critical thinking (as a deep learning strategy). Participants who identified inquiry in various forms as supportive of creative thinking within their program also had significantly higher scores on measures of ideation and critical thinking.

Finally, quantitative analysis of the qualitative findings of the present study allowed us to propose a new theoretical model (Chapter 4, Figure 39) that connects two of the constructs under study (achievement emotions and learning strategies) to creative thinking through two distinct and separate features of the learning environment (flexibility and inquiry). The dissertation thus integrates some of the present theories in the field and offers a more holistic lens for viewing how specific constructs in educational psychology interact to influence creative thinking.

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