

An Examination of the Motivational Determinants of Academic Achievement Through a Dual-  
Process Perspective: The Case of the Integrative Process in Self-Determination Theory

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## General Abstract

Self-determination theory posits, through an organismic perspective of human development, that all humans are inherently curious to assimilate new information and all naturally behave for their psychological growth. Central to this natural tendency is the determinant role of the social environment in maintaining or hindering this inherent function of the *self*. Humans thus develop, through their life, motivational patterns that can be characterized as being either internalized or not. For SDT, this natural process of integrating one's motives, values, and belief in the *self* can be observed through the internalization continuum of self-determination. The self-determination continuum describes the behavioral regulation of individuals and can be broke down in two large dimensions: autonomous vs controlled motivation. When applied to the educational context, the theory would say that students who invest themselves in their academic activities for more internalized and autonomous reasons will be more likely to experience positive educational outcomes (e.g., achievement, perseverance, deeper learning, well-being, and lower dropout intentions). However, recent meta-analyses revealed a small positive association between explicit self-evaluation of autonomous motivation (AM) and academic achievement ( $r \approx .177$ ; Cerasoli, Nicklin, & Ford, 2014; Richardson, Abraham, & Bond, 2012; Taylor et al., 2014). In those studies, the internalization dimensions have been mainly measured through self-report methodology, and even if those measures are valid and reliable they should only be interpreted as the accessible declared self-knowledge one individual has about his own motivational dispositions. As such, this thesis embarks on the premise that those explicit self-evaluations mainly tap into the reflective/conscious side on the human brain and that taking a dual-process perspective over the integration process could alleviate our understanding of human motivation. This thesis also acknowledges, as in most dual-

process theories, the determinant role of working memory capacity (WMC) in the interplay between the explicit/reflective/controlled and implicit/impulsive/automatic processes. The ability to control and direct attention, as measured by WMC, is an important individual differences that can explain why some dual-process effect might be working for some individuals but not for the other (Barrett, Tugade, & Engle, 2004). In this dissertation, my hypotheses were anchored in SDT and inspired by the implicit social cognition approach. Accordingly, I aimed at exploring the internalization process of university students in the educational context. To that end, I proposed three original studies described in three different articles. In *Article 1*, I first developed a lexical decision task of implicit AM based on the preliminary work of Burton, Lydon, D'Alessandro, and Koestner (2006). I hypothesized that explicit and implicit AM should interact in a synergistic manner in the prediction of subsequent academic achievement. Moreover, this synergistic effect should depend on the WMC of the students, as the integrative process is likely to be cognitively challenging. A sample of 272 university students were recruited and participated in a lab study (INSPIRE lab). Results of moderated regression analysis revealed that explicit AM was a significant predictor of semester GPA, but only for students with high level of implicit AM, and average to high levels of WMC. This prediction was double the size of past meta-analyses estimate ( $\beta = .445$ ), thus demonstrating that incorporating a dual-process perspective of AM enable a more precise account of internalization. In *Article 2*, I extended the lexical decision task with additional stimuli, replicated the effect of *Article 1* with Bayesian estimation and tested a reciprocal hypothesis between academic AM and achievement. I hypothesized that the past academic achievements of students are likely to influence the development of AM for university studies. Again in the INSPIRE lab, 258 undergraduate students participated in this study. Results of a mediational model revealed a significant

reciprocal effect of past academic achievement, explicit AM and subsequent academic achievement at university. Moreover, results from *study 1* were included as informative prior in the Bayesian analysis of *study 2*. A moderated-moderation mediation model was tested and revealed a significant synergistic effect between explicit and implicit AM, thus replicating the effect found in *study 1*. This effect was also moderated by WMC, once again replicating the results of *study 1*, by demonstrating that sufficient WMC is needed for the synergistic effect of AM to be operant. Lastly, in *Article 3* I developed an in-lab learning situation to evaluate if dispositions of AM could be activated outside of the students' awareness and enable explicitly declared AM to be predictive of subsequent learning performance (math and verbal components). The beneficial effect of explicit AM on subsequent learning performance was only observed for the students who were subliminally primed with AM words. This experimental study thus stressed on the importance of the environment in shaping individuals' behavior, even when that environment is unconsciously perceived. The findings of this experimental study were thus repositioned in a *person x environment* interpretation, as opposed to *study 1* and *2* which were framed in a *person x person* interpretation. Of particular interest, contrary to *studies 1* and *2*, only students with low to average levels of WMC seemed to benefit from the situational priming of AM words. Students with lower levels of WMC can thus benefit from implicit situational cues of AM, as the results demonstrate that it can activate the synergistic effect of AM and ultimately help them perform better on the exam. Overall, this thesis has provided empirical evidence for adopting a dual-process perspective of AM combining motivation and cognitive research in the prediction of academic achievement.

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### Statement of Co-Authorship

All of the articles presented in this dissertation were prepared in collaboration with my thesis advisor, Dr. Patrick Gaudreau, who contributed as the second author in all of them. *Article 1*, entitled “Working Memory Moderates the Effect of the Integrative Process of Implicit and explicit Autonomous Motivation on Academic Achievement” was published in the *British Journal of Psychology*. *Article 2*, entitled “The Relationship Between Autonomous Motivation and Academic Achievement Goes Both Ways and Depends on Implicit Motivation and Working Memory Capacity” was submitted to *Learning and Individual differences*, and is currently under review. This second article was prepared with the collaboration of Laurence Boileau (Ph.D. student at University of Ottawa). Her role was to review the literature of implicit motivation in SDT, assist me during the data collection in the INSPIRE lab, and help during the revision of the final manuscript. *Article 3*, entitled “Subliminal Priming of Autonomous Motivation Enables Explicit Autonomous Motivation to Predict Examination Performance: A Dual-Process Perspective of Self-Determination Theory” has not been submitted to any journal yet. This third article was also prepared with the collaboration of Laurence Boileau. Her role was to assist me in the development of the learning situation and experimental procedures.

In all of the thesis articles, I was the first author. My role consisted of developing the studies procedures, reviewing the literature, writing the ethical applications, collecting, managing, cleaning and analyzing the data, write the manuscripts, and revise them for publication. For all of those articles, Dr. Patrick Gaudreau, offered me guidance in all of the aforementioned task. For all of the articles, I received extensive feedback that was added in the final version of each manuscript.

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## CHAPTER 1: General Introduction

If someone would interrogate students or any actors of the educational environment about the key ingredients of academic success, one of their answers would probably be the motivation of students. Many educational institutions have identified the motivation of students as an important determinant of academic success (CACUSS, 2013; CEA & OISE, 2011; Hidi & Harackiewicz, 2000) and a potential target for interventions (Lazowski & Hulleman, 2016). Hence, a common belief among actors of the educational environment is that students need to be motivated to reach satisfactory academic achievement. Moreover, it is safe to assume that people view motivation and achievement as *strongly and positively* related to one another. Empirical and theoretical investigations of the association between academic motivation and achievement have been at the forefront of educational research for over 50 years (Wentzel & Wigfield, 2009). Regardless of the theoretical framework (i.e., attributional theory, self-efficacy theory, expectancy-value theory, achievement goal theory, self-worth theory, and self-determination theory) used to define motivation and its related constructs, the students' motivation have been found to be positively related with a myriad of positive educational outcomes, such as learning, persistence, engagement, well-being, and achievement (Lazowski & Hulleman, 2016; Wentzel & Wigfield, 2009). Furthermore, academic achievement is known to be an important determinant of well-being, school completion, future success, and mental and physical health (Guay, Ratelle, & Chanal, 2008; Richardson et al., 2012; Wentzel & Wigfield, 2009). Overall, the students' motivation is an important determinant of academic success and their general psychological growth as individuals in our societies.

Out of the different theoretical approaches, the Self-Determination Theory framework (SDT; Ryan & Deci, 2017) has been proven to be extremely useful to describe the antecedents

and consequences of academic motivation. SDT is a macro-theory of human development proposing that humans are active agents of their social world, and engage with curiosity with their surroundings with an inherent thirst for developing their efficiency, social affiliation, and autonomy. This fundamental assumption is referred in the theory as the *integrative process*, and is said to be essential for optimal social functioning and personal well-being (Ryan & Deci, 2017). Through the influence and interplay of the environment, behavioral regulations can be observed as being either internalized or not, as described by the internalization of continuum of self-determination. In the educational context, SDT would suggest that individuals with behavioral regulations that are more internalized/self-determined/autonomous (now referred as autonomous motivation; AM), are more likely to experience positive educational outcomes. However, recent meta-analyses have revealed a somewhat smaller than expected association between academic AM and achievement ( $r \approx .177$ ; Cerasoli et al., 2014; Richardson et al., 2012; Taylor et al., 2014). Many questions immediately arise from this observation: Why is having higher AM does not strongly translate in having higher academic achievement? Is this positive effect only present in some students and not in other students? Are students fully aware of their own motivational disposition when completing the self-report measures typically used to measure AM in the extant literature? As such, the main goal of this thesis was to elucidate for whom and under which conditions AM may facilitate higher academic achievement.

At the root of psychology is the assumption that all mental operations are not always being carried out in a conscious manner (Carpenter, 1874; James, 1890). This thesis main premise thus revolves around the idea that individuals do not all have access to the same extant to their own motivation dispositions and the underlying reasons that energized their behaviors. Educational psychology empirical investigations on the unconscious side of motivation are almost absent

(Weiner, 1990), but have recently gained some deserved attention from the SDT stream of research outside of the education literature (e.g., Burton et al., 2006; Levesque, Copeland, & Sutcliffe, 2008; Lévesque & Pelletier, 2003). Even though SDT assumes that individuals are active agents with freedom, will and autonomy, researchers have nonetheless acknowledged that behavioral regulation can be automatically triggered outside of individuals' awareness and activate some motivational processes (Levesque et al., 2008). Initial SDT propositions have been made on behavioral automaticity to account for this conscious vs unconscious differentiation (Deci & Ryan, 1980), but have not been thoroughly and empirically tested. Thus far, most SDT studies have examined internalization of one's behavioral regulation through self-report questionnaires, which assume that individuals have access to – and are fully aware of their own motivation disposition. I argue, in this thesis, that the assessment of motivation through self-report measures only assesses a *declarative form of self-knowledge* one has about his or her motivations. These self-reported measures, although reliable and valid, are offering little perspective to capture the extent to which such declarative knowledge has been fully processed and integrated within a broader network of mental representations about the *self* (Gawronski & Bodenhausen, 2006; Hofmann, Gawronski, Gschwendner, Le, & Schmitt, 2005).

On the basis of a dual-process perspective, tenants of the SDT approach have recently suggested that converging declarative/explicit/conscious and non-declarative/implicit/unconscious self-knowledge could be taken to characterize a more and integrated sense of autonomy (Weinstein, Przybylski, & Ryan, 2013). As such, the self-reported declarative knowledge of one's motivation should be taken as an indicator of a more reflective and integrated functioning *only when* it has been fully processed and integrated within a broader network of cognitively accessible mental representations about the self. In this thesis, I adopted a dual-

process perspective to have a more precise account of the *integrative process* of SDT. The basis of this dual-process perspective is to acknowledge that sometime AM can be mainly guided by a reflective/explicit/controlled process or an impulsive/implicit/automatic process (Strack & Deutsch, 2004). The dual-process perspective that I am proposing also acknowledges that individual differences in the ability to control/direct attention, in the form of working memory capacity, is an important moderator of the interplay between explicit and implicit AM, as it was proposed by the seminal article of Barrett et al. (2004) on dual-process theories.

The present thesis proposed three original studies to foster our understanding of internalization through a dual-process perspective that also acknowledges the role of working memory in this complex interplay. In the *first study*, I proposed a model of explicit and implicit AM to predict the academic achievement of university students. The *second study* replicated the finding of the first study through a Bayesian analysis and investigated a reciprocal effect of academic AM and achievement to show that AM not only influences achievement but achievement also influences AM. In the last and *third study*, I created an experimental learning situation and examined the effect of subliminally priming students with autonomous words on the association between self-reported AM and performance on a subsequent exam. The overarching goal of this thesis was thus to explore the interplay of two different cognitive processes of AM in the educational context using alternative methods (self-report vs indirect measures) as a means to further our understanding of the unexpectedly small association between academic AM and achievement.

### **Autonomous Motivation and Achievement in the Academic Context**

As previously pointed out, many theories have been proposed to explain how the motivation of students can influence their well-being, persistence, academic achievement, and

general academic career. In this thesis, I focused on the SDT framework for its useful applicability to achievement-oriented contexts (e.g. work, sport, and education). Observations and predictions within the SDT framework come from integrating the organismic perspective of most humanistic approaches to the behavioral and modern cognitive approaches. The macro-theory framework thus has tremendous heuristic value for investigating human motivation and cognition interplay in the educational setting.

### **What is Autonomous Motivation?**

SDT builds upon a humanistic approach that considers that all individuals have a natural tendency toward growth and development of their *self* through engagement, curiosity, and exploration. This tendency denotes a propensity in individuals to *make sense* of their inner psychological experiences and to connect with other individuals in authentic, profound, and mutually respectful manners. Moreover, the definition of motivation offered by SDT goes beyond the notions of effort and willingness by conceptualizing motivation as a multidimensional construct in which different reasons or motives are varying in quality based on the extent to which the behavioral regulation is internalized in the *self*. Individuals who successfully internalize their regulations will experience their behavior as being more volitional, self-determined, and autonomous. Behaviors that are perceived as more autonomous will shift the perception of causation to be more internal, in contrast to external. The continuum of internalization distinguishes six reasons/regulations ranging from a total absence of regulation (i.e. amotivation) to more and more internalized regulations (i.e., extrinsic, introjected, identified, integrated, and intrinsic). When an individual is externally regulated his/her behaviors are contingent on controlling rewards and punishments. Expectation of a reward and avoidance of punishments thus become the main source of motivation for those individuals. An external

regulation can also be introjected if the external contingencies are waived. The experience of introjection is internal but guided by an intrapersonal social factor that give the individuals a sense that he/her should or must do a particular behavior. The external and introjected regulations are thus both described as being controlled motivation and guided by external factors to the *self*. Overall, individuals with high levels of controlled motivation pursue their given activities for external reasons and are mostly accompanied with feelings of guilt, shame, and self-imposed pressure along with an incentive toward receiving rewards or inversely avoiding undesirable consequences.

Regulations that are more internalized than the introjected regulation are described as being more autonomous, volitional, and self-determined. Behaviors guided by an identified regulation are more aligned with one's value and identity and are felt to be personally important for the individual. The actions of those individuals are consciously endorsed and have a relative lack of conflict and resistance to behave. Following the internalization continuum, the integrated regulation provides the basis for autonomous behaviors. Those regulations are in full congruence with the self, they are authentic and reflect the endorsed values, goals, and needs that are already part of the self. the more internalized regulation is the intrinsic regulation which describes an individuals that engage in his/her activities for its interest, enjoyment, and inherent satisfaction. The identified, integrated, and intrinsic regulation all describe a motivational pattern that is more volitional and autonomous. Overall, the actions of individuals with high levels of AM are more self-endorsed. Activities are thus pursued for the pleasure and interest as well as because they are perceived as an inherent part of the self and are viewed as important by the person.

Early investigations of the internalization continuum demonstrated that regulations theorized to be closer together were more highly correlated than those theorized to be distant

(Ryan & Connell, 1989; Vallerand & Bissonnette, 1992). Researchers have also used bi-factorial analysis to examine the validity of the internalization continuum and found that autonomous form of motivation loaded more highly on the general autonomy factor than the controlled form of motivation (Gunnell & Gaudreau, 2015; Howard, Gagné, Morin, & Van den Broeck, 2016; Litalien et al., 2017). The distinction between autonomous and controlled motivation have thus been validated across multiple studies and was found to be highly relevant for predicting meaningful educational outcomes, like persistence, dropout, achievement, learning, and subjective well-being (Guay, Lessard, & Dubois, 2016; Guay et al., 2008).

### **Potential Consequences of Autonomous Motivation in the Academic Context**

According to SDT, students who pursue their academic activities for pleasure in ways that are consistent with their personal interests, values, and goals, are expected to experience a host of desirable consequences, because their motivation disposition are more autonomous (Deci & Ryan, 1985; Ryan & Deci, 2002). For example, Levesque, Zuehlke, Stanek, and Ryan (2004) found that AM was positively associated with subjective well-being across German and American university students. Moreover, AM was also positively linked to persistence (Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004) and negatively associated with dropout intentions, over and above academic achievement (Hardre & Reeve, 2003). As such, it would appear natural to assume that AM plays an important role in promoting the academic achievement of students. Traditionally, students' achievement at university is expressed in terms of grade point average (GPA). This indicator of achievement is also used as a selection criterion for graduate studies, graduate employment and can even predict occupational status (Strenze, 2007). Overall, GPA has been proved to be a reliable indicator of academic achievement, as well

as having good temporal stability. In the current thesis, academic achievement in the form of GPA will be used as the main dependent variable.

A positive association has commonly been found between AM and academic achievement, but the magnitude of this association has been inconsistent across studies. Some studies have reported a strong association (e.g., Ahmed & Bruinsma, 2006; Fortier, Vallerand, & Guay, 1995; Guay & Vallerand, 1997; Soenens & Vansteenkiste, 2005), whereas others have reported a weak association (e.g., Kusrkar, Ten Cate, Vos, Westers, & Croiset, 2013), or even a non-significant association (e.g., Acee, Cho, Kim, & Weinstein, 2012). These mixed results are consistent with a recent meta-analysis on this topic. Taylor et al. (2014) performed a meta-analysis on studies ( $n = 18$ ) that used the Academic Motivation scale (AMS; Vallerand et al., 1992) – a specific scale for evaluating students' motivation through the lens of SDT – with the goal of assessing the relationship between each motivational regulation and academic achievement. Small positive effect sizes were found for intrinsic ( $r = .134$ ) and identified regulations ( $r = .172$ ) whereas small and negative effect sizes were found for introjected ( $r = -.059$ ) and external regulation ( $r = -.109$ ). Autonomous motivation, which is composed of intrinsic, identified, and integrated regulation, does seem to have a positive effect on academic achievement. In addition, the effect size of the relationship between autonomous regulations and academic achievement was not significantly heterogeneous across studies. Furthermore, effect sizes for intrinsic and identified regulations did not differ whether the studies used a cross-sectional or a prospective design. Overall, students who regulate their behavior more autonomously are experiencing higher academic achievement, but this association was found to be relatively small.

A second meta-analysis (Richardson et al., 2012) found that intrinsic motivation had a small effect only when the design was cross-sectional ( $r = .21$ ) and no effect for studies using a prospective design ( $r = .07$ ). This specific result was also corroborated in a 40-year meta-analysis (Cerasoli et al., 2014) on intrinsic motivation and performance (school context;  $r = .21$ ). In sum, the association of AM with academic achievement is generally positive, albeit relatively small. Investigating for whom and under which condition this association might be of stronger magnitude thus seems to be an important endeavour. As previously pointed out, the assessment of AM is mainly done through self-report measures which only capture the accessible knowledge that one individual has about his/her motivation. In this thesis, I reinvestigated the role of AM in academic achievement using a dual-process perspective under SDT to better understand the interplay of awareness, automaticity, cognition, and AM in the prediction of academic achievement.

## **Toward a Dual-Process Investigation of AM**

### **Differentiating Explicit and Implicit AM**

All studies included in past meta-analyses have reported the association between self-report measures of AM indicators and academic achievement. This is a common practice in educational research wherein AM has been primarily measured using self-report methodologies (Guay et al., 2008). Self-report measures were developed a long time ago and are based on an important premise – introspection – that has been forgotten over the long haul (Locke, 2009). The accessible content of our brain is only a small portion of what really occurs inside, relative to the content that is outside of awareness. Explicit measures that rely on introspection can be limited by *the motivation of individuals* in reporting their mental content, *the circumstance* in which they are reporting their mental content, *their own ability* in reporting this specific content

and/or *their awareness* of the mental content, as the content can be unavailable or blocked during the introspection process (Nosek, Hawkins, & Frazier, 2011). There is little doubt that self-report measures offer valuable information about psychological constructs that are well defined and organized around a theory. However, self-report measures only measure the accessible self-knowledge that an individual has about the questions researchers are asking. As such, this *declarative knowledge*, which is based on declarative/conscious/controlled/explicit cognitions, needs to be differentiated from those cognitions that can be assessed through non-declarative/unconscious/automatic/implicit forms of measurement. The idea that humans possess two different forms of self-knowledge is inherent to most dual-process theories on learning, reasoning, and social cognition. According to the Systems of Evaluation Model (McConnell, Rydell, Strain, & Mackie, 2008; Rydell & McConnell, 2006), two separate systems of knowledge (i.e., implicit vs. explicit) are needed to fully understand the extent to which different mental representations of the same object can be differentially associated to behavioral outcomes. There is a long theoretical and research tradition that aim at examining how attitudes and mental representations about the self can coexist and be processed differently to more fully explicate behavioral responses (Evans & Frankish, 2009). My thesis will build on this research tradition to further our understanding of the relationship between AM and academic achievement.

Different theoretical models already exist to differentiate types of processing, systems or modes of functioning of the brain and they all pertain to the same big family, namely the *dual-process theories*. Although there is almost no cross-referencing between those theories, as pointed out by Evans and Frankish (2009), superficially, the core arguments and categorizations of the mental processes are similar: one operates automatically whereas the other operates in a

controlled fashion (Gawronski & Creighton, 2013). Different dual-process theories have been proposed to explain this possible brain functioning duality. The *reflective-impulsive model* (RIM; Krishna & Strack, 2017; Strack & Deutsch, 2004) is the most influential theory of that nature to predict social behavior. The RIM assumes that the automatic/impulsive and controlled/reflective processes are distinct cognitive processes that operate in parallel and interact in the prediction of behavior, but the impulsive component is always in activation, in contrast to the reflective process that is highly dependent on cognitive resources. The reflective process is theorized to be rational and rule-based, in contrast with an associative cognitive process. This more controlled/reflective process can be constrained by the working memory capacity of an individual, as the number of proposition/rule-based operations increase, more element need to be held in memory for and individual to behave in particular way. This rule-based cognitive process is thus operating in a conscious manner even if some actions are requiring few cognitive resources and might not be accompanied with a full sense of intentionality (Deutsch, Kordts-Freudinger, Gawronski, & Strack, 2009). The RIM thus offers useful heuristic to generate testable hypotheses likely to further our understanding of the underlying processes of AM in the prediction of academic achievement.

### **Two Streams of Implicit Motivation Research in SDT**

The investigation of implicit processes in SDT is still an emerging perspective (e.g., Lévesque & Pelletier, 2003; Ratelle, Baldwin, & Vallerand, 2005) that has received significantly less attention compared to explicit forms of AM. Nonetheless, two distinct lines of SDT research can be distinguished and repositioned within the experimental versus the correlational tradition that typically characterizes social and personality psychologists. On the one hand, protagonists of the experimentalist approach have used and developed experimental techniques to manipulate or

prime the AM of participants using subliminal or supraliminal tasks. On the other hand, advocates of the correlational approach have developed measurement techniques in order to capture individual differences in implicit AM. Underlying both methods of investigation is the assumption that a semantic network of mental representation exists about the reasons one has for pursuing an activity. In the subsequent sections, I will review both approaches, and the unique and complementary contributions they have made.

### **The Experimental/Priming Approach to Implicit Motivation**

The incorporation of unconscious processes in SDT was introduced by Lévesque and Pelletier (2003) under the theoretical assumptions of the Auto-Motive model of Bargh (1990). Simply stated, this model proposes that goals can be primed or activated outside of an individual consciousness in a manner that is likely to influence behavioral output as if the individual was fully aware of the goals. Different tasks – widely used to manipulate attitudes and self-related constructs in social psychology research (Molden, 2014) – have been adapted to prime participants with stimuli associated with mental representations of autonomous versus controlled motivation. In such cases, researchers hypothesize that the unconscious activation of mental representations about one AM disposition (i.e., priming) should influence behavioral, emotional, and cognitive responses. Several experimental studies have relied on priming methods and demonstrated that individuals primed with AM performed significantly better on a variety of tasks assessing cognitive and motor skills (e.g. Hodgins et al., 2010; Lévesque & Pelletier, 2003; Radel, Sarrazin, Jehu, & Pelletier, 2013; Radel, Sarrazin, Legrain, & Gobancé, 2009; Radel, Sarrazin, & Pelletier, 2009). Largely speaking, priming methods can be categorized according to the extent to which individuals are partially unaware (i.e., supraliminal tasks) versus fully

unaware (i.e., subliminal tasks) of the stimuli used to activate the mental representations of motivation.

A pioneer research project, investigated the automaticity of motivation by creating a supraliminal primed manipulation for autonomous and controlled motivation with a Scrambled Sentence Test designed to activate mental representations of motivation (Lévesque & Pelletier, 2003). After the manipulation, participants had to work on a crossword puzzle for 15 minutes. In the first study, participants who were primed autonomously were significantly more intrinsically motivated, had more enjoyment while doing the task, perceived more choice, and filled more words in the crossword puzzle ( $r = .296$ ). However, the authors proceeded with a replication in their fourth study and failed to replicate the results of the first study. In the second study, the authors asked participants to write down ten reasons they had for attending university and coded the first two motives as being either autonomous or controlled one a scale ranging from -3 to +3, and were described as being chronically accessible motivational orientation. Motivational chronicity was significantly correlated with a self-report measure of academic motivation ( $r = .34$ ). Hodgins, Yacko, and Gottlieb (2006) used the same supraliminal prime procedure of Lévesque and Pelletier (2003) and found that participants primed with AM words reported lower desire for escape, lower self-serving bias, and less self-handicapping than participants primed with controlled motivation words. Following those results, another study using the same priming methodology found that individuals primed autonomously reported lower threat perception, and lower physiological response of threat which ultimately increased their performance while giving a speech (Hodgins et al., 2010)

Using subliminal primes is useful because it can guarantee that participants are fully unaware that researchers are trying to activate mental representation of their motivation. Radel,

Sarrazin, Legrain, et al. (2009) have incorporated AM words (e.g., willing, free and desire) or controlled motivation words (e.g., constraint, forced and obligation) in a slideshow displayed to university students during a lecture in a classroom. The location of the words on the slide was selected randomly for each presentation. Words were presented for 32 milliseconds and a backward mask was presented for 16 milliseconds. Participants were assigned randomly to the autonomous or the controlled condition and were ultimately quizzed on the content of the lesson at the end of the class. No significant differences ( $r = .165$ ) were found between the priming condition when predicting the quiz performance, while controlling for regular performance (i.e., end of semester final grade). However, when they subsequently tested an interaction model using mindfulness disposition as a moderator, it was found that students who were less mindful were more affected by the priming manipulation, with autonomous prime leading to higher performance on the quiz. In another study using subliminal prime methodology, autonomous and controlled words were presented for 45 milliseconds in the parafoveal vision area and followed by a 60 milliseconds backward mask (Radel, Sarrazin, & Pelletier, 2009). The location of the prime on the screen was randomly selected to be presented in one of the four quadrants of the screen. Afterwards, participants were invited to learn a new motor task, and it was found that individuals in the autonomous condition performed better on the task ( $r = .25$ ), were more persistent, put more effort into it, had more interest and enjoyment, and felt more autonomous. Overall, those experimental priming studies revealed that mental representation of AM can be activated outside of the participants' awareness, and that such activation of autonomous behavioral schemata can influence self-regulation mechanisms and ultimately task performance.

### **The Correlational/Measurement Approach to Implicit Motivation**

Research stemming from a correlational/measurement tradition posits that individual differences in motivation exist and can be quantified using both explicit/declarative measures and implicit/indirect measures. As such, we can have access to the mental representations about one's motivation by measuring the rapidity to which an individual reacts to different stimuli (e.g., words, images) associated with a specific form of motivation. For example, if someone possesses a strong AM, he/she should rapidly react to stimuli that are part of his semantic network of mental representation, as this information should be more accessible for this person. In contrast, a person with low AM should not react rapidly to the stimuli associated with AM because such stimuli should not be easily accessible.

Studies that have assessed individual differences in implicit autonomous motivation have either used Implicit Association Tests (IAT; Keatley, Clarke, & Hagger, 2012; Keatley, Clarke, & Hagger, 2013a, 2013b; Levesque & Brown, 2007) or lexical decision tasks (LDT; Burton et al., 2006; Radel, Pelletier, Sarrazin, & Milyavskaya, 2011) – two frequently used assessment methods in social psychology research (Ferguson, Hassin, & Bargh, 2008). These two methods have the advantage of using response latency, which is more suited for measuring implicit traits, disposition and social phenomena than other more subjective or projective measures (e.g., Thematic Apperception Test, Picture Story Exercise, and Operant Motive Test) that require qualitative coding based on relatively arbitrary inferences. Accordingly, an Implicit Association Test was developed by Levesque and Brown (2007) for assessing implicit dispositional AM. In this specific IAT, participants had to categorize stimuli associated with AM in two target categories (self/me vs other/they) as fast as possible. After this first categorization task, the categories on the screen were reversed (i.e. left side vs right side) and later used to calculate the implicit autonomous motivation score (Greenwald, McGhee, & Schwartz, 1998). This new

measure of implicit AM was used to demonstrate that implicit AM predict day-to-day autonomy (i.e. explicit AM) but only for individuals with lower dispositional mindfulness.

Keatley et al. (2012) relied on the IAT task developed by Levesque and Brown (2007) and investigated the motivational antecedents of health-related behaviors (i.e. condom usage, physical activity and fruit/vegetable consumption). Interestingly both implicit and explicit measure of AM significantly predicted physical activity while only explicit AM predicted fruit and vegetable consumption. This result was replicated by Keatley et al. (2013a) when predicting time spent on solvable (study 1) or unsolvable (study 2) tasks. Both of the implicit and explicit autonomous motivations were significant predictors of perseverance on the task in the regression model, hence demonstrating the unique contribution of each motivational process. Despite their noteworthiness, readers should interpret these findings cautiously because Keatley and his colleagues have measured motivation after the task performance, which prevented a non-ambiguous interpretation of the directional effect from motivation to task perseverance.

Alternatively, SDT researchers have also developed a LDT for assessing implicit autonomous motivation (study 2b of Burton et al., 2006). In a LDT participants are given instructions to answer the question, “is this a word?” as quickly as possible. Half of the presented stimuli are non-words (i.e., strings of letters with no meaning) and the other half are divided in two categories: neutral words and motivation words. The reaction time is recorded at each stimulus presentation and the average reaction time on the neutral words is subtracted to the average on the motivation words, as a mean to control for individual differences in processing speed. In their study, Burton et al. (2006) collected the student’s final exam grades and administered both implicit and explicit measures of intrinsic and identified regulation – two indicators of AM – at some point during the semester. Burton et al. (2006) reported a positive

partial correlation of both implicit ( $r = -.36$ )<sup>1</sup> and explicit ( $r = .25$ ) identified motivation with final examination grades. However, results of a hierarchical regression analysis revealed that only implicit motivation uniquely predicted achievement of the students. This finding should be interpreted cautiously given the small sample size ( $n = 53$ ) and the fact that explicit motivation was measured earlier than implicit motivation during the semester, which may explain their different association with final examination grades.

### **Bringing Explicit and Implicit AM Together**

The correlational/measurement research paradigm offers a particularly useful paradigm to examine the unique contribution of explicit and implicit autonomous motivation in both lab and field studies. Thus far, this research stream has been fragmented and need to be brought together, in a dual-process model of explicit and implicit AM. Nonetheless, results from studies investigating the interplay of explicit and implicit AM can be reinterpreted in light of *three alternative hypotheses* regarding the effects of explicit and implicit measures in a dual-process models (Fazio, 1990; Krishna & Strack, 2017; Perugini, 2005; Strack & Deutsch, 2004).

First, a *double dissociative hypothesis* would assume that explicit/controlled/reflective measures should significantly predict deliberate and intentional behaviors whereas implicit/automatic/impulsive processes should significantly predict spontaneous and unplanned behaviors. Academic achievement requires deliberate and thoughtful decisions and efforts across different tasks over an extended period of time. As such, and consistent with a double dissociative pattern, it might be assumed that *only explicit AM* should positively predict academic achievement because the school context affords sufficient time to enable students to learn and deliberately think about their decisions. To our knowledge, research has yet to provide support for this double dissociative hypothesis for AM in the academic context.

Second, an *additive effects hypothesis* would assume that both explicit and implicit processes should comparably and incrementally predict behavioral outcomes. As demonstrated in a meta-analysis of 152 samples, implicit and explicit measures each can predict unique variance that the other measure is not explaining (Greenwald, Poehlman, Uhlmann, & Banaji, 2009). For academic AM, such an *additive hypothesis* appears defensible because school achievement might also require the spontaneous enactment of implicit processes to help students mastering the ever-changing demands and opportunities of the school environment. It is not rare for students to be placed under time constraints and mental overload (e.g., during exams) that force them to rapidly think and act without fully reflecting about their decision. Such daily requirements, over the long haul, might often require the students to alternate between their implicit/automatic/impulsive and explicit/controlled/reflective processes to obtain optimal level achievement. As such, both implicit and explicit AM might be comparably associated with achievement outcomes. As previously reviewed, some support has been found for this *additive hypothesis* (Keatley et al., 2012, 2013a).

Finally, an *interactive/moderation hypothesis* would posit that explicit/controlled/reflective and implicit/automatic/impulsive processes should interact to predict behavioral outcomes. The dual-process theory of Strack and his colleagues (Krishna & Strack, 2017; Strack & Deutsch, 2004) exactly describe this kind of interaction hypothesis. In their reflective-impulsive model, they suggest that the impulsive process is always effortlessly active. In contrast, the reflective process can sometime be tuned down or inactive. Thus, when the reflective process is active, it will always operate in parallel with the impulsive process. Those authors also suggest that synergy between reflective and impulsive processes can reduce the cognitive effort exerted by individuals. In their recent review of the social cognition

literature, Shoda, McConnell, and Rydell (2014) have concluded that discrepancies between different *systems of evaluation* (i.e. dual-process mechanisms) can bring ambivalence and cognitive dissonance that will eventually lead people to exhibit suboptimal behaviors and decisions. This kind of consistency hypothesis thus seems to be valuable in contrasting explicit and implicit AM. Failure to account for a multiplicative effect of implicit and explicit AM could explain why researchers have not found strong associations between explicit AM and academic achievement. AM might yield desirable achievement outcomes only for individuals with high levels of explicit AM and implicit AM, in a synergistic manner, as this combination might facilitate the academic achievement of students.

This *interactive/moderation hypothesis* has been tested in the studies of Burton et al. (2006) and Keatley et al. (2013a). These researchers have found mixed support, but methodological characteristics of these studies warrant a cautious interpretation of their findings. On the one hand, Burton et al. (2006) have reported a significant implicit  $\times$  explicit interaction to predict the grades of university students but only for the identified regulation of SDT. The researchers probed this interaction using a median-split approach with a relatively small sample – a method known to create spurious interactions that rarely replicate across samples (Bissonnette, Ickes, Bernstein, & Knowles, 1990). On the other hand, Keatley et al. (2013a) failed to replicate this finding in their studies as the interaction term did not reach significance. Nevertheless, this later finding should be interpreted prudently because the null multiplicative effect was obtained with small samples ( $n = 72$  and  $73$ ). In addition, the effect size of the interactions was not reported, and the results were discussed exclusively in light of statistical significance. Furthermore, this study tested participants in the lab rather than examining the role of AM on real-life outcomes such as the academic grade point average of university students.

Overall, past research that tested the interactive hypothesis provided scant evidence that does not allow a clear evaluation of the veracity of the interactive effect.

### **The Role of Working Memory Capacity in Dual-Process Models**

In the previous section, I introduced dual-process hypothesis that could be used to investigate the interplay of explicit and implicit AM in the prediction of academic achievement. The main duality distinction that is put forward by dual-process theories is that behavior is a product of automatic and controlled processing. Above I have described the basis of the reflective-impulsive model (RIM) but purposely avoided to clarify the importance of self-regulatory and cognitive resources in the interplay of the two theorized processes. In the RIM, the reflective process is said to be limited by the ability to process information and thus the working memory capacity of individuals. Studies have demonstrated that manipulating the cognitive load of individuals can impair their logical reasoning (DeWall, Baumeister, & Masicampo, 2008; Neys, 2006) and self-regulatory behavior (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008; Thush et al., 2008). Working memory capacity can be largely described as the ability to control and orient the attention (Barrett et al., 2004) and thus can have tremendous implication for dual-process model in psychology. The idea that some mental operations are more easily controlled by some individuals compared to other individuals is key to our understanding of the dual-process interplay (Barrett et al., 2004). As such, the explicit-implicit model of AM proposed in this thesis acknowledges the pivotal role of working memory capacity in the prediction of academic achievement, by considering its modulating influences on the interplay of explicit and implicit AM.

### **Integrating Working Memory Capacity to a Dual-Process Perspective of AM**

As previously detailed, the integrative process of SDT is an inherent tendency to assimilate ongoing experiences that is observable via the internalization continuum. This psychocognitive process of internalizing autonomous regulation in the *self* vary in quality across individuals. The internalization of autonomous regulation in its dispositional form is often assessed with self-report methodology. When participants are filling those measures, they are extracting self-knowledge about their own regulation through a controlled/reflective/explicit cognitive process. Of course this process is most likely influenced by their own motivation, the situation they are in, and their ability for reporting such information about themselves (Nosek et al., 2011; Wilson & Brekke, 1994), but I assume, in this thesis, that self-evaluation of AM have enough true variance associated with them to consider the aforementioned factors as measurement error. In their everyday life, students are guided by their motivation disposition, sometime through a controlled and volitional process (explicit AM) that is hypothesized to in interaction with its impulsive counterpart (implicit AM). Moreover, the ability of students to consciously engage and process motivational information might be limited by their working memory capacities.

In the educational literature, working memory has already been targeted as one of “the most relevant cognitive factors for both short-term and long-term learning” (Fenesi, Sana, Kim, & Shore, 2015, p. 333). This research stream demonstrated that working memory is indeed positively related to academic achievement, with medium-to-large effect sizes ( $r \approx .30$ ;  $d \approx .63$ ; e.g. Alloway & Alloway, 2010; Alloway et al., 2005; Krumm, Ziegler, & Buehner, 2008; K. Lee, Ning, & Goh, 2013; Lehto, 1995; Owens, Stevenson, Norgate, & Hadwin, 2008; St Clair-Thompson & Gathercole, 2006; Swanson & Alloway, 2012) but with potentially weaker effects at the university level (Gareau & Gaudreau, 2017; Rohde & Thompson, 2007). Working memory is an essential component of higher-order cognitive processes (i.e., executive functions) known

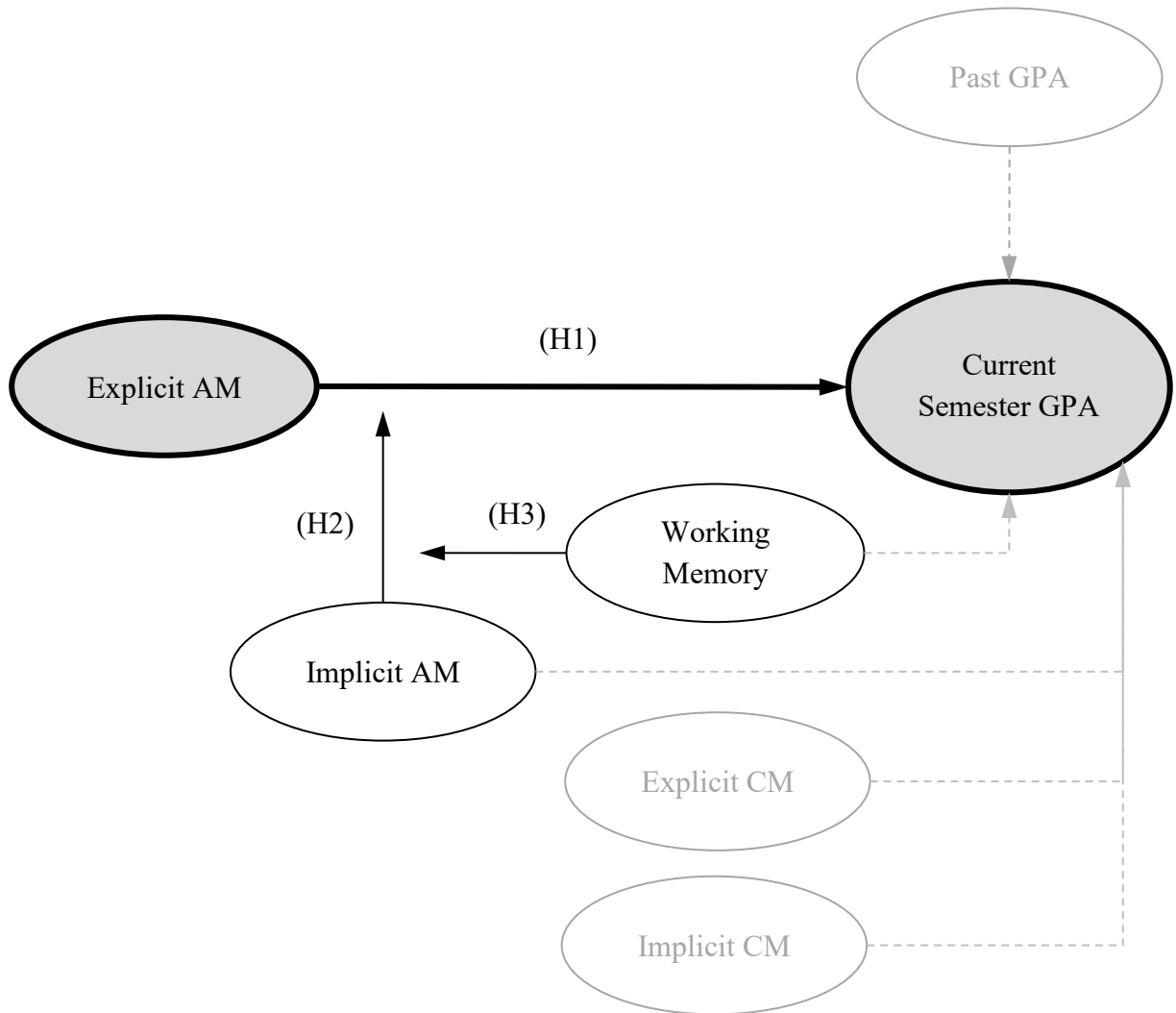
to play a significant role in helping individuals regulate their thoughts, plans, and actions such as prioritizing tasks and managing their time (Cowan, 2014). However, the potential role of working memory in modulating motivational forces has hardly been investigated.

The reflective-impulsive model (Strack & Deutsch, 2004) and the seminal article of Barrett et al. (2004) are both pointing in the same direction, and hypothesized that the working memory capacity is an individual differences variable that could enable researchers to examine for who and under which conditions dual-process interplay can be optimized. Following this footpath, in this thesis, I investigated the modulating influence of working memory capacity on the interplay of explicit and implicit AM. I hypothesized that the true benefit of internalization might be uncovered for individuals who self-evaluate their regulation to be autonomous and have an impulsive/automatic process of AM that is more easily accessible. This synergistic pattern of explicit and implicit AM is also hypothesized to be contingent on the working memory capacity of students. Similarly, Weinstein et al. (2013) proposed that the integrative process is likely to be cognitively challenging and well anchored in the neurobiology of individuals, as evidenced by neuropsychological studies. The explicit-implicit model that I proposed to investigate is shown in Figure 1, which displays the moderating effect of implicit AM and working memory capacity on the association between explicit AM and academic achievement. Overall, this dual-process perspective should enlighten our understanding of the effect of AM on subsequent achievement by bringing implicit social cognition principles right into the heart of SDT – through the investigation of the integrative process.

### **The Current Doctoral Thesis**

The overarching goal of this thesis was to investigate, through a dual-process perspective of AM, the integrative process of SDT by integrating notion from implicit social cognition to

better understand for which student AM is promoting higher level of achievement in the university setting. The investigation, as proposed in the introduction will be, on the one hand, to elucidate the somehow weak association of AM and academic achievement and, on the other hand, to explore the integrative process in SDT through new theoretical perspective in SDT, all with the aid of a dual-process perspective. Three studies are presented in this thesis in form of articles with different objectives. In *Article 1*, an initial exploration of the explicit-implicit model of AM was investigated. The first step of this exploration was to develop an implicit lexical decision task of AM, which was inspired by past studies using similar methodology (Burton et al., 2006; Lévesque & Pelletier, 2003). Hierarchical moderated regression analysis was performed to examine the central hypothesis of my thesis. In *Article 2*, I continued my exploration of the explicit-implicit model of AM by first examining reciprocal effect of explicit and implicit AM with academic achievement (i.e., whether AM predicts achievement, achievement predicts AM, or both), and secondly by replicating the results of *Article 1*. Moderated mediation analysis was used to test the two different objectives within the confine of a sole model. Lastly, in *Article 3*, a learning situation was designed to investigate an experimental priming effect of AM on examination performance. Accordingly, students were randomized in different priming conditions to investigate whether subliminal activation of AM could trigger, synergistically, explicit self-reported AM to be a better predictor of subsequent performance on an in-lab exam. Overall, I sought by this thesis to expand the knowledge of unconscious processes in SDT and how they influence subsequent achievement in the academic domain.



*Figure 1.* The explicit-implicit model of AM with main thesis hypotheses. H1 = main effect hypothesis, H2 = synergistic hypothesis, H2 = cognitive resources hypothesis, AM = autonomous motivation, CM = controlled motivation, GPA = grade point average.

## CHAPTER 2: First exploration of the explicit-implicit model of AM

Working Memory moderates the effect of the integrative process of implicit and explicit  
autonomous motivation on academic achievement

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### **Abstract**

In previous research, autonomous motivation (AM) has been found to be associated with school achievement but the relation has been largely heterogeneous across studies. AM has typically been assessed with explicit measures like self-report questionnaires. Recent self-determination theory (SDT) research has suggested that converging implicit and explicit measures can be taken to characterize the integrative process in SDT. Drawing from dual-process theories, we contended that explicit AM is likely to promote school achievement when it is part of an integrated cognitive system that combines easily accessible mental representations (i.e. implicit AM) and efficient executive functioning. A sample of 272 university students completed a questionnaire and a lexical decision task to assess their explicit and implicit AM, respectively, and they also completed working memory capacity measures. Grades were obtained at the end of the semester to examine the short-term prospective effect of implicit and explicit AM, working memory, and their interaction. Results of moderation analyses have provided support for a synergistic interaction in which the association between explicit AM and academic achievement was positive and significant only for individuals with high level of implicit AM. Moreover, working memory was moderating the synergistic effect of explicit and implicit AM. Explicit AM was positively associated with academic achievement for students with average to high levels of working memory capacity, but only if their motivation operated synergistically with high implicit AM. The integrative process thus seems to hold better proprieties for achievement than the sole effect of explicit AM. Implications for SDT are outlined.

According to Self-Determination Theory (SDT), people who pursue their activities for pleasure and in ways that are consistent with their personal interests, values, and goals are expected to experience a host of desirable consequences (Deci & Ryan, 1985; Ryan & Deci, 2002). In the school domain, *achievement* is the prototypical indicator used to evaluate the learning and success of students (Hattie, 2013; Richardson, Abraham, & Bond, 2012). Several researchers have found a positive association between such autonomous forms of motivation and academic achievement (e.g., Fortier, Vallerand, & Guay, 1995; Grolnick, Ryan, & Deci, 1991; Guay, Ratelle, Roy, & Litalien, 2010). However, recent meta-analyses have revealed an unexpectedly small average effect size for the associations of intrinsic motivation ( $r = .17$  and  $r = .13$ ; Richardson et al., 2012; Taylor et al., 2014) and identified motivation ( $r = .17$ ; Taylor et al., 2014) – two indicators of *autonomous motivation* (AM) – with academic achievement.

The goal of this study was to propose innovative bridges across SDT, implicit social cognition, and executive functioning to further elucidate for whom and under which conditions AM facilitates academic achievement. Students are not always conscious of their own motivation, or the underlying reasons that are energizing their behaviors. Students who display synergy between their explicitly stated AM and implicit/unconscious AM could be considered as having integrated their motivations more deeply and would ultimately achieve better grades in school. Moreover, this integrative process probably requires some cognitive resources, which can be understood in terms of working memory capacity. In this study, we propose a model in which the relation between explicit AM and academic achievement is moderated by implicit AM, and in which this moderation effect is also moderated by the students' working memory capacity (Figure 1). This Explicit-Implicit Model of autonomous motivation builds on recent propositions from SDT researchers that converging high levels of both implicit and explicit motivation can be

taken to characterize a more integrated sense of autonomy (Levesque, Copeland, & Sutcliffe, 2008; Radel, Pelletier, Sarrazin, & Milyavskaya, 2011; Radel, Sarrazin, Legrain, & Gobancé, 2009; Weinstein, Przybylski, & Ryan, 2013). This model also tries to integrate cognitive and non-cognitive predictors to better understand their interplay in promoting academic achievement. Working memory is thus added to the model in order to foster a deeper understanding of the *integrative process* of explicit and implicit autonomous motivation, which is likely to be cognitively challenging (Weinstein et al., 2013). Overall, working memory capacity should play a bolstering role to support the relationship between an integrated autonomous motivation (high implicit combined with high explicit AM) and academic achievement.

### **Autonomous Motivation and Academic Achievement**

Motivation theories have a long history of identifying and investigating the precise motivational processes capable of predicting and promoting academic achievement (Wentzel & Wigfield, 2009). SDT has been widely applied in educational psychology research because it distinguishes six sources/reasons (non-regulation, external, introjected, identified, integrated, and intrinsic) underlying the pursuit of school activities (Deci & Ryan, 2008). These five motivational regulations can also be used to distinguish AM (identified, integrated, and intrinsic) versus controlled motivation (external and introjected). Individuals with high level of controlled motivation pursue their given activities for external reasons and are mostly accompanied with feelings of guilt and shame along with an incentive toward receiving rewards or inversely avoiding undesirable consequences. In contrast, the actions of individuals with high level of AM are more volitional. They are pursued for the pleasure and interest of the activity as well as because they are perceived as an inherent part of the self and are viewed as important by the person. In this study, we deliberately focused on AM as autonomous functioning is a cardinal

feature of SDT and a desirable characteristic hypothesized to promote well-being and achievement.

Although positive associations are commonly found between AM and academic achievement, the strength of this association is not consistent across studies; some have reported a strong association (e.g. Fortier et al., 1995; Guay & Vallerand, 1997; Mega, Ronconi, & De Beni, 2014) whereas others have reported a weak association (e.g. Black & Deci, 2000; Cokley, Bernard, Cunningham, & Motoike, 2001; Fairchild, Horst, Finney, & Barron, 2005). These mixed results are certainly consistent with the relatively small effects reported in the meta-analysis of Taylor et al. (2014) and the heterogeneous association reported in the meta-analysis of Richardson et al. (2012). In the extant literature, AM has been primarily measured using self-report methodologies (Guay, Ratelle, & Chanal, 2008). However, self-report measures only assess accessible content of one's motivation, which is not to be underestimated. This content, also described as *declarative knowledge*, only reveals one side of the motivational story. The idea that humans possess two different forms of self-knowledge is an integral postulate to most dual-process theories on learning, reasoning, and social cognition. As such, two separate systems of knowledge (i.e., implicit vs. explicit) are thus needed to fully understand the extent to which different mental representations of the same object can be differentially associated to behavioral outcomes. There is a long theoretical and research tradition that aimed at examining how attitudes and mental representations about the self can coexist and be processed differently to more fully explicate behavioral responses (Evans & Frankish, 2009). A closer examination of AM – using a mixture of implicit/indirect and explicit/direct methodologies – is a promising avenue to unpack its relatively inconsistent relationship with academic achievement.

The investigation of implicit process in SDT is an emerging perspective (e.g., Lévesque & Pelletier, 2003; Ratelle, Baldwin, & Vallerand, 2005) that has received significantly less attention compared to explicit measurement of AM. Several experimental studies have relied on priming methods and demonstrated that individuals primed with AM performed significantly better on a variety of tasks (e.g. Hodgins et al., 2010; Lévesque & Pelletier, 2003; Radel, Sarrazin, Jehu, & Pelletier, 2013; Radel, Sarrazin, Legrain, et al., 2009; Radel, Sarrazin, & Pelletier, 2009). Despite their strengths, these studies have rarely examined the contribution of both explicit and implicit AM. Other researchers have used implicit association tests (Keatley, Clarke, & Hagger, 2012, 2013a, 2013b) and lexical decision tasks (Burton, Lydon, D'Alessandro, & Koestner, 2006) to assess individual differences in implicit AM within the confines of a dual-process approach. Results of these studies can be reinterpreted in light of *two alternative hypotheses* regarding the effects of explicit and implicit measures in a dual-process model (Fazio, 1990; Perugini, 2005).

First, it can be hypothesized that both explicit and implicit processes should comparably and incrementally predict behavioral outcomes, as in an *additive hypothesis* (Greenwald, Poehlman, Uhlmann, & Banaji, 2009). In the context of school motivation, such an *additive hypothesis* appears defensible because school achievement might also require the spontaneous enactment of implicit processes to help students mastering the ever-changing demands and opportunities of the school environment. It is not rare for students to be placed under time constraints and mental overload (e.g., during exams) that force them to rapidly think and act without fully thinking about their decision. Over the long haul, it can be assumed that daily behaviors often require alternating between implicit and explicit processes to obtain optimal level of task success. As such, both implicit and explicit AM might be comparably associated

with achievement outcomes. Some support has been found for this *additive hypothesis* (Levesque et al., 2008). In a study with a sample of Canadian university students, Burton et al. (2006) reported a positive partial correlation of both implicit ( $r = -.36$ )<sup>1</sup> and explicit ( $r = .25$ ) identified motivation – an indicator of AM – with final examination grades. However, results of a hierarchical regression analyses revealed that only implicit motivation uniquely predicted achievement of the students. This finding should be interpreted cautiously given the small sample size ( $N = 53$ ) and the fact that explicit motivation was measured earlier in the semester than implicit motivation, which may account for their differential association with semester grade point average (SGPA). Across two studies with British university students, Keatley et al. (2013a) reported that both implicit AM and explicit intrinsic motivation (i.e., enjoyment) significantly and comparably predicted perseverance in an unsolvable and solvable task. These findings should be interpreted cautiously because measures of motivation were taken after the task performance, which prevented a non-ambiguous interpretation of the directional effect from motivation to task perseverance.

It can also be hypothesized that explicit and implicit processes might interact to predict behavioral outcomes, as in an *interactive hypothesis*. What should happen when the implicit and explicit systems display similar evaluations? Failure to account for a multiplicative effect of implicit and explicit AM could explicate why explicit AM has often failed to strongly predict higher level of academic achievement. For explicit AM to yield desirable achievement outcomes, it might need to be coherently and consistently accompanied with higher levels of implicit AM. Higher levels of implicit and explicit AM might facilitate the academic achievement of students. The convergence of both explicit and implicit AM could be considered as an indicator of integration in the self (Weinstein et al., 2013), a central assumption to the SDT that has yet to be

thoroughly tested. This *interactive/moderation hypothesis* has recently been rejected in the study of Keatley et al. (2013a). Nevertheless, these findings should be interpreted prudently because the null multiplicative effect was obtained with small samples ( $N = 72$  and  $73$ ), the effect size of the interactions was not reported, and the results were discussed exclusively in light of statistical significance. This hypothesis has yet to be tested in sufficiently large samples that would offer more statistical power to reject the null hypothesis and outside of the lab in the real academic lives of students.

### **Dovetailing of Working Memory and Autonomous Motivation**

Two distinct streams of research in cognitive and motivational sciences have established strong tradition in the prediction of academic achievement, paying closer attention to cognitive and non-cognitive factors, respectively. In an attempt to bring together these two research traditions, we were inspired by the seminal *unified model* of Kanfer and Ackerman (1989) which simultaneously tried to incorporate and understand how individual-differences in cognitive abilities and processes of motivation could interact when predicting performances. As such, allocating some of our research attention to working memory as an indicator of cognitive resources in individuals appears like another promising avenue to clarify the relation between AM and school achievement.

Working memory has been described as the cognitive ability of simultaneously storing and processing information; working memory assessments are thus considered measures of the executive function that characterizes the extent to which people can “maintain access to goal-relevant information in the face of concurrent processing and/or distraction” (Conway, Macnamara, & Engle de Abreu, 2013, p.21). As such, working memory is not a memory system in itself, but rather an attentional system for memory that passes through conscious awareness

(Kane, Conway, Hambrick, & Engle, 2007). In the realm of cognitive psychology, working memory has been positively associated with various high-order cognitive skills such as reading, listening and language comprehension, following oral and spatial directions, vocabulary learning from different context, note taking in class, writing, hypothesis generation, and complex-task learning (Conway et al., 2005). Interestingly, all of these cognitive skills are required by students in the overarching goals of the educational system to foster learning of new material and achievement across a wide range of relatively standardized tests. Being a student often requires many of the above-mentioned cognitive skills, whether during classes, when studying alone, reading textbooks, or even discussing with other students.

As shown in our model displayed in Figure 1, the positive association between *working memory capacity* and academic achievement has been firmly established in the literature with medium-to-large effect sizes ( $r \approx .30$ ;  $d \approx .63$ ; e.g. Alloway & Alloway, 2010; Alloway et al., 2005; Krumm, Ziegler, & Buehner, 2008; Lee, Ning, & Goh, 2013; Lehto, 1995; Owens, Stevenson, Norgate, & Hadwin, 2008; St Clair-Thompson & Gathercole, 2006; Swanson & Alloway, 2012) obtained and replicated across different measures of working memory (Conway et al., 2013). The *working memory capacity* of students was also found to be involved with learning at different developmental stages (e.g. Alloway & Alloway, 2010) – with potentially weaker effects in tertiary education (Rohde & Thompson, 2007) – and across a variety of achievement tasks (reading; Carretti, Borella, Cornoldi, & De Beni, 2009; Gathercole, Tiffany, Briscoe, & Thorn, 2005; math; Swanson & Beebe-Frankenberger, 2004).

Although both working memory and AM are key factors in the development and the understanding of academic achievement, research has yet to fully investigate their interplay to further elucidate their joint contribution in academic achievement. Our model, shown in Figure

1, was built on dual-process theories principles for describing the additive and the potential synergistic effects of implicit and explicit processes – in this case AM – when predicting academic achievement. We expected that both explicit AM and implicit AM will positively predict SGPA as per the *additive hypothesis* in a dual-process approach. On the basis of a dual-process perspective, tenants of a SDT approach have recently suggested that converging implicit and explicit self-knowledge can be taken to characterize a more and integrated sense of autonomy (Levesque et al., 2008; Radel et al., 2011; Radel, Sarrazin, Legrain, et al., 2009; Weinstein et al., 2013). As such, the self-reported knowledge about one's AM should be taken as an indicator of more reflective and integrated functioning *only when* it has been fully processed and integrated within a broader network of cognitively accessible mental representations about the self. Therefore, we hypothesized that the positive relation between explicit AM and academic achievement will be significantly stronger for students with high level of implicit AM (*synergistic hypothesis*).

Our model also recognizes the need to examine the joint contribution of AM and working memory capacity. As such, we contended that explicit AM is likely to promote school achievement when it is part of an *integrated cognitive system that combines* easily accessible mental representations (high implicit AM) and efficient executive functioning (high working memory capacity). Working memory is likely to set the upper-bound limit for the effectiveness of an integrated motivational system that combines high levels of explicit AM and implicit AM. The integrative process needed to build and sustain a cohesive and unified system of explicit and implicit AM may be cognitively challenging (Weinstein et al., 2013). As such, individuals with high explicit AM and easily accessible mental representations of their AM (i.e., high implicit AM) might reach higher level of school achievement only to the extent that they possess a

sufficient amount of working memory capacity. As eloquently summarized by Alloway (2009), working memory is a potential bottleneck for learning. In more operationalized terms, we propose a *resource availability hypothesis* in which working memory capacity will moderate the synergistic effect of implicit AM and explicit AM to predict academic achievement. More precisely, we hypothesized that the positive relation between explicit AM and academic achievement will be significantly stronger for students with high level of implicit AM (as per the *synergistic hypothesis*), *but only for* students with higher levels of working memory capacity.

### **The present study**

A short-term longitudinal design was employed with explicit AM, implicit AM, and working memory capacity measured during the semester in order to predict the end of semester grade point average (SGPA) after controlling for previous academic achievement. As shown in Figure 1, we hypothesized that the relation between explicit AM and academic achievement is moderated by implicit AM (*synergistic hypothesis*). We also hypothesized the synergistic implicit AM  $\times$  explicit AM to be moderated by working memory capacity (*resource availability hypothesis*).

### **Method**

#### **Participants and Procedures**

University students were recruited through a participant pool system at a Canadian university. The sample consisted of 272 undergraduate students (86% female) who studied full time (92.3%), or part-time (4%) and were between the ages of 16 and 38 years ( $M = 18.85$ ;  $SD = 2.41$ ). Students were enrolled in a variety of programs: psychology (20.2%), biomedicine (15.1%), nursing (11.8%), health sciences (11.4%), communication (8.8%), natural sciences (7.0%), human kinetics (6.6%), social sciences (6.3%), and other (5.9%). The sample consisted

of first (67.3%), second (22.1%), third (5.9%), and fourth (1.5%) year students. Participants described themselves as Caucasian (64.3%), Asian (9.9%), Afro-American (7.7%), Arabic (7.4%), Aboriginal/Native (0.7%) and other (6.3%). Each participant received 1 point toward their introduction to psychology class.

Each participant completed an electronic informed consent form and 215 also authorized the researchers to have access to their SGPA. A short questionnaire then followed to obtain socio-demographic information and to complete the explicit motivation assessment. Two computerized working memory tasks (Operation Span, OSPAN and Reading Span, RSPAN; Unsworth, Heitz, Schrock, & Engle, 2005) were then administered using the E-PRIME software 2.0. Afterward, a computerized lexical decision task measuring implicit motivation was administered on E-PRIME 2.0. Between each of the computerized tasks, a two-minute break was given to the participants in order to lessen the cognitive demands of the design. The lexical decision task was purposely put at the end of the experiment to ensure that any fatigue effect was generalized across participants and therefore response latencies was assumed as being comparable between participants.

## Measures

**Explicit academic motivation.** A self-report questionnaire was administered as a measure of explicit motivation assessing the five regulations of SDT with two items per regulations; intrinsic ( $\alpha = .772$ ), integrated ( $\alpha = .813$ ), identified ( $\alpha = .687$ ), introjected ( $\alpha = .746$ ), and external ( $\alpha = .927$ ). Participants were asked to respond to which extent each items corresponds to the reason they pursue academic activities (e.g., *It is part of who I am as a person*) on a scale of 1 (*not at all*) to 7 (*totally*). This new questionnaire has gone through an extensive validation process across multiple samples with a confirmatory factor analytical

approach (e.g., CFI = .962, SRMR = .043, factor loadings all above .65) with good evidence for its reliability, concurrent, and predictive validity (Gaudreau, 2014). A hierarchical confirmatory factor analysis, in which the five motivational regulations (i.e., first-order factors) are organized into autonomous and controlled motivation (i.e., second-order factors), yielded appropriate fit in this sample,  $\chi^2_{(30)} = 75.407, p = .001$  CFI = .961, RMSEA = .076 90%CI [.055, .097], SRMR = .064). Composite reliability was acceptable for autonomous (*H coefficient* = .853) and controlled motivation (*H coefficient* = .833).

**Implicit academic motivation.** A lexical decision task was administered as a measure of implicit motivation. Participants were presented with strings of letters and asked to indicate whether the strings were words or non-words. Participants were instructed to respond to the strings as quickly as possible and to be as accurate as possible. Half of the strings were non-words ( $n = 20$ ; e.g., foiw) and the other half contained 10 neutral words (e.g., chair), 5 autonomous motivation words (enjoying, freely, satisfied, volunteer, and autonomous), and 5 controlled motivation words (rewarded, pressured, controlled, constrained, and proving). The specific motivational words were taken from two past studies that used a lexical decision task for assessing implicit AM (Burton et al., 2006; Lévesque & Pelletier, 2003). A total of 40 strings were thus randomly presented for 2000 *ms* in the center of the screen while response time (RT) for each was recorded in milliseconds. Participants had to press as quickly as possible on the “W” key for words and on the “O” key for non-words. All inaccurate response as well as RTs below 250 *ms* were filtered out and not included in the scoring protocol. Moreover, RTs 2.5 standard deviations above and below each individual’s mean were also taken out of the analysis. Individual mean scores were then created for neutral words, autonomous words, and controlled words. The mean of the neutral words was subtracted from the average autonomous and

controlled score, respectively (e.g., autonomous RT(mean) – neutral RT(mean)) in order to control for individual variance (Burton et al., 2006). These final scores of AM and controlled motivation were then used in the subsequent analyses as measures of implicit motivation. Low scores reflect high levels of autonomous or controlled motivation because they indicate that mental representations of the motivation are more easily and rapidly accessible (i.e., faster response time).

**Working memory capacity.** Two different computerized tasks programmed by the Attention and Working Memory Lab at Georgia Tech (Unsworth et al., 2005) were used in this study to assess the participants working memory capacity (OSPAN and RSPAN). Both are short-term memory tasks that are cueing participants to remember different series of letters (encoding) while performing a secondary task (processing). Each task had a total of 75 letters to be remembered accompanied by either a mathematical (OSPAN) or a sentence problem (RSPAN). Participants were prompted to keep errors in the secondary task at minimum (85% or above hit rate; Conway et al., 2005). A detailed explanation of the sequence involved in the OSPAN and RSPAN can be found in Unsworth et al. (2005). Working memory capacity scores ranged from 0 to 75 and reflect the number of *memorandum* elements that were remembered by individuals (partial-credit load scoring, see Conway et al. (2005)). This scoring method for the OSPAN and RSPAN has been shown to hold good psychometric properties: test-retest, internal consistency, construct validity, and convergent validity (Redick et al., 2012). For the purpose of this study, a global working memory capacity score was created by averaging the OSPAN and RSPAN score – this is a suggested method to obtain a more global indicator of overall working memory capacity (Conway et al., 2013). Internal consistency for the global working memory was acceptable ( $\alpha = .76$ ).

**Academic achievement.** The semester Grade Point Average (SGPA) of students who have authorized the researchers to have access to their SGPA was obtained via the university central administration (e.g., Office of vice-president institutional research and planning) after obtaining the consent of students. SGPA ranged between 0 (F) to 10 (A+). The academic performance used in this study was collected at the end of the semester in which the data collection for working memory capacity and academic motivation occurred. We also obtained admission GPA to control for past academic achievement in the analyses.

## Results

### Preliminary Analysis

All descriptive statistics and zero-order correlations are shown in Table 1. The descriptive statistics of the OSPAN and RSPAN partial-scoring were similar to the normative sample agglomerated by Redick et al. (2012). Explicit AM was positively correlated with SGPA ( $r = .189, p = .006$ ) with a magnitude that was similar to recent meta-analytical estimates (Richardson et al., 2012; Taylor et al., 2014). Implicit AM also bears similar strength in its association with academic achievement ( $r = -.154, p = .006$ ). However, working memory had a relatively smaller association with SGPA than expected ( $r = .126, p = .080$ ). Admission GPA had the strongest association with SGPA ( $r = .291, p < .001$ ), thus highlighting the importance of controlling for this variable in subsequent statistical analyses.

### Hierarchical Moderated Regression Analysis

All regression models were tested in the MPLUS software with the *maximum likelihood robust* estimator, which corrects the standard errors of the parameters in the model. Also, we used the *full information maximum likelihood* algorithm for handling missing data in our sample. To evaluate the pattern of missing data we used *Little's test of missing completely at random*

(Little, 1988). Overall, the mean percentage of missing data for the studied variables was 7.1 % ranging between 1.5 and 21% (i.e., 215 of 272 participants have authorized the researchers to have access to their SGPA). Research in both psychological (Schlomer, Bauman, & Card, 2010) and educational sciences (Cheema, 2014) have revealed that including participants with such missing data is preferable to excluding them using a listwise deletion approach. This test was not significant (MCAR  $\chi^2_{(36)} = 46.640, p = .110$ ) meaning that the observed pattern of missing data was not significantly different than a completely random pattern of missing data. All predictors were standardized before creating interaction terms. In the first analysis, we tested the explicit  $\times$  implicit AM interaction to predict SGPA (*synergistic hypothesis*). In the second analysis, we tested if the previous interaction would interact with working memory capacity in a three-way interaction model (*resource availability hypothesis*). We controlled for the effect of explicit and implicit controlled motivation as well as the effect of admission GPA in all analyses.

**Explicit and implicit motivation interaction.** A first regression model was tested with explicit and implicit AM to predict SGPA: ( $R^2 = .144; F_{(5,266)} = 11.820; p = .001$ ). Only explicit AM ( $\beta = .178; t = 2.928; p = .003$ ) and admission GPA ( $\beta = .27; t = 4.156; p < .001$ ) significantly predicted variance in SGPA. In a second step of this analysis, we entered the interaction term of explicit  $\times$  implicit motivation ( $\beta = -.130; t = -2.205; p = .027$ ), which resulted in a significant increase of 1.3% in explained variance ( $\Delta R^2 = .013; \Delta F_{(1,265)} = 4.507; p = .027$ ). As recommended by Cohen et al. (2003), we then proceeded to probe the interaction at  $+1SD$  and  $-1SD$  levels of implicit AM (see Figure 2, panel A). High implicit AM corresponds to faster reaction time ( $-1SD$ ) on the lexical decision task whereas low implicit AM corresponds to slower reaction time ( $+1SD$ ); results of simple slopes and figures should be interpreted accordingly. Individuals with high implicit AM displayed a significant and positive association between

explicit AM and SGPA ( $\beta = .316; t = 3.591; p < .001$ ). However, the relation between explicit AM and SPGA was non-significant for individuals with low implicit AM ( $\beta = .002; t = 0.018; p = .986$ ).

**Working memory, implicit motivation, and explicit motivation three-way interaction.** In a first step, all the main predictors and control variables were entered simultaneously (see step 1 in Table 2). Only explicit AM and admission GPA positively and significantly predicted SGPA and the model explained 15.9 % of the variance. Then, in a second step we entered the two-way interactive effects of AM (i.e., explicit AM  $\times$  working memory, implicit AM  $\times$  working memory, explicit AM  $\times$  implicit AM). This model did not explain significantly more variance than in step 1. In a final step, the three-way interaction term significantly explained 5 % of unique variance over and above the main effects, the two-way interactions, and control variables.

We then proceeded with simple slope analyses to estimate the relationship between explicit AM and SGPA (across low and high levels of implicit AM) for individuals with low ( $-1SD$ ), moderate (mean), and high ( $+1SD$ ) levels of working memory. The different levels of working memory moderated the interaction of explicit  $\times$  implicit AM, which was not significant at low levels of working memory ( $\beta = .172; t = 1.716; p = .086$ ), significant at average levels of working memory ( $\beta = -.145; t = -2.043; p = .041$ ), and significant at high levels of working memory ( $\beta = -.462; t = -4.024; p < .001$ ). For individuals with *low working memory capacity* (see Figure 2, panel B), the relation between explicit AM and SGPA was significant for those with low implicit AM ( $\beta = .397; t = 2.562; p = .010$ ) but non-significant for those with high implicit AM ( $\beta = .048; t = 0.425; p = .671$ ). For individuals with *average working memory capacity* (see Figure 2, panel C), the relation between explicit AM and SGPA was significant for those with

high implicit AM ( $\beta = .313$ ;  $t = 3.911$ ;  $p < .001$ ) but non-significant for those with low implicit AM ( $\beta = .018$ ;  $t = 0.174$ ;  $p = .862$ ). For individuals with *high working memory capacity* (see Figure 2, panel D), the relation between explicit AM and SGPA was significant and positive for those with high implicit AM ( $\beta = .578$ ;  $t = 4.306$ ;  $p < .001$ ) whereas it was significant and negative for those with low implicit AM ( $\beta = -.360$ ;  $t = -2.475$ ;  $p = .013$ )<sup>3</sup>.

### Discussion

The relation between AM and academic achievement has been found to be inconsistent across studies and remains to be further explained in the SDT literature. In this study, we adopted a dual-process perspective to differentiate the effects of explicit AM and implicit AM. Our results showed that the relation between explicit AM and academic achievement was positive and significant for students with high levels of implicit AM, thus providing support for our *synergistic hypothesis*. Furthermore, this synergistic interaction between explicit AM and implicit AM was moderated by working memory capacity. For students with lower levels of working memory capacity, the positive relation between explicit AM and academic achievement was significant only for those with low implicit AM. For students with high levels of working memory capacity, the positive relation between explicit AM and academic achievement was significant only for those with high implicit AM. These findings will be discussed in light of self-determination theory, social cognitive processes, and our *resource availability hypothesis*.

#### Synergistic Effect of Explicit and Implicit AM

Based on the different systems of knowledge (McConnell, Rydell, Strain, & Mackie, 2008; Rydell & McConnell, 2006), we have explored the additive and synergistic effects of implicit and explicit AM for predicting academic achievement. Both implicit and explicit AM had a significant bivariate correlation with academic achievement. Their respective size (.189 for

explicit and  $-.154$  for implicit) was comparable to what was found in past literature and meta-analysis ( $r \approx .17$ ). This finding is also similar to the results of Keatley et al. (2013a) who reported a significant and comparable association of both explicit and implicit AM to predict perseverance during solvable and unsolvable tasks. Contrary to our prediction, the results of our multiple regression analysis have shown that only explicit AM significantly predicted academic achievement over and above past GPA. At a first glance, this finding might seem to contradict the results of past studies. However, results of complementary analyses revealed similar effects of explicit AM ( $\beta = .208, p = .002$ ) and implicit AM ( $\beta = -.155, p = .049$ ) when not controlling for past GPA in the regression model. Because previous studies did not control for past performance, it appears that the support for the additive hypothesis might be contingent upon the decision to control or not for past performance.

Nonetheless, our results provided a more convincing support for the *synergistic hypothesis* because we found a significant interaction of explicit and implicit AM when predicting academic achievement. As expected, the association between explicit AM and academic achievement was positive and significant only for individuals with high level of implicit AM. Measures of implicit AM are presumed to capture the extent to which mental representation of autonomous motivation are easily accessible. To feel motivated, as measure by explicit autonomous motivation, is not enough to achieve high grades in school. What is even more important is to have this feeling reciprocated within the self, as measure by the reaction time in the lexical decision task. Explicit autonomous motivation is thus a good predictor of academic achievement when implicit autonomous motivation is high. Recent theoretical developments in SDT have posited that holding high levels of both implicit and explicit AM might be taken as an indicator of integration (Levesque et al., 2008; Weinstein et al., 2013).

Integration can also be conceptualized as the result of having access to this self-knowledge more quickly and vividly. Hence, explicit AM is a declarative form of self-knowledge in which the individuals reflect upon, identify, and assess the reasons why they participate in their school activities. To the extent that such declarative self-knowledge is accompanied with easily accessible mental representations, one can assume that it forms a unified, coherent, and more integrated web of knowledge about the self that is likely to facilitate the attainment of desirable life outcomes such as the academic achievement of university students.

Explicit AM might lack the needed volition and energy to translate into measurable behavioral outcomes such as academic achievement when it is accompanied with less easily accessible mental representations (i.e., low levels of implicit AM). In such a case, the discrepancy between implicit and explicit assessments might indicate greater defensiveness and weaker personality integration likely to minimize the likelihood of securing desirable achievement outcomes (Weinstein, Deci, & Ryan, 2011). This interpretation is also consistent with research of Thrash, Maruskin, and Martin (2012) which has shown that implicit-explicit motive congruence increases volitional strength, flow experiences, and well-being. Another notable finding is that implicit motives are said to orient, direct, and select attention in a way that helps individuals attend to stimuli in the environment in a more effective manner (Woike & Bender, 2009). Therefore, having more accessible mental representations of a specific motive – in our case high implicit AM – implicitly guides students toward relevant information, whether in class or while reading textbooks that are more likely to be needed for academic achievement to be higher. Overall, our results in support of the synergistic interaction hypothesis showed that much can be learned about the underlying processes that bring one's motivation to predict

academic achievement when AM is understood with a dual-process perspective conveying the integrative process of SDT.

### **Cognitive Resource Availability Bolsters the Synergistic Effect**

We furthered this investigation by examining the effect of working memory capacity on the dual-process perspective of motivation. Results revealed a three-way interaction between explicit AM  $\times$  implicit AM  $\times$  working memory capacity that significantly predicted academic achievement. The working memory capacity of students acted as a moderator of the interactive/synergistic effect of implicit AM in the relation between explicit AM and academic achievement, thus providing initial support to our *resource availability hypothesis*. Interestingly, explicit AM was positively associated with academic achievement for students with average to high levels of working memory capacity, but only if their motivation operated synergistically – with high implicit AM.

As we previously pointed out, high level of implicit AM in synergy with high explicit AM can be taken as an indicator of integration. Despite all the positive effects associated with integration in the SDT literature (Levesque et al., 2008), the processes involved in integration are potentially cognitively complex and demanding (Weinstein et al., 2013). As we showed with our results, the synergistic interplay of explicit and implicit AM appears to be maximized when working memory capacity is higher (mean level and +1SD) as the integrative process requires higher cognitive resources to be able to generate positive behavioral outcomes such as academic achievement. As the working memory capacity increases, it appears as if explicit AM is able to better predict academic achievement for individuals with high level of implicit AM. Hence, we can infer from our results that individuals with less available resources (i.e., low working memory capacity) do not gain from expressing a synergistic pattern of explicit and implicit AM.

Cognitive resources appear to be important – if not necessary – for the integrative process of self-determination to be expressed. This idea is also reflected in the theoretical paper of Strack and Deutsch (2004) on dual-process. Within this theoretical framework, two behavioral processes are described – the reflective and impulsive. Although the reflective system (i.e. explicit system) requires higher amount of cognitive resources to help the regulation of behavior, behavioral outcomes are highly dependent on the compatibility of the two forces. For students with lower working memory capacity, a synergistic interplay of implicit and explicit AM was not capable to predict their academic achievement. Our results showed a positive association between explicit AM and academic achievement, but only for those students with low implicit AM. Integration is a cognitively challenging process that is potentially harder to obtain for individuals with lower cognitive resources. As such, our results suggest that individuals with lower cognitive resources are better off without the integration of their implicit and explicit motivation as they obtained higher academic achievement when their implicit AM was less salient.

The integrative process in SDT can be described as a natural tendency toward awareness and congruence within the existing web of self-knowledge. The recruitment of self-knowledge, being an involved step of the integrative process is presumed to have strong prefrontal-cortex activity (Nakao et al., 2009) – a region that is often associated with the executive function. Moreover, the prefrontal cortex is a region of the brain that is associated with autonomous regulation, specifically the right prefrontal cortex (Ryan, Kuhl, & Deci, 1997). The integrative process of implicit and explicit AM seems to have most of its activity in the prefrontal region, which is incidentally a brain area also associated with working memory. In this study, we measured working memory as a proxy of cognitive resources and have found evidence that the

integrative process – the synergistic effect of explicit and implicit AM is contingent on those resources to predict academic achievement. The synergistic interplay of implicit and explicit AM might rely on some of the same cognitive resources and/or neural systems involved in working memory, which would potentially explain why students with lower levels of working memory capacity displayed a non-significant synergistic effect.

### **Strengths, Limits, and Future Directions**

In this study, we interpreted the implicit AM  $\times$  explicit AM  $\times$  working memory effect in light of our cognitive resource availability hypothesis. Past research has shown that working memory and intelligence are highly correlated (Ackerman, Beier, & Boyle, 2005). Therefore, it remains uncertain whether our results are specific to working memory or if working memory, general intelligence, or both are responsible for the effect that we observed in this study.

Researchers should measure both working memory and intelligence to investigate their unique contribution in moderating the implicit AM  $\times$  explicit AM effect. Observing that only intelligence moderates the synergistic effect of implicit and explicit AM would indicate that individual differences in cognitive abilities is the pivotal factor explicating why the integrative process does not always positively predict academic achievement. Observing that only working memory moderates the synergistic effect would support our cognitive resource availability hypothesis. For now, considering that we only measured working memory, it is important to highlight that both interpretations are equally defensible and would require future scrutiny in a study designed to compare their tenability.

This study relied on a longitudinal design in which all variables were measured rather than experimentally manipulated. Although our results cannot be interpreted as offering support for the causal effect of AM, it is important to highlight that motivation measured during the

semester *prospectively predicted* their semester grade point average while controlling for admission GPA. Understanding the factors associated with success of university students is a national priority to promote well-being, optimal learning, and timely graduation on the campuses across the country (CACUSS, 2013; Douce & Keeling, 2014). Nonetheless, research will be needed to determine whether we can generalize our result to younger populations of students such as those in high school and elementary school. Investigating the synergistic effect and the integrative process at earlier educational and developmental stages during which greater variance should be found in cognitive resources of students would permit greater generalization of these effects. The integrative process of one's motivation into a unified sense of self has probably some developmental features that will also need to be investigated in future research. Knowing that working memory capacity follow the general trend of brain maturation from childhood to late adolescence (Conklin, Luciana, Hooper, & Yarger, 2007), we could expect the integrative process to follow the same maturation process. Interestingly, the association of working memory and academic achievement had only been infrequently assessed with university students (Rohde & Thompson, 2007). Our study thus complements this scant literature while highlighting the need to examine to which extent and why does the relation between working memory and school achievement seems to fluctuate across age groups. Overall, replication is warranted considering the complexity of our hypothesis and our acceptable but relatively small sample size.

In recent research, other measures like the implicit association test (IAT) were used to assess implicit motivation within the SDT framework (Keatley, Clarke, Ferguson, & Hagger, 2014; Keatley et al., 2013a, 2013b). So far, research has yet to compare the predictive power of different methods used to assess implicit AM. As such, future research should incorporate multiple measures of implicit motivation to compare their predictive validity. Moreover, our

study did not yield a large number of trials for the lexical decision task which could limit the interpretability of our implicit scores of motivation. The number of trials was however based on past studies using the same methodology (Burton et al., 2006) in order to facilitate comparison of our results with those already published in the extant literature. Despite the need to triangulate our findings with other implicit measures, a notable strength of our study was the minimization of common-method bias because different methods were used for each variable: self-report measure for explicit AM, response latency scores for implicit AM, span task scores for working memory capacity, and objective semester grade point average for academic achievement. Therefore, we have reason to believe that the effects reported in this study have not been overestimated by a shared method variance bias.

An important avenue of future investigation in motivation sciences would be to expand our findings by examining different positive outcomes. In the SDT literature, integration has been associated with well-being (Weinstein et al., 2011), sustained energy (Ryan & Deci, 2008), better adaptation to stress (Weinstein & Ryan, 2011), and non-defensiveness (Weinstein, Brown, & Ryan, 2009). Success in the school domain can be difficult to obtain because it requires sustained effort, dedication and task engagement, and it is also something that is rare given that a normal curve is either implicitly or explicit imposed on the distribution of grades. Accordingly, investigating the association of integration with other performance outcomes that might be less influenced by administrative schooling policies (e.g., school engagement, personal goal progress, and personal improvement) is an interesting avenue for future research.

### **Conclusion**

In past studies, the association between AM and academic achievement was weaker than expected and inconsistent across studies. In this study, we explored different avenues from social

cognition in order to unpack the somehow small association between AM and academic achievement. Information obtained with self-report questionnaires is valuable but probably gives an incomplete picture of the motivations at play (Wigfield, Cambria, & Eccles, 2012). We have thus used a mixture of explicit/direct and implicit/indirect measures of motivation as a way to captures the intricate nature of the integrative process – a central argument of SDT. In this study, we contended that explicit AM is likely to promote school achievement when it is part of an *integrated cognitive system that combines* easily accessible mental representations (high implicit AM) and efficient executive functioning (high working memory capacity). We showed that high level of working memory appears needed to maximize the extent to which the synergistic interaction between implicit and explicit AM positively predicts academic achievement. Although the integration of implicit and explicit AM might be desirable to promote academic achievement, such as synergy appears to benefit those students with a higher level of working memory. Integration might be cognitively demanding and it appears like a sufficiently high amount of working memory capacity can act as a bottleneck that limits the potentially desirable effect of autonomous motivation on academic achievement.

### Footnotes

<sup>1</sup> Please note that this negative correlation should be interpreted as a positive correlation. High scores on an implicit measure with a lexical decision task denote low level of implicit motivation and vice versa. In this particular association, higher level of implicit motivation was associated with higher semester grade point average.

<sup>2</sup> Study 2b of Burton et al. (2006) reported a significant implicit  $\times$  explicit effect to predict semester GPA. However, the study relied on a sample of participants who previously took part in a study in which intrinsic motivation was primed (see Study 2a). Furthermore, the statistical analyses were under-powered due to a small sample size and the median-split approach to probe the interaction may have complicated the interpretation while potentially creating spurious findings that are unlikely to replicate.

<sup>3</sup> Explicit and implicit controlled motivation interaction was tested and revealed no significant interaction ( $\Delta F_{(1,265)} = 0.947; p = .330$ ). Triple interaction of explicit controlled motivation, implicit controlled motivation, and working memory was also not significant ( $\Delta F_{(1,261)} = 0.712; p = .399$ ) when predicting academic achievement.

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Table 1  
*Descriptive Statistics and Zero-Order Correlations*

Variables	<i>M</i>	<i>SD</i>	Skew	Kurtosis	1	2	3	4	5	6
1. Explicit AM	4.924	1.039	-0.399	-0.260						
2. Explicit CM	2.544	1.299	0.755	-0.061	.039					
3. Implicit AM <sup>a</sup>	35.006	62.143	2.007	11.703	.115*	.054				
4. Implicit CM <sup>a</sup>	33.227	62.925	0.926	5.245	.057	-.063	.530**			
5. Global WMC	55.271	11.404	-0.900	0.664	.046	.065	-.019	-.044		
6. Admission GPA	8.464	1.308	-0.899	0.615	.089	-.117	-.112*	.044	.187*	
7. Semester GPA	6.700	1.702	-0.344	-0.176	.189**	.050	-.154**	-.119	.126	.291**

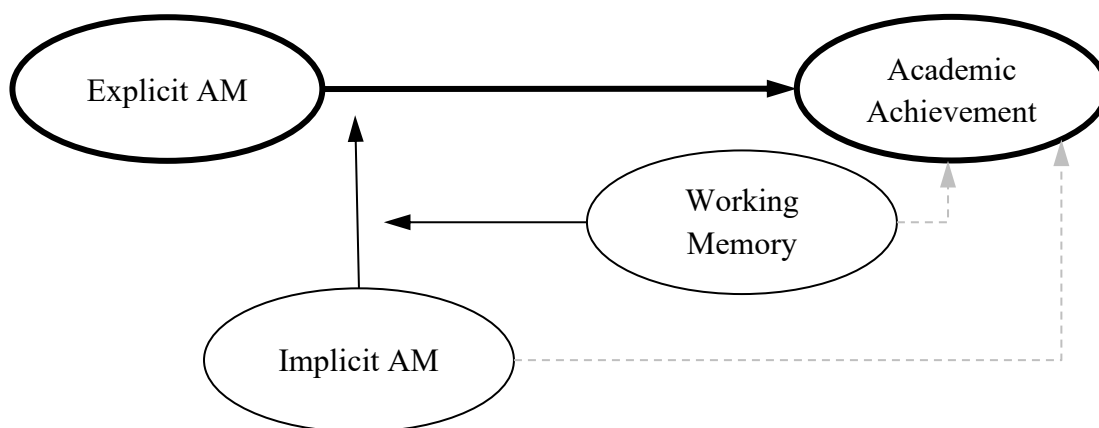
*Note.* \*  $p < .05$  \*\*  $p < .01$ . AM = Autonomous motivation. CM = controlled motivation. WMC = working memory capacity. <sup>a</sup> Faster reaction time (lower score) denotes higher implicit motivation.

Table 2

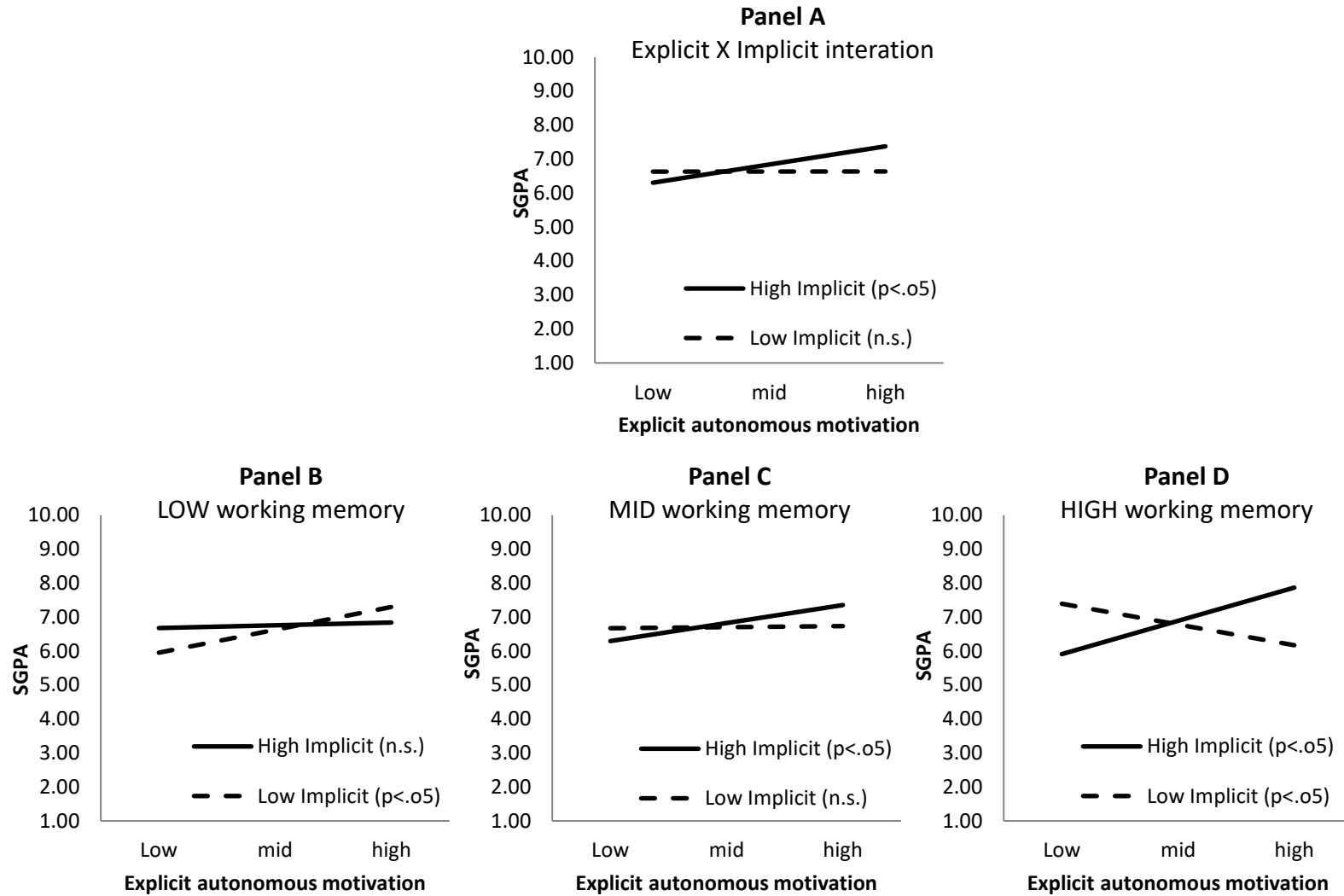
*Hierarchical moderated regression analysis for the three-way interaction models*

Variables	Step 1		Step 2		Step 3	
	<i>t</i>	$\beta$	<i>t</i>	$\beta$	<i>t</i>	$\beta$
Main effects						
Explicit autonomous motivation (AM)	2.852	.177**	2.452	.157*	2.763	.166**
Implicit autonomous motivation (AM) <sup>a</sup>	-1.333	-.106	-0.753	-.064	-0.423	-.035
Working memory capacity (WMC)	0.921	.059	0.941	.062	0.651	.043
Interaction terms						
Explicit AM $\times$ implicit AM			-1.816	-.129	-2.043	-.122*
Explicit AM $\times$ WMC			-0.314	-.021	-0.974	-.056
Implicit AM $\times$ WMC			-0.009	-.001	0.041	.003
Explicit AM $\times$ implicit AM $\times$ WMC					-3.911	-.226**
Control variables						
Explicit controlled motivation	1.147	.071	1.081	.065	1.198	.073
Implicit controlled motivation <sup>a</sup>	-0.791	-.078	-0.815	-.080	-0.640	-.063
Admission GPA	3.836	.265**	3.843	.270**	3.816	.269**
Variance explained $R^2$ ( $\Delta R^2$ )	14.7%		15.9% (1.2%)		20.9% (5%)	
F change statistics	7.611**		1.132		15.296**	

Note. \*  $p < .05$  \*\*  $p < .01$ . <sup>a</sup> Faster reaction time (lower score) denotes higher implicit motivation.  $N = 272$ . Standardized coefficients are presented. Presented t-tests are based on the unstandardized coefficients and their respective standard errors.



*Figure 1.* The explicit-implicit model of autonomous motivation. Implicit AM moderates the association between explicit AM and academic achievement whereas working memory moderates the explicit AM  $\times$  implicit AM interaction. AM = Autonomous motivation.



*Figure 2.* Results from simple slope analysis. Panel A is for the explicit-implicit interaction. Panel B-C-D pertain to the three-way interaction. High implicit corresponds to faster reaction time (lower response latencies) on implicit autonomous motivation. Low implicit corresponds to slower reaction time (higher responses latencies) on implicit autonomous motivation.

### **CHAPTER 3: Reciprocal effect of AM and replication of study 1**

The Relationship between Autonomous Motivation and Academic Achievement Goes Both  
Ways and Depends on Implicit Motivation and Working Memory Capacity

Submitted at *Learning and Individual Differences* on the 30<sup>th</sup> of August 2018

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### Abstract

Self-determination theory (SDT) assumes that students who act with more volition and autonomy are more likely to be successful in their academic career. In this study, we sought to investigate two lingering issues about the association between autonomous motivation (AM) and academic achievement. On the one hand, past academic achievement are most certainly important to the development of future AM, but the reciprocal nature of this association has been largely ignored in the literature. On the other hand, assessments of dispositional AM through self-reported methodology may not fully capture the internalization process of AM. Recently, it was proposed that adopting a dual-process perspective over AM could enable of more precise observation of internalization (*explicit-implicit model of AM*; Gureau & Gaudreau, 2017). We sought to replicate the results of this model which contends that AM is mostly efficient when accompanied in synergy with high levels of implicit AM and working memory. During a semester, 257 university students completed a self-report measure of AM, a lexical decision task of AM and working memory tasks. Semester GPA was used as the main dependent variable and, in order to explore reciprocal mechanisms, admission GPA was used as an indicator of past academic achievement. A Bayesian moderated mediation model was estimated and revealed a small significant reciprocal effect of explicit AM and academic achievement. The Bayesian model succeeded to replicate the result of Gureau and Gaudreau (2017), thus strengthening postulates of the dual-process perspective of AM. Implications for SDT are further discussed.

## The Relationship between Autonomous Motivation and Academic Achievement Goes Both Ways and Depends on Implicit Motivation and Working Memory Capacity

Self-Determination Theory (SDT) proposes that individuals who pursue their activities out of pleasure and for reasons that are aligned with their personal interest, values and goals are more likely to thrive in the educational domain (Deci & Ryan, 2008). Countless studies have revealed that academic autonomous motivation (AM) is a desirable psychological factor for a host of academic outcomes, from primary to tertiary education. Students with higher AM experience more positive achievement emotions (Gonzalez, Paoloni, Donolo, & Rinaudo, 2012; Kim & Pekrun, 2014), generally persevere more in their studies (Guay, Lessard, & Dubois, 2016), can consolidate new knowledge better (Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004), have higher subjective well-being (Levesque, Zuehlke, Stanek, & Ryan, 2004), and experience lower dropout intentions (Hardre & Reeve, 2003; Vallerand, Fortier, & Guay, 1997). Ultimately, students who display higher levels of AM should be psychologically equipped to reach higher levels of achievement. However, a meta-analysis revealed a surprisingly small but positive association between academic AM of university students and their academic achievement ( $r = .17$ ; Richardson, Abraham, & Bond, 2012). Even if AM is a strong and robust predictor of many good educational outcomes, academic achievement remains the yardstick used to benchmark students. Hence, exploring more deeply this unexpectedly small relationship is pivotal for further theory elaboration and the development of motivational interventions that would promote the academic success of university students.

In this study, our goal was to address two lingering issues about the relationship between AM and academic achievement. First, researchers have largely focused on the unidirectional influence of AM on academic achievement. However, SDT assumes that the development and

particularly the maintenance of AM operates reciprocally with the environment (Ryan & Deci, 2017). Past academic achievements are more than just a test-retest of achievement overtime and can thus be conceptualized as an informational-feedback for students that may facilitate the development and maintenance of AM during their academic curriculum. In turn, the developed AM of university students should predict their subsequent university achievement while controlling for their past achievements. Secondly, a recent study from Gareau and Gaudreau (2017) proposed a novel approach that explains why the relation between AM and academic achievement is of such low magnitude. Based on arguments from implicit social cognition, they proposed that the relation between AM and academic achievement is higher for students who also possess higher levels of implicit AM and working memory capacity. Herewith, the goal of this study was to replicate the preliminary findings from this *explicit-implicit model of AM* (Gareau & Gaudreau, 2017) and to expand this research by examining a reciprocal model in which past academic achievement predicts explicit AM, which in turn predicts subsequent academic achievement.

### **AM Predicts Academic Achievement and Vice Versa**

SDT assumes that individuals are inherently curious, self-motivated and eager to develop and maintain their competence, because succeeding, regardless of the context, is personally satisfying and rewarding. However, this natural tendency is not deployed similarly across individuals because of the direct influence of socio-environmental factors that are known to modulate the satisfaction of basic psychological need (i.e. autonomy, competence, affiliation). For these reasons, SDT has been widely applied to the educational context because of its heuristic value in investigating interindividual differences in academic motivation. SDT distinguishes five types of behavioral regulations (external, introjected, identified, integrated, and

intrinsic) that guide individuals' behavior. The actions of individuals who display higher levels of external and introjected regulation are said to be more controlled and mostly guided by external factors to their *self*. In contrast, individuals who display higher levels of identified, integrated, and intrinsic regulations act more autonomously and their behaviors are mostly dictated by their *self* (Deci & Ryan, 2008). On the one hand, students who pursue their academic activities with high levels of controlled motivation (CM) are doing it for external reasons, to obtain rewards, avoid undesirable consequences, and out of shame or guilt. On the other hand, students displaying high levels of AM are pursuing their academic activities out of volition, pleasure, interest, and because they feel that going to school is part of who they are. In the current study, we focused on AM given the centrality of autonomy in SDT and its importance in promoting achievement, well-being, health, and general self-functioning.

Positive associations have usually been found between indicators of AM and academic achievement. However, the strength of this association has not been consistent across studies. Some studies reported a strong association (Fortier, Vallerand, & Guay, 1995; Guay & Vallerand, 1997; Mega, Ronconi, & De Beni, 2014) and others reported a weak association (Black & Deci, 2000; Cokley, Bernard, Cunningham, & Motoike, 2001; Fairchild, Horst, Finney, & Barron, 2005). Recent meta-analyses have revealed a positive association between indicators of academic AM and achievement across different educational levels (Cerasoli, Nicklin, & Ford, 2014; Richardson et al., 2012; Taylor et al., 2014). The overall effect found in those meta-analyses was relatively small but positive ( $r \approx .177$ ), thus revealing the need to further elucidate for whom and under which conditions AM can influence academic achievement more strongly.

Most studies conducted thus far have examined the influence of AM on achievement without considering the influence of achievement on AM. The reciprocal nature of the

relationship between academic AM and achievement has remained largely unexplored despite being a central assumption of SDT (Sheldon & Houser-Marko, 2001; Vallerand, Pelletier, & Koestner, 2008). University students have completed primary and secondary education; they thus have an extensive developmental history of academic achievements. Throughout their K-12 education journey, university students have accumulated knowledge and psychosocial skills that provide them with resources to deal with the many challenges of tertiary education. As such, students do not enter university with a blank slate and their past academic achievements are likely to influence the reasons why they participate in tertiary education. Studies investigating the reciprocal effect of AM and achievement have mostly been conducted with samples of elementary school students. Results revealed a somewhat smaller than expected positive reciprocal effect of intrinsic motivation and academic achievement (Garon-Carrier et al., 2016; Schaffner, Philipp, & Schiefele, 2016; Weidinger, Spinath, & Steinmayr, 2015; Weidinger, Steinmayr, & Spinath, 2017). Similar findings were obtained in a long-term longitudinal study with a sample of students followed from primary (3<sup>rd</sup> grade) to junior high school (8<sup>th</sup> grade; Corpus, McClintic-Gilbert, & Hayenga, 2009). High school students were also surveyed in another study, and a small positive reciprocal effect of academic intrinsic motivation and self-reported academic achievement was found over a one year period (Taylor et al., 2014). A study was also conducted on the transition from high school to pre-university college (Taylor et al., 2014; study 3) and it was found that intrinsic motivation was still a relevant predictor of subsequent achievement, but introjected and amotivation regulations were also negative predictors of achievement in the first year of college. In the same study, high school achievement was not a significant predictor of intrinsic motivation once in college, but it is important to note that for this specific study past achievement was an aggregation of math and science only.

Overall, AM and achievement do seem to operate under relatively small reciprocal effects that are nonetheless fairly consistent across studies.

### **A Dual-Process Perspective of AM**

All of the above reviewed studies have reported associations between self-report measures of AM and academic achievement. Even if self-report measures offer valid and reliable information on individuals' motivation, they are highly contingent on the cognitive accessibility of such abstract construct. Participants are retrieving mental representations about themselves when filling up a self-report measure, but the clarity of this retrieval can be limited by *the motivation of individuals* in reporting their mental content, *the circumstance* in which they are reporting their mental content, *their own ability* in reporting this specific content and/or *their awareness* of the mental content, as the content can be unavailable or blocked during the retrieval process (Nosek, Hawkins, & Frazier, 2011). Consistent with most dual-process theories on learning, reasoning and social cognition (Evans & Frankish, 2009), the *explicit-implicit model of AM* (Gareau & Gaudreau, 2017) differentiates the *declarative knowledge* assessed with self-report methodology through a conscious/controlled/explicit/declarative cognitive process from the *non-declarative knowledge* assessed with indirect cognitive methodology through an unconscious/automatic/implicit/non-declarative cognitive process.

Dual-process theories have yet to be fully taken into consideration by SDT researchers. However, propositions have been made to include social cognition principles like automaticity, awareness, and defensiveness to the SDT framework (Levesque, Copeland, & Sutcliffe, 2008; Weinstein, Przybylski, & Ryan, 2013). Different experimental studies have used priming methodology to induce AM and have found that individuals primed with words characterized by autonomous motivation performed better on a variety of tasks (e.g. Hodgins et al., 2010;

Lévesque & Pelletier, 2003; Radel, Sarrazin, Jehu, & Pelletier, 2013; Radel, Sarrazin, Legrain, & Gobancé, 2009; Radel, Sarrazin, & Pelletier, 2009). Based on the principle of automaticity (Bargh, Schwader, Hailey, Dyer, & Boothby, 2012), the mental representation accessibility of one's AM and CM can be indirectly measured by assessing the rapidity to which an individual reacts to specific stimuli of AM and CM. Researchers conducting correlational studies have thus used indirect cognitive measures to capture individual differences in implicit AM (Burton, Lydon, D'Alessandro, & Koestner, 2006; Keatley, Clarke, & Hagger, 2012, 2013a, 2013b; Levesque & Brown, 2007; Lévesque & Pelletier, 2003). For example, if someone has high levels of AM, he/she should react more rapidly to stimuli (e.g., words) associated with AM, as this information should be more easily accessible for this person.

In a recent theoretical paper, Weinstein et al. (2013) have proposed that the convergence between implicit and explicit AM should be taken as an indicator of integration. In other words, the integrative process might not be fully captured by the sole explicit assessment of AM. A complete account of one's integration of AM in the *self* would be better conveyed through a dual-process model that considerate both the awareness of such motivation and how easily accessible those mental representations are. Based on this assumption, Gareau and Gaudreau (2017) recently proposed an *explicit-implicit model of AM* to elucidate the complex association between AM and academic achievement. Results of a study conducted with a sample of 272 university students revealed that implicit AM moderated the relationship between explicit AM and academic achievement. Explicit AM was a significant predictor of academic achievement only for students with higher levels of implicit AM. For the students with lower implicit AM, the association between explicit AM and academic achievement was not significant. Those results hold up even when controlling for explicit CM and past academic achievement. The explicit-

implicit model of AM advanced by Gareau and Gaudreau (2017) thus seem to explicate why studies examining the association of explicit AM and academic achievement has produced mixed and small effects. The explicit process of AM might need to act in synergy with its implicit counterpart to maximize the beneficial effect of explicit AM on achievement. It appears that both explicit and implicit AM should be part of a dual-process system in which conscious and unconscious motivation are coherently linked in the self. As such, this coherently organized sense of self – labeled and referred to as an integrative process – suggests that converging high levels of both implicit and explicit self-knowledge denotes and represents an integrated sense of autonomy likely to be conducive of the most desirable outcomes (Weinstein et al., 2013).

As in many dual-process theories, the explicit-implicit model of AM also acknowledges the undeniable influence of cognitive functions, such as the working memory capacity of individuals (Barrett, Tugade, & Engle, 2004; Carlston, 2010; Strack & Deutsch, 2004). Individual differences in the ability to control attention, as conveyed by working memory, might explain have an important role to play in bringing and handling mental representation into awareness. Simply stated, working memory can be seen as the cognitive ability of simultaneously storing and processing information, and can also be described as an attentional system for memory that maintains activation of goal-relevant representations outside of the individual awareness (Kane, Conway, Hambrick, & Engle, 2007), through is executive center (Baddeley, 2012). The activation mechanism that passes through the central executive can thus be considered as “the gateway of accessibility that is the essence of controlled processing” (Barrett et al., 2004, p. 554). Paired with dual-process principles, individual differences in working memory capacity will likely influence individuals’ ability to reflect on their own experience and to control their thought and feelings. As such, the explicit-implicit model of AM

proposed that explicit AM can predict academic achievement when it is accompanied with high levels of both implicit AM (*synergistic hypothesis*) and working memory capacity (*cognitive resources availability hypothesis*). Results from the study of Gareau and Gaudreau (2017) provided initial support for this complex three-way interaction (i.e., explicit AM  $\times$  implicit AM  $\times$  working memory) in predicting academic achievement of university students. Thus a dual-process perspective of AM offers novel insights to further our understanding of the integrative process of SDT by incorporating social cognition principles to the humanistic approach of SDT.

### **The Present Study**

In this study, our goals were twofold: (1) estimating the reciprocal effect of explicit and implicit AM on subsequent academic achievement and (2) replicating the three-way interaction revealed in Gareau and Gaudreau (2017). In this study we relied on a longitudinal design to evaluate the reciprocal effect of explicit and implicit AM on subsequent academic achievement of university students. We hypothesized that admission GPA (i.e., past achievement) would have a positive but small effect of explicit AM at university and that higher levels of explicit AM at university would predict subsequent academic achievement (*reciprocal hypothesis*). We also hypothesized that the association between explicit AM and subsequent academic achievement would be moderated by implicit AM (*synergistic hypothesis*) and that this moderation would be contingent on working memory capacity (*cognitive resources availability hypothesis*). We thus expected that explicit AM predict subsequent academic achievement more strongly for individuals with high levels of both implicit AM and working memory.

### **Method**

#### **Participants and Procedures**

University students were recruited through a participant pool at a Canadian university. The sample consisted of 258 undergraduate students (74.8% female) who studied full time (94.6%), or part-time (5%) and were between the ages of 17 and 58 years ( $M = 19.72$ ;  $SD = 4.16$ ). Students were enrolled in a variety of programs across different faculties: sciences (28.3%), social sciences (26%), health sciences (21.3%), art (14.3%), medicine (4.7%), management (2.7%), and engineering (2.3%). The sample consisted of first (62%), second (22.9%), third (7%), and fourth (7%) year students. Participants described themselves as Caucasian (55.8%), Afro-American (10.2%), Asian (14.8%), Arabic (6.6%), Hispanic (3.1%), Aboriginal/Native (0.7%) and other (8.5%). Each participant received two points toward their introductory psychology class. It is important to mention that this sample did not overlap the sample of Gareau and Gaudreau (2017). However, this sample was used to examine a separate research question, with different nonoverlapping psychological variables predicting semester GPA (Gareau, Chamandy, Kljajic, & Gaudreau, 2018)

Each participant completed an electronic informed consent form and 202 out of the 258 students also authorized the researchers to have access to their semester GPA and high school GPA. A short questionnaire followed to obtain socio-demographic information and a self-reported measure of academic motivation<sup>1</sup>. Two computerized working memory tasks (Operation Span, OSPAN and Reading Span, RSPAN; Unsworth, Heitz, Schrock, & Engle, 2005) were then administered using the E-PRIME software 2.0. Lastly, a lexical decision task measuring implicit motivation was also administered with E-PRIME 2.0. The whole procedure was performed in a lab setting and took approximately 90 minutes.

## **Measures**

**Explicit academic motivation.** A self-report questionnaire was administered as a measure of explicit motivation assessing the five regulations of SDT with two items per regulations; intrinsic ( $\alpha = .867$ ), integrated ( $\alpha = .826$ ), identified ( $\alpha = .785$ ), introjected ( $\alpha = .826$ ), and external ( $\alpha = .909$ ). Participants were asked to respond to which extent each items corresponds to the reason they pursue academic activities (e.g., *It is part of who I am as a person*) on a scale of 1 (*not at all*) to 7 (*totally*). This questionnaire has gone through many confirmatory factor analysis across different samples with good evidence for its reliability, concurrent, and predictive validity (Brunet, Gunnell, Gaudreau, & Sabiston, 2015; Gaudreau, 2015; Gaudreau, Gareau, Franche, Kljajic, & Perreault, 2018). Composite reliability was acceptable for autonomous ( $H\ coefficient = .934$ ) and controlled motivation ( $H\ coefficient = .843$ ).

**Implicit academic motivation.** A lexical decision task (LDT) was administered as a measure of implicit motivation. Participants were presented with strings of letters and asked to indicate whether the strings were words or non-words. Participants were instructed to respond to the strings as quickly as possible and to be as accurate as possible. A total of 276 strings were presented to each participants, half of those strings were non-words generated with Rastle, Harrington, and Coltheart (2002) non-word database. Thus, 136 pronounceable non-words that varied from 5 to 7 letters were used in this LDT. The other half were words split in three categories: neutral, autonomous and controlled words. The specific motivational words were first selected from Gareau and Gaudreau (2017), however, a notable limit of that previous study was that not enough words were presented, which can mitigate the precision of the aggregated reaction time scores. To complement the list of autonomous and controlled motivation words, we scanned various self-report questionnaires that measured the SDT regulation and extracted 46

autonomous and 46 controlled motivation words. In the end, 136 non-words, 46 neutral words, 46 autonomous words and 46 controlled words were used in the LDT. However, once taken out of their original sentence (as per an item in a self-report questionnaire) many of these words were no longer representing the concepts of autonomous and controlled motivation (e.g., happy, joy, love, rule, envied, etc...). Therefore, we decided to only select theory-driven words that were closely aligned with the operational definition of motivation, which led us to select and retain 18 autonomous words and 18 controlled words to create hereafter the scores used in our analyses.

All stimuli were randomly presented for 2000 *ms* in the center of the screen while response time (RT) for each was recorded in milliseconds. Participants had to press as quickly as possible on the “W” key for words and on the “O” key for non-words. All inaccurate response as well as RTs below 250 *ms* were filtered out and not included in the scoring protocol. Moreover, RTs 3.0 standard deviations above and below each individual’s mean were also taken out of the analysis. An individual mean of neutral words was then calculated to assess the baseline reactivity of each participant. All of the motivational words RT were then subtracted from this baseline RT to control for individual variance. The final RTS for each motivational word were thus more comparable across individuals. The 18 theoretically-selected autonomous words and controlled words were then respectively averaged to create the implicit motivation scores. Low scores reflect high levels of autonomous or controlled motivation because they indicate that mental representations of the motivation are more easily and rapidly accessible (i.e., faster response time).

**Working memory capacity.** Two different computerized tasks programed in E-PRIME 2.0 by the Attention and Working Memory Lab (OSPAN and RSPAN; Unsworth et al., 2005) were used in this study to assess the students’ working memory capacity. Both tasks consisted of

remembering different series of letters (encoding) while performing a secondary task (processing). A detailed explanation of the sequence involved in the OSPAN and RSPAN can be found in Unsworth et al. (2005). Working memory capacity scores ranged from 0 to 75 and reflected the number of *memorandum* elements that were remembered by participants (partial-credit load scoring, see Conway et al. (2005)). This scoring method for the OSPAN and RSPAN has been shown to hold good psychometric properties: test-retest, internal consistency, construct validity, and convergent validity (Redick et al., 2012). OSPAN and RSPAN were aggregated to form an overall indicator of working memory capacity. Spearman-brown coefficient was calculated for the two-tasks aggregation (Eisinga, Grotenhuis, & Pelzer, 2013) and provided evidence of acceptable reliability for this sample ( $\rho = .712$ ).

**Academic achievement.** The semester Grade Point Average (SGPA) and the admission GPA (last year of high school) of consenting students was obtained via the registrar's office. The following grading scale is used by the university: 0 = F, 1 = E, 2 = D, 3 = D+, 4 = C, 5 = C+, 6 = B, 7 = B+, 8 = A-, 9 = A, and 10 = A+. SGPA was collected at the end of the semester during which the data collection for explicit motivation, implicit motivation and working memory capacity occurs.

### **Plan of analyses**

Given the main goals of this study, we ran a mediation model of AM between admission GPA and current SGPA (*reciprocal hypothesis*) with the moderation effects (*synergistic and cognitive resources hypothesis*) that were proposed in the explicit-implicit model of AM from Gareau and Gaudreau (2017). We used a Bayesian SEM approach in which informative priors based on previous findings were directly integrated in our hypothesized model.

Regression parameters are thus attributed a starting point (informative priors) that is mixed with the new data to form a *posterior distribution*. This idea of updating the results of past studies through a Bayesian approach has been brought to the field of psychology as a tool to overcome the limited interpretability of a sole study (van de Schoot, Winter, Ryan, Zondervan-Zwijenburg, & Depaoli, 2017). Overall, this approach has many advantages compared to traditional SEM. First, Bayesian estimation has the advantages of not relying on large-sample theory, which facilitates model convergence without compromising the trustworthiness of parameter estimates. Plus, this approach also creates an actual distribution (i.e., posterior distribution) around key parameters rather than assuming a normal distribution. Given that, the parameters estimated in the model can then be interpreted in terms of their most probable values (Kruschke & Liddell, 2017). The distributions properties of the posterior parameters obtain from the Bayesian estimation are easier to interpret and are interpreted more intuitively than the traditional p-value interpretation and/or the 95% confidence intervals around parameters estimated with the maximum likelihood estimator used in the frequentist approach. With the Bayesian approach, we can use the posterior distribution's mean and standard deviation to assess the probability of an effect to be completely null given the data. Posterior probability intervals (PPI) are thus calculated with 95% interval to assess the probability of the true value to lie between the two boundaries. However, in order to not fall into a black-and-white thinking it was recommended by Kruschke and Liddell (2017) to define a region of practical equivalence (ROPE) around the null value to avoid interpreting the effect size only in light of their potential absence. For this study, we suggest that an effect size smaller than .05 would be impracticable (ROPE =  $< |.05|$ ). This zone will be used to represent effects that are practically insignificant.

Bayesian SEM does not use traditional fit indices to evaluate the exactness of the hypothesized model with the data. First, Bayesian analysis uses the Markov Chain Monte Carlo (MCMC) algorithm for the estimation process. Different chains (two chains for our model) work in parallel and their convergence can be assessed with the potential scale reduction (PSR < 1.01) factor and graphical observation of each trace plot parameters. For the fit of the model, the posterior predictive check (PPC) was created to compare the observed data with the data simulated based on the posterior estimation. PPC-values around .50 indicate a well-fitting model. Model selection was done with the deviance information criterion (DIC) and the effective number of parameters ( $pD$ ) that can be interpreted as the posterior mean of the deviance minus the deviance of the posterior means. Lower DIC and  $pD$  suggest that the model is less prone to predictive errors in a future dataset with the same structure. All of the analysis were performed in MPLUS 7 (L. K. Muthén & Muthén, 1998-2012).

## Results

### Preliminary analyses

A first Bayesian model was estimated with all of the zero-order correlations between the observed variables. Observed variables were standardized beforehand and informative priors on the mean of each variable was set to reflect a normal distribution with a mean of 0.0 and a standard deviation of 1.0. This Bayesian model was well-fitted ( $ppp = .437$ ) and had good convergence (PSR = 1.002). Descriptive statistics and zero-order correlations are shown in Table 1. As expected, explicit AM was positively correlated with SGPA ( $r = .244$ , 95% PPI [.096, .393]) which was also found in a past meta-analysis (Richardson et al., 2012). However, implicit AM, explicit CM, and implicit CM were not significantly associated with SGPA. Interestingly for our reciprocal hypothesis, admission GPA was positively correlated with explicit AM ( $r =$

.177, 95% PPI [.024, .340]) but not with implicit AM, explicit CM, and implicit CM. Admission GPA was also positively correlated with SGPA ( $r = .330$ , 95% PPI [.175, .502]) demonstrating a somewhat general pattern of achievement stability across individuals. Lastly, as expected, working memory was positively correlated with both admission GPA ( $r = .200$ , 95% PPI [.047, .366]) and SGPA ( $r = .236$ , 95% PPI [.081, .402]).

### **Bayesian SEM analyses of the moderated mediation model**

For the main analysis, we estimated a Bayesian model with admission GPA as the main independent variable and SGPA as the main dependant variable. All of the motivational constructs were mediators in this relationship and working memory was a predictor of SGPA. Moreover, moderation effects were added on the path from explicit AM to SGPA. Implicit AM was the first moderator to be added to this specific path and then working memory was added as a moderator of the previous moderation – in a triple interaction fashion. This model was created to first depict the reciprocal hypothesis of achievement and AM and then the synergistic hypothesis and the cognitive resources hypothesis proposed by Gareau and Gaudreau (2017). This final model is presented in Figure 1.

In light of the methodological recommendations (van de Schoot et al., 2017; Zyphur & Oswald, 2013), different priors were used in this Bayesian SEM (see Table 2). First, the default prior setting for the residual variance of each observed variable was over ruled to express an inverse gamma distribution that excludes completely the possibility of estimating a value below zero, as per the recommendation (van de Schoot, Broere, Perryck, Zondervan-Zwijnenburg, & van Loey, 2015). In addition, it is also recommended to standardized all of the observed variable in order to set regression path priors according to a common scale (B. Muthén & Asparouhov, 2012). Since, all observed variables were standardized, we decided to add priors on the intercept

and mean parameters reflecting a normal distribution with a mean of 0.0 and a standard deviation of 1.0. Given our goal of replicating the effects found in Gareau and Gaudreau (2017), we added informative priors based on the reported standardized effect and the standard error of this past study, on all of the regression coefficient predicting SGPA. Lastly, we added a prior on the regression path between admission GPA and explicit AM to depict a small but positive effect, as found in past literature reporting reciprocal effect of achievement and AM. The variance of this effect was set to reflect the possibility that a null effect might be true ( $\sigma = .01$ ; 95% limits  $\pm .20$ ).

This Bayesian SEM with all of the specified priors reached good convergence (PSR = 1.005, chains = 2, iterations = 50 000) and inspection of trace plots was deemed satisfactory. The probability of hypothesized model was also acceptable (PPP = .465). As recommended by van de Schoot et al. (2017) sensitivity analyses were also performed on all of the replication priors to ensure that the different specified priors were not dramatically influencing the parameters' posterior distribution (see Table 3). More specifically, we increased the variance around the set value for each replication regression coefficient priors. The interaction effect of explicit AM and implicit AM (*synergistic hypothesis*) while controlling for the effect of working memory capacity was found to be highly stable across models using slightly different priors. The interaction of explicit AM, implicit AM, and working memory showed some instability that seemed to be generated by the stronger association found between working memory and SGPA and the simple interaction of implicit AM and working memory. We further examined the sensitivity of the interaction terms pertaining to the triple interaction effect as reported in Figure 2. The instability was not excessive as we increased the variance of the replications priors. More importantly, we can observe in Table 3 that the *DIC* and the *pD* was the lowest when the replication priors were added and their respective variances were un-modified. Both key

interaction terms were far enough from the predetermined ROPE ( $< |.05|$ ), thus indicating that their effects were practically interpretable. Therefore, based on all of the evidence, the model in bold was the one retained for subsequent analysis of both the indirect effects and simple slopes of the significant interactions (see Table 3).

### **Indirect effects for the reciprocal hypothesis**

Indirect effects were calculated in the Bayesian SEM and are presented in Table 4. Explicit AM was found to be a significant mediator in the relationship between admission GPA and SGPA ( $\beta = .026$ ,  $SD = .012$ , 95% *PPI* [.006, .054]). None of the other motivational constructs were found to be significant mediators. However, the direct effect between admission GPA and SGPA remained significant when mediators were included ( $\beta = .261$ ,  $SD = .048$ , 95% *PPI* [.167, .354]). Explicit AM was thus predicting subsequent SGPA even when controlling for admission GPA. In other words, explicit AM significantly predicted change in academic achievement overtime. More importantly, admission GPA was also a significant predictor of explicit AM at the university level. Therefore, we can assume that the relation between explicit AM and achievement operates in a reciprocal manner with admission GPA influencing explicit AM and explicit AM influencing subsequent GPA.

### **Simple slope effects for the synergistic and cognitive resources hypothesis**

Given the significance of the triple interaction revealed from our chosen Bayesian SEM (see Table 3), we decomposed the interaction in different simple slopes to better illustrate where the effect of explicit AM on SGPA varies in function of the two superimposed moderators (triple interaction effect). A hierarchical sequence was nonetheless performed to assess the amount of unique variance explained by the explicit AM  $\times$  implicit AM, and explicit AM  $\times$  implicit AM  $\times$  working memory interaction terms. From a first model with only the main effects (model 1,  $R^2 =$

.159) to a model with the simple interaction of explicit AM  $\times$  implicit AM (model 2a,  $R^2 = .172$ ) we registered a change of 1.3% of variance explained. Lastly, from a model with all of the first-order interactions (explicit AM  $\times$  implicit AM; working memory  $\times$  explicit AM; working memory  $\times$  implicit AM; model 2b,  $R^2 = .184$ ) to a model with the triple interaction term of explicit AM  $\times$  implicit AM  $\times$  working memory we registered a change of 2.0% of variance explained (model 3,  $R^2 = .204$ ).

Simple slope were calculated at  $\pm 1$  SD of working memory to examine the significance of the explicit AM  $\times$  implicit AM interaction effect. The interaction effect of explicit AM  $\times$  implicit AM was found to be significant for individuals with mean level ( $\beta = -.136$ ,  $SD = .044$ , 95% *PPI* [-.222, -.051]) and high level of working memory capacity ( $\beta = -.280$ ,  $SD = .062$ , 95% *PPI* [-.402, -.158]). There was no significant interaction effect of explicit AM  $\times$  implicit AM for individuals with low level of working memory capacity ( $\beta = .007$ ,  $SD = .055$ , 95% *PPI* [-.101, -.115]). The of explicit AM  $\times$  implicit AM interactions were subsequently examined using simple slope at  $\pm 1$  SD of implicit AM. For individuals with low working memory capacity, the relation between explicit AM and SGPA was significant for those with low level ( $\beta = .221$ ,  $SD = .083$ , 95% *PPI* [.058, .384]) and high level of implicit AM ( $\beta = .206$ ,  $SD = .095$ , 95% *PPI* [.020, .393]). For individuals with average working memory capacity, the relation between explicit AM and SGPA was significant for those with high level of implicit AM ( $\beta = .299$ ,  $SD = .063$ , 95% *PPI* [.177, .421]) but not for those with low level of implicit AM ( $\beta = .027$ ,  $SD = .063$ , 95% *PPI* [-.097, .150]). For individuals with high working memory capacity, the relation between explicit AM and SGPA was significant for those with high level of implicit AM ( $\beta = .393$ ,  $SD = .087$ , 95% *PPI* [.221, .564]) but not for those with low level of implicit AM ( $\beta = -.167$ ,  $SD = .097$ , 95% *PPI* [-.359, .023]). Results of the simple slopes are shown in Figure 3.

## Discussion

In this study, the main goals were to explore the reciprocal effect of explicit and implicit AM with academic achievement and to replicate the findings of Gareau and Gaudreau (2017) in order to reevaluate the explicit-implicit model of AM through a dual-process perspective.

Consistent with our *reciprocal effect hypothesis*, past achievement predicted the explicit AM of university students which, in turn, predicted their subsequent academic achievement. Results of our Bayesian SEM provided further support for the hypotheses of the explicit-implicit model of AM. The association between explicit AM and subsequent academic achievement was moderated by implicit AM (*synergistic hypothesis*) and these results were moderated by working memory capacity (*cognitive resources hypothesis*). As expected students with high levels of explicit AM, implicit AM, and working memory capacity reached, in average, an higher semester GPA. These findings will be discussed in light of their theoretical implications for SDT, implicit cognition and the promotion of academic success.

### The Reciprocal Effect of Academic AM and Achievement

In this study, we explored the potential reciprocal association between AM and achievement of university students. The past achievements of university students encompass an accumulation of academic knowledge and a history of successes and failures that may act as a resourceful motivational factor likely to influence the development of AM once at the university. Our results revealed a small positive association ( $\beta = .161$ ) between admission GPA and explicit AM at university. In turn, explicit AM at university was a significant predictor of SGPA ( $\beta = .163$ ), and significantly mediated the association between past and subsequent achievement. Overall, these findings offer novel support for the reciprocal effect hypothesis. Students who achieved better in their last year of high school were found to display higher levels of explicit

AM at university. Past achievements are thus holding some motivational properties that seem to be used by the students when they are explicitly reflecting on the reasons that motivate their participation at university.

Despite being relatively small, the reciprocal relationship between academic achievement and explicit AM observed in our study provides, for SDT, a strengthened support. SDT is mainly based on an organismic principle that revolves around the idea that humans have an inherent tendency toward growth and unity. This natural process is often referred as the integrative process, which through an accumulation of experiences, skills and knowledge help people develop feelings of effectiveness and wholeness of the self (Ryan & Deci, 2017). The self is said to always aim at maintaining and enhancing its component while preserving its integrity. Interestingly, the self is also theorized to be in an open state, as it is in constant interaction and exchange with the environment. This back-and-forth reciprocity of mutual influence has been largely ignored in the overall empirical SDT literature. As such, our results are important because they illustrate that explicit AM significantly predicts *increases in academic achievement over time*. This finding is consistent with the idea that autonomy is part of an upward spiral (Sheldon & Houser-Marko, 2001) capable of bringing positive changes not only in the well-being of university students but also in their academic achievement. This finding can be reinterpreted in light of many theory-driven arguments.

First, SDT assumes through a cognitive evaluation theory that satisfaction of the need for competence, autonomy, and relatedness is required to sustain the development of AM. Quite clearly, past achievement can be seen as a positive competence feedback likely to promote a more internal perceived locus of causality which allows the students to feel more autonomous and display higher levels of explicit AM. As demonstrated in an experimental study, students

who received informational feedback were more interested and intrinsically motivated, plus they also performed better on the final exam compared to the group that received controlling feedback on their grade (Ryan, 1982). Graduating from high school with good grades also give to the students the opportunity to choose a university and a program in which they really want to get enroll. This opportunity to choose would certainly make the students feel autonomous while facilitating the development of strong social ties, a sense of belonging, and feelings of institutional integration. Hence, the positive association between past achievement and subsequent explicit AM can easily be reinterpreted in light of a need satisfaction perspective.

Regardless, the effect found in this study, from admission GPA to explicit AM at university, is relatively small. One potential reason for such small effect can be interpreted in light of the cognitive evaluations that are made by students when receiving their grades. Grades may not be perceived by all students as pure performance-contingent rewards as they may also be perceived as a natural occurrence of the school context and thus can be perceived primarily as a competence-based information (Ryan & Deci, 2017). A study by Marinak and Gambrell (2008) suggested that the same reward can be constructed differently in order to enhanced intrinsic motivation. Interestingly, when grades are sufficient for graduating, students may cognitively evaluate their grades as information for their competence or as a controlling factor, regardless of the actual level of the grade. Each one may trigger a different development of AM overtime, which may have attenuated the effect found in this study.

Second, many theories of human motivation assume that feedback is required for optimal self-regulation (Bandura, 1997; Carver & Scheier, 1991; Locke & Latham, 1990). On the one hand, grades are used at all levels of education to inform students of their academic competence, progress, competence relative to others, and learning/task mastery. Grades can be seen as a form

of mastery-based informative feedback likely to help students increase and maintain their volitional engagement with school. On the other hand, grades can also be seen as a form of evaluative feedback nested in a system in which the rewards are contingent on a certain degree of achievement. Students are benchmarked based on their grades for admission purposes, access to graduate school, and awards/scholarships. As a result, many students experience achievement-related concerns (e.g., test anxiety, fear of failure, perfectionistic concerns) likely to attenuate the satisfaction of their need for competence. Grades are ubiquitous in the educational environment and students have developed perceptive patterns of what those grades really mean to them. The dual functions of grading (i.e., informing and evaluating), likely explain why the size of the effect of past achievement on explicit autonomous motivation is relatively small rather than strong.

Third, several theories of human motivation emphasize the pivotal role of success for the development and maintenance of motivation (e.g., Bandura, 1997; Marsh, Xu, & Martin, 2012; Weiner, 2010). On the one hand, the feedback provided by the grades on the competence of the students is certainly tied to their feelings of effectiveness in this world. Positive expectancies in the form of self-efficacy and self-concept are both influenced and are influencing academic achievement (Chemers, Hu, & Garcia, 2001). Therefore, our results contribute to this growing perspective by showing that both quantity-based and quality-based motivational processes, like explicit AM, can also operate in a reciprocal manner. Much can be learned from expectancy-based motivation to understand the relatively small effect of achievement on explicit AM. Expectancies are not formed solely based on one's level of achievement. Students from more selective high school end up experiencing lower academic self-concept than students from less selective high school (Marsh & Hau, 2003). Such a big-fish-little-pound effect could potentially

explain why not all students with high admission GPA possess positive academic expectancies and perhaps also high levels of explicit AM. Hence, the reciprocal effect of academic achievement and AM is perpetual and inevitable, but is interspersed with diverse psychological and social factors. Overall, future work is required to investigate the precise mechanisms both mediating and moderating the relationship between past achievement and explicit AM.

### **Replication of the Synergistic Effect of Explicit and Implicit AM**

This study provides additive support to the synergistic hypothesis of explicit and implicit AM in the prediction of subsequent academic achievement. Moreover, as it was previously found, the synergistic effect of explicit and implicit AM was contingent upon the cognitive resources of the students. The replication of the three-way interaction effect was estimated with an updating Bayesian approach. The estimated effect sizes found in Gareau and Gaudreau (2017) were incorporated in our SEM as informative priors and were deemed to have adequate sensibility on the new data. On the one hand, the interaction of explicit AM and implicit AM was highly stable across the sensibility analysis, demonstrating that students with high level of implicit AM were more likely to benefit from having higher levels of explicit AM. On the other hand, the three-way interaction of explicit AM x implicit AM x working memory was less stable when we assessed the sensitivity of the informative priors. Nonetheless, the triple interaction posterior distribution was significant and outside of the predetermined ROPE across the different sensitivity level (99.2% to 77.5%).

The internalization process described by SDT thus seem to be captured more efficiently when the explicit and implicit assessments of AM are taken into account, as demonstrated by our replication of the synergistic effect of AM. To feel autonomously motivated, as captured by the self-report measure of AM, might not encapsulate how well the different regulations are

internalized in the *self*. The self-report measure of AM would capture the full length of the integrative process if everyone had the same introspective ability. However, as demonstrated by our results, students with quicker AM accessibility benefit from having higher levels of explicit AM. Their self-report reflections of AM are thus more unified and coherent within their *self* and lead them to achieve better than the other students who did not have the same accessibility of AM. As proposed by recent theoretical developments in SDT, convergence between explicit and implicit measures of AM could be taken as an indicator of integration (Weinstein et al., 2013).

Moreover, in this study it was also hypothesized that the integrative process would be contingent on the students' cognitive resources. The integrative process is potentially cognitively challenging and demanding, as any other psycho-cognitive processes that take place within the brain. SDT never ignored the neurobiological roots of human behavior and did suggest through an organismic perspective that the integrative process is anchored in the biology of individuals (Ryan & Deci, 2017). Different neuroscience studies revealed that areas of the prefrontal cortex are often activated when self-determined choice are made (Murayama et al., 2013), self-regulation processes are being used (Ryan, Kuhl, & Deci, 1997), and individuals are asked to recruit self-knowledge from their memory (Ochsner et al., 2005). Even in the neuropsychological review of Kuhl, Quirin, and Koole (2015), it was suggested that the integrated self is mostly operant in the right anterior cortex. Interestingly the anterior cingulate cortex (ACC), which is placed exactly between the frontal gyrus and the limbic lobe, has been described as a significant cognitive mediator on emotion regulation (Stevens, Hurley, & Taber, 2011). Internalization thus seems to operate in the prefrontal cortex. The prefrontal cortex is also known to be associated with general executive function and cognitive control and is mostly important for top-down cognitive processes that must be guided by internal states and intention (Miller & Cohen, 2001).

The results of this study reinforce those neurobiological observations. Students with quicker accessibility over their AM were benefiting from displaying higher levels of explicit AM but only if their working memory was average or high. The explicit AM effect on academic achievement was stronger when it was accompanied with high level of implicit AM and average to high level of working memory. Overall, our study did replicate the findings of Gareau and Gaudreau (2017) with a Bayesian modeling approach that included previous findings in the estimation process.

### **Strengths, Limits and Future Directions**

This study relied on a Bayesian estimation approach to replicate a three-way interaction between explicit AM, implicit AM and working memory which has strong implications for SDT. This Bayesian statistical approach to psychological science has been praised by a lot of statisticians in recent years (Kruschke & Liddell, 2017; van de Schoot et al., 2017). This method allows for a more intuitive interpretation of effects given that an actual distribution is estimated on the statistical parameters (posterior distribution). Additionally, using a Bayesian approach orients the researcher attention on the effect size and its distribution instead of the p-value, which is aligned with the recent effort of the “new statistic” (Cumming, 2014). Moreover, this study used a longitudinal design to investigate the reciprocal effect of academic AM and achievement. This is the first study to demonstrate such an effect with university students. Knowing how achievement can contribute to AM and vice versa is important because it shows how achievement feedback is essential for the students to development adequate motivation. Once more, demonstrating the importance of adding institutional resources aimed at helping students engaged autonomously in their academic activities. The success and well-being of university students are a worldwide priority for our societies to be efficient and healthy.

Regardless, this study is not without limitation. First, even if the LDT used to assess implicit AM was improved by incorporating more AM and CM words, the inference and analysis of such measure remain imperfect. Psycholinguistic researches on word processing revealed that reaction times can be influenced by many extraneous factors but the most important one is word frequency in the language (Brysbaert, Mandera, & Keuleers, 2017). Hence, by selecting comparable words in language frequency future research might control for such influence on the reaction time of individuals and enable a more precise estimation of implicit AM.

Future research could use the explicit-implicit model of AM to explore positive outcomes hypothesized to be associated with a well-integrated sense of self (e.g., positive feelings, well-being, and non-defensiveness). Past research revealed a positive association with indicator of integration and well-being (Weinstein, Deci, & Ryan, 2011), adaptation to stress (Weinstein & Ryan, 2011), and emotion regulation (Weinstein, Hodgins, & Ostvik-White, 2011). Regarding the educational context, the explicit-implicit model of AM could also be used to predict other outcome known to be determinant for the success and graduation rate (Rowan-Kenyon, Savitz-Romer, Ott, Swan, & Liu, 2017).

### **Conclusion**

In this study we contended that the association between explicit AM and subsequent achievement is, on the one hand reciprocal, and on the other hand moderated by implicit AM and working memory capacity. Interestingly, the direct influence of past academic achievement on the development or sustainment of AM has hardly been investigated, even though SDT postulates that feelings of competence and effectiveness are crucial for the development of intrinsic motivation. When those feelings of competence are accompanied with feelings of autonomy and a sense of volition over action, individuals will likely develop higher levels of AM

(Ryan & Deci, 2000). In this study we found a small significant reciprocal effect of AM and academic achievement, thus demonstrating that past academic successes are important for the development of AM later in the academic career of students. Once at the university, the explicit AM was also found to be moderated by implicit AM and working memory capacity. The results of the explicit-implicit model of AM described in Gareau and Gaudreau (2017) were replicated with a Bayesian estimation approach. SDT internalization process thus seems to be more precisely estimated when incorporating a dual-process perspective of the *self*. Self-report measures of AM are not erroneous but most likely do not cover the whole internalization process. When in synergy, explicit and implicit AM can predict much more of the variance in academic achievement than the sole effect of explicit AM. In other words, it does not suffice to be aware and to state explicitly your own motivation. For individuals to have fully integrated their AM they need easily accessible mental representations of AM and to be aware of such motivation at the same time. The integrative process was also found to be contingent on the working memory capacity of the students, as the process of integrating one's motivation is cognitively challenging, hence requires efficient executive functioning. The integration of dual-process theories to the general SDT framework still needs to be investigated more thoroughly, but the initial evidence that was provided supports the original SDT proposition.

### Footnotes

<sup>1</sup> This dataset also had measures of self-oriented perfectionism, socially-prescribed perfectionism, coping strategies, goal progress, academic procrastination, task delay, and in class laptop behaviors.

<sup>2</sup> A hierarchical confirmatory factor analysis with the five motivational regulations organized into autonomous and controlled motivation was tested for explicit motivation scale. The fit of this model was deemed appropriate ( $\chi^2_{(30)} = 152.198, p < .001$  CFI = .922, RMSEA = .126 90%CI [.107, .146], SRMR = .105).

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Table 1

*Bivariate association between all observed variables using Bayesian estimation*

Variables	M	SD	1	2	3	4	5	6
1. Admission GPA	8.433	1.030						
2. Explicit AM	4.726	1.133	<b>.177*</b> <b>(.080)</b>					
3. Implicit AM	18.494	40.383	-.019 <b>(.078)</b>	<b>.189*</b> <b>(.071)</b>				
4. Explicit CM	2.951	1.425	-.071 <b>(.079)</b>	-.004 <b>(.069)</b>	.020 <b>(.068)</b>			
5. Implicit CM	19.884	37.407	-.057 <b>(.080)</b>	.023 <b>(.071)</b>	<b>.485*</b> <b>(.076)</b>	.099 <b>(.069)</b>		
6. WMC	55.708	10.511	<b>.200*</b> <b>(.080)</b>	-.060 <b>(.070)</b>	<b>-.188*</b> <b>(.070)</b>	-.077 <b>(.069)</b>	<b>-.152*</b> <b>(.072)</b>	
7. Semester GPA	6.412	2.001	<b>.330*</b> <b>(.083)</b>	<b>.244*</b> <b>(.076)</b>	-.022 <b>(.077)</b>	-.086 <b>(.075)</b>	-.080 <b>(.080)</b>	<b>.236*</b> <b>(.081)</b>

*Note.* In parentheses are the standard deviation from the estimated posterior distribution. When the 95% posterior probability intervals were not including zero the bivariate correlation is marked with an \* in bold. AM = autonomous motivation, CM = controlled motivation, WMC = working memory capacity, GPA = grade point average.

Table 2

*Specified priors and justification of chosen priors*

Regression parameters	Specified prior	Justification
Variance of all observed variables	$\sim\text{IG}(0.5,0.5)$	van de Schoot et al. (2015)
Intercepts of all observed dependent variable	$\sim\text{N}(0,1)$ ;	Observed variables are all z-score transformed
Means of all observed independent variable	$\sim\text{N}(0,1)$ ;	Observed variables are all z-score transformed
<u>Regression path</u>		
Admission GPA on explicit AM	$\sim\text{N}(.15, .01)$	Reflect a small positive effect as found in past literature with a variance that can include the absence of the effect.
Admission GPA on implicit AM	No prior	
Admission GPA on explicit CM	No prior	
Admission GPA on implicit CM	No prior	
Admission GPA on int1	No prior	
Admission GPA on int2	No prior	
Admission GPA on int3	No prior	
Admission GPA on int4	No prior	
Admission GPA on SGPA	$\sim\text{N}(.269, .004356)$	Gareau & Gaudreau (2017)
WMC on SGPA	$\sim\text{N}(.043, .004225)$	Gareau & Gaudreau (2017)
Explicit AM on SGPA	$\sim\text{N}(.166, .0036)$	Gareau & Gaudreau (2017)
Implicit AM on SGPA	$\sim\text{N}(-.035, .006889)$	Gareau & Gaudreau (2017)
Explicit CM on SGPA	$\sim\text{N}(.073, .0036)$	Gareau & Gaudreau (2017)
Implicit CM on SGPA	$\sim\text{N}(-.063, .010201)$	Gareau & Gaudreau (2017)
Int1 on SGPA	$\sim\text{N}(-.122, .003364)$	Gareau & Gaudreau (2017)
Int2 on SGPA	$\sim\text{N}(-.056, .005184)$	Gareau & Gaudreau (2017)
Int3 on SGPA	$\sim\text{N}(-.003, .005184)$	Gareau & Gaudreau (2017)
Int4 on SGPA	$\sim\text{N}(-.226, .003249)$	Gareau & Gaudreau (2017)

*Note.* GPA = grade point average, AM = autonomous motivation, CM = controlled motivation, SGPA = semester grade point average, WMC = working memory capacity, int1 = explicit AM x implicit AM, int2 = explicit AM x WMC, int3 = implicit AM x WMC, int4 = explicit AM x implicit AM x WMC.

Table 3

*Test of different models with increasingly added priors plus a sensitivity analysis for the replication priors*

Models	Model fit indices			Effect size for interaction terms									
	Free parameters = 77			expAM x impAM		expAM x WMC		impAM x WMC		expAM x impAM x WMC		% D ≠ 0	ROPE
	PPP	DIC	pD	$\beta$	<i>SD</i>	$\beta$	<i>SD</i>	$\beta$	<i>SD</i>	$\beta$	<i>SD</i>		
MLR				-.139	.067	-.042	.079	-.083	.079	-.062	.052		
Default Priors	.405	7465.096	72.992	-.137	.071	-.041	.082	-.082	.080	-.061	.061	.841	.572
+ residual priors	.444	7463.085	73.045	-.137	.071	-.041	.081	-.083	.080	-.061	.061	.841	.572
+ intercepts priors	.449	7463.356	73.174	-.137	.071	-.041	.081	-.083	.080	-.061	.061	.841	.572
+ reciprocal prior	.453	7462.718	72.838	-.137	.071	-.041	.081	-.082	.080	-.061	.061	.841	.572
<b>+ replication priors</b>	<b>.465</b>	<b>7456.756</b>	<b>67.687</b>	<b>-.136</b>	<b>.044</b>	<b>-.050</b>	<b>.053</b>	<b>-.015</b>	<b>.051</b>	<b>-.143</b>	<b>.039</b>	<b>.999</b>	<b>.992</b>
+ .005 on $\sigma^2$	.471	7457.633	69.385	-.137	.055	-.049	.062	-.035	.060	-.111	.048	.989	.898
+ .010 on $\sigma^2$	.475	7458.773	70.451	-.137	.059	-.048	.067	-.046	.065	-.098	.051	.973	.827
+ .015 on $\sigma^2$	.468	7459.121	70.812	-.137	.061	-.047	.069	-.053	.068	-.090	.053	.955	.775

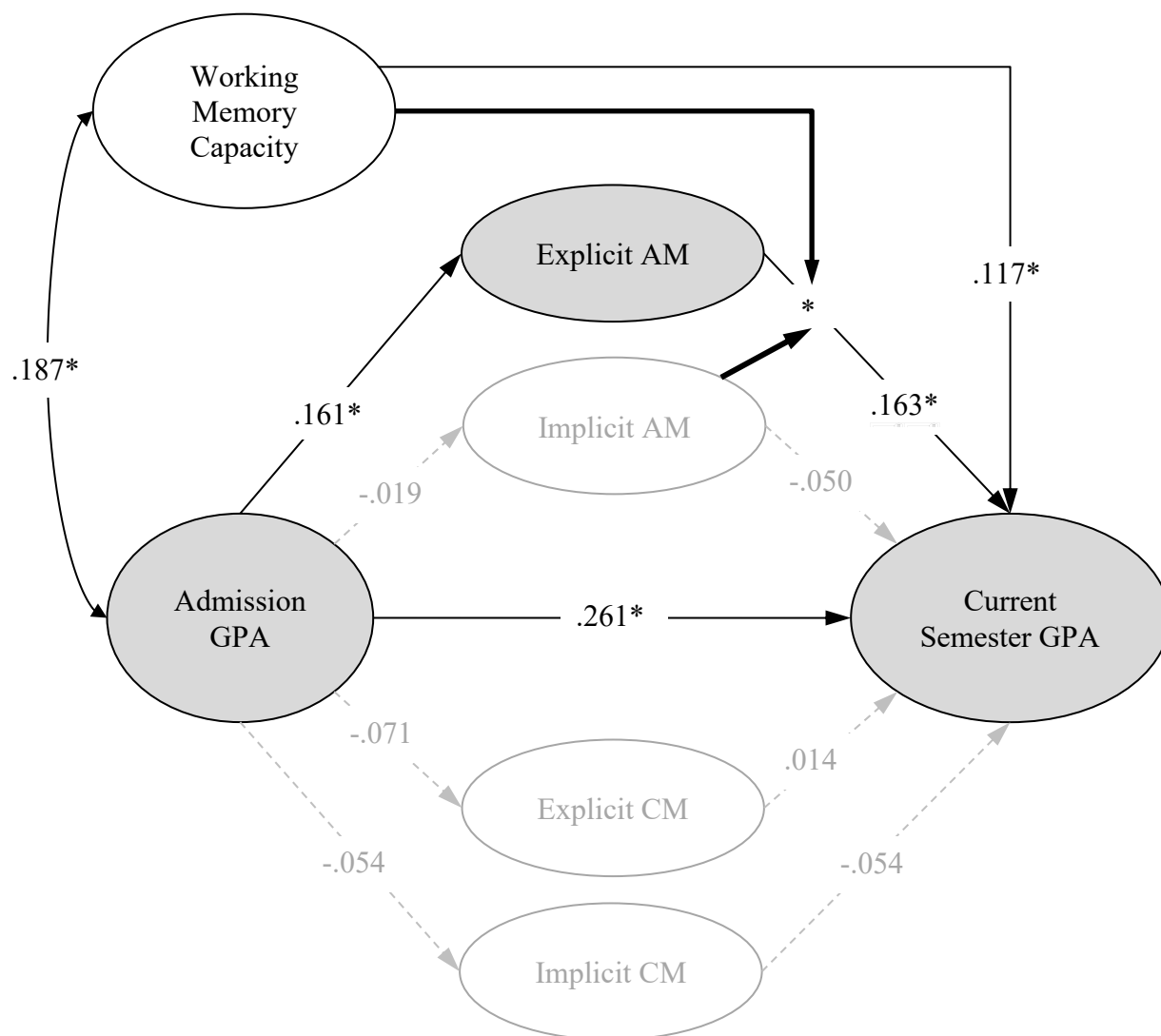
*Note.* PPP = posterior predictive p-value, DIC = deviance information criterion, pD = effective number of parameters, exp = explicit, imp = implicit, AM = autonomous motivation, WMC = working memory capacity, % D ≠ 0 = percentage of the posterior distribution that does not include zero. The model in bold is the mode retain for subsequent analysis. SDs for the MLR models are actually the standard error of the parameters given that no distribution is estimated in the frequentist approach.

Table 4

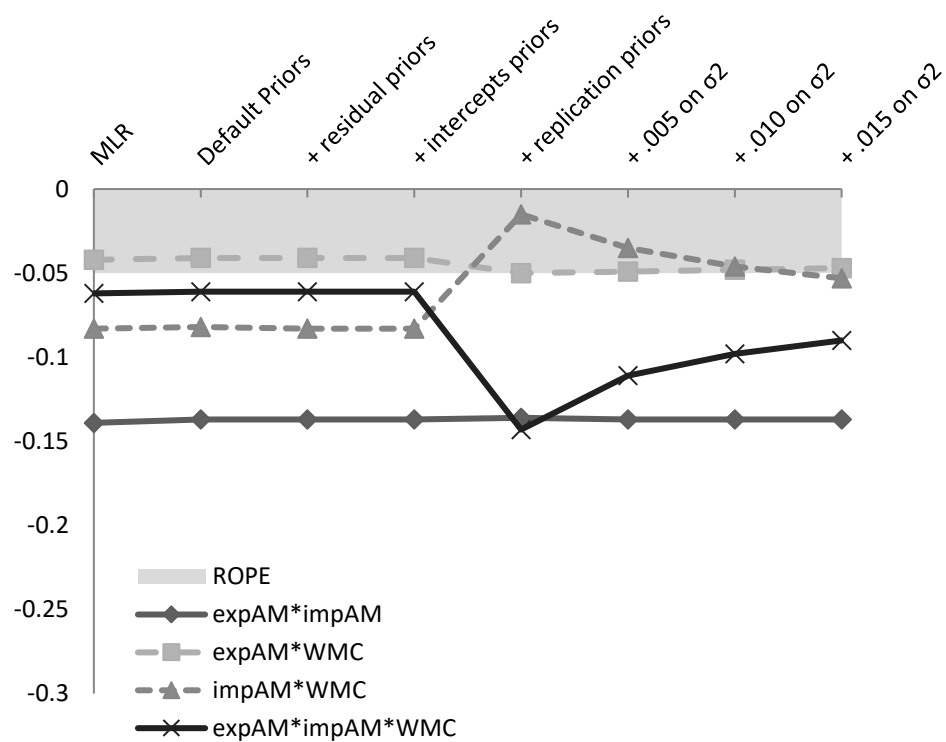
*Unstandardized Estimates of the Total, Direct, and Indirect Effects with 95% Posterior Probability Intervals*

	Total Effect		Direct Effect		Total indirect effect	
	B	95% PPI	B	95% PPI	B	95% PPI
Admission GPA to SGPA	<b>.291</b>	<b> [.194, .388]</b>	<b>.261</b>	<b> [.168, .356]</b>	<b>.029</b>	<b> [.001, .063]</b>
					<u>Specific and conditional indirect effects</u>	
Admission GPA to SGPA via Explicit AM					<b>.026</b>	<b> [.006, .054]</b>
@ +1SD Implicit AM & +1SD WMC					<b>.063</b>	<b> [.015, .124]</b>
@ - 1SD Implicit AM & +1SD WMC					-.027	[-.072, .004]
@ +1SD Implicit AM & mean WMC					<b>.048</b>	<b> [.012, .093]</b>
@ - 1SD Implicit AM & mean WMC					.004	[-.017, .028]
@ +1SD Implicit AM & - 1SD WMC					<b>.033</b>	<b> [.001, .080]</b>
@ - 1SD Implicit AM & - 1SD WMC					<b>.036</b>	<b> [.005, .080]</b>
Admission GPA to SGPA via Explicit CM					-.001	[-.012, .008]
Admission GPA to SGPA via Implicit AM					.001	[-.010, .015]
Admission GPA to SGPA via Implicit CM					.003	[-.009, .020]

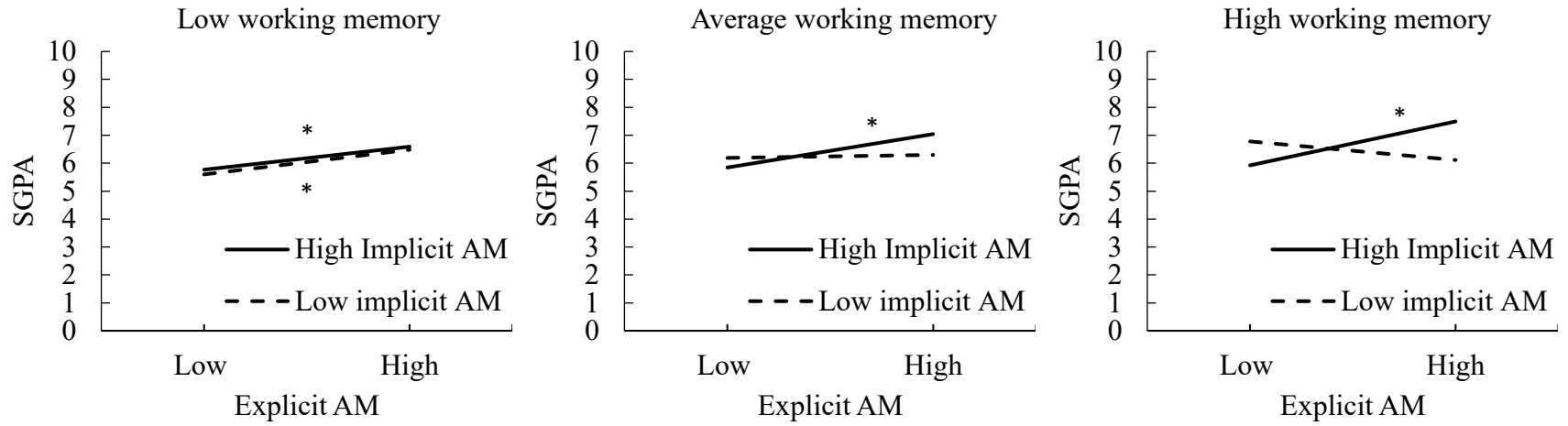
*Note.* SGPA = semester grade point average, GPA = grade point average, AM = autonomous motivation, WMC = working memory capacity.



*Figure 1.* Standardized effects for the Bayesian moderated mediation model. \* denotes effects that are significant. The two bold lines represent the two superimposed moderation effects that form the triple interaction on the path from explicit AM to SGPA. AM = autonomous motivation, CM = controlled motivation. GPA = grade point average.



*Figure 2.* Sensitivity analysis of important hypothesized parameters. ROPE = region of practical equivalence, exp = explicit, imp = implicit, AM = autonomous motivation, WMC = working memory capacity



*Figure 3.* Results of the simple slope analysis for the three-way interaction effect. High implicit level corresponds to faster reaction time (lower response latencies; -1 SD). Low implicit level corresponds to slower reaction time (higher response latencies; +1 SD). IAM = implicit autonomous motivation, AM = autonomous motivation, GPA = Grade Point Average.

**CHAPTER 4: Priming effect of AM on the association between explicit AM and task  
performance**

Subliminal priming of autonomous motivation enables self-evaluation to predict learning  
performance: A dual-process perspective of self-determination theory

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### Abstract

Adopting a dual-process perspective within self-determination theory has recently been found to alleviate predictive issue of academic autonomous motivation (AM) on academic achievement (Gareau & Gaudreau, 2017; Gareau, Gaudreau, & Boileau, 2018). The explicit-implicit model of AM proposed that when both motivational processes are in synergy individuals are regulating their behavior more autonomously, which ultimately benefit their task performance. Moreover, in this predictive model, the motivational synergy is hypothesized to be contingent on working memory capacities (WMC). This study examined the causal influence of subliminal priming of AM on the association between explicit self-reported AM and examination performance. An experimental learning situation, on modular arithmetic, was developed with the objective of replicating as much as possible the academic environment in which university students are exposed. Participants ( $n = 164$ ) first completed measures of explicit AM to learning and working memory capacity. Before the learning situation, participant were randomly assigned to a subliminal priming condition (AM, controlled motivation, neutral). At the end of the learning situation, all participants completed an exam on the learned content. Moderated regression analysis revealed that explicit AM was positively predicting the verbal component of the exam, but only for the AM primed group. This synergistic effect was contingent on WMC, as this effect was only observed for individuals with average to low levels of WMC. Contrary to the past findings of the explicit-implicit model of AM, WMC had an opposite influence on the synergistic effect. The main findings are discussed according to their implications of for SDT.

Subliminal priming of autonomous motivation enables self-evaluation to predict learning performance: A dual-process perspective of self-determination theory

Recent self-determination theory (SDT) studies in the educational domain has proposed that autonomous motivation (AM) should predict academic achievement more strongly when synergistically coupled with higher levels of implicit AM (Gareau & Gaudreau, 2017; Gareau et al., 2018). Individuals who display synergistic patterns between their explicitly declared AM and their implicit cognitive accessibility of AM are said to have integrated those motivational dispositions more deeply and with a more unified sense of self. This is what SDT refers to as the *integrative process*; an inherent tendency to coherently integrate experiences that are reflected in autonomous behavior. Researchers have incorporated new theoretical and methodological directions steaming from the implicit social cognition to the original SDT propositions, in order to have a more precise account of this theoretically important psycho-cognitive process (Weinstein, Przybylski, & Ryan, 2013). More precisely, the *explicit-implicit model of AM* proposed by Gareau and Gaudreau (2017) assumes a dual-process perspective over the integrative process of SDT, that integrates key principles, like automaticity and awareness. Moreover, dual-process model assumes that all behaviors are determined by the interplay of both explicit/controlled/conscious and implicit/automatic/unconscious processes. This cognitive interplay in human behavior has for long been proposed to be contingent upon the working memory capacity of individuals (Barrett, Tugade, & Engle, 2004). Hence, the *explicit-implicit model of AM* also proposes that the synergistic interplay of explicit and implicit AM depends on the available cognitive resources of an individual.

Past studies have shown that it is possible to experimentally activate AM disposition outside of the participants' awareness (Lévesque & Pelletier, 2003; Radel, Sarrazin, Legrain, &

Gobancé, 2009; Radel, Sarrazin, & Pelletier, 2009). These studies revealed that individuals primed with AM words displayed higher levels of intrinsic motivation, interest, enjoyment, perceived choice, and performance on the observed task. Based on these findings, the *explicit-implicit model of AM* proposes that explicit AM collected with self-report methodology should predict task performance, but only for individuals who are implicitly primed with AM. In this study, our goal was to examine the moderating effect of priming AM on the association between explicit self-reported AM and learning performance in an experimental learning situation.

### **Synergistic effect of explicit and implicit AM: Unto the integrative process of SDT**

The integrative process is not limited to SDT. Historically speaking, integration has been a central construct for many psychological theories. William James, who is often cited as the most influential and insightful psychological theorist, pioneered the idea that humans have a natural tendency to strive for a *coherent stream of thought* and *self-actualization*. This idea, which is a central assumption of SDT, can now be precisely investigated using cognitive methodologies stemming from the implicit social cognition approach. Primarily, integration has been inferred within the SDT framework through the internalization of a behavioral regulation going from being externally regulated by the environment to being more and more internally regulated by the *self*. According to SDT, five types of regulations can be distinguished to form a continuum of internalization (i.e. external, introjected, identified, integrated, and intrinsic). On the one hand, individuals whose actions are more controlled by the environment through external and introjected regulations are said to have higher levels of controlled motivation. On the other hand, individuals who regulate their behavior with identified, integrated, and intrinsic regulation are said to have higher levels of autonomous motivation (AM). These two dimensions of motivation have often been measured with self-report methodologies, which are argued to assess

the explicit self-knowledge individuals have about their motivational disposition. Explicit self-evaluation of AM has been found to be positively associated with a host of desirable educational outcomes: deeper learning (Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004), positive emotion and school satisfaction (Ryan & Connell, 1989), subjective well-being (Levesque, Zuehlke, Stanek, & Ryan, 2004), and academic achievement (Richardson, Abraham, & Bond, 2012; Taylor et al., 2014). These explicit self-evaluations of AM and CM, although reliable and valid, are offering limited perspective to capture the extent to which such declarative knowledge has been fully processed and integrated within a broader network of mental representations about the *self* (Gawronski & Bodenhausen, 2006; W. Hofmann, Gawronski, Gschwendner, Le, & Schmitt, 2005). Accordingly, Weinstein et al. (2013) suggested that convergence between explicit and implicit assessment AM might be taken as an indicator of integration.

### **Correlational vs experimental studies of implicit AM**

Past studies have explored the influence of individual differences in the cognitive accessibility of mental representation of AM by examining the rapidity to which individuals were reacting to different stimuli of AM (Burton, Lydon, D'Alessandro, & Koestner, 2006; Gareau & Gaudreau, 2017; Gareau et al., 2018; Keatley, Clarke, & Hagger, 2012, 2013a, 2013b). The underlying assumption of this reaction time paradigm is that an individual with a more internalized sense of AM should react quicker to words associated with the AM construct. In this line of research, researchers initially assumed that the implicit cognitive access of AM disposition would predict behavioral performance on a task over and above explicit measures of AM. This additive hypothesis was supported by researchers who used an implicit association test of AM (Levesque & Brown, 2007) to predict self-reported physical activity (Keatley et al., 2012) and persistence of solvable and unsolvable puzzles (Keatley et al., 2013a). Another study used a

lexical decision task to assess implicit identified regulation and found a significant main effect on final examination grade at university (Burton et al., 2006). Another competing hypothesis that was put forward was that explicit and implicit AM should interact when predicting task performance. An interaction effect was uncovered in Burton et al. (2006) with explicit and implicit identified regulation when predicting final examination grades. This hypothesis was then theoretically repositioned using the dual-process perspective to create the *explicit-implicit model of AM* (Gareau & Gaudreau, 2017). This model advanced and found that explicit AM was a better predictor of academic achievement for individuals who reacted more rapidly to AM words in a lexical decision task (Gareau & Gaudreau, 2017; Gareau et al., 2018). The interaction effect of explicit and implicit AM depicted in those studies may represent more precisely, what is meant by internalizing one's behavioral regulation in a more unified sense of self.

A second set of studies investigated the effect of implicit AM relied on an experimental priming paradigm. The primary aim of this line of research was to examine if it was possible to activate mental representation of AM outside of the participants' awareness (Lévesque & Pelletier, 2003; Radel, Sarrazin, Legrain, et al., 2009; Radel, Sarrazin, & Pelletier, 2009). Specifically, Radel, Sarrazin, and Pelletier (2009) found that participants primed with AM performed better on a motor task, persisted more, used more free time, exerted more effort, had more interest, enjoyment, and autonomy satisfaction. Similar results were found by Lévesque and Pelletier (2003), as their study revealed that priming AM had a positive influence on self-reported intrinsic motivation, interest, enjoyment, perceived choice, and time spend freely doing a task. Those priming studies were all done within the confines of a lab with environmental conditions being highly controlled. In an attempt to improve the external validity of the implicit priming effect, Radel, Sarrazin, Legrain, et al. (2009) experimentally modified the slideshow

presented to university students with subliminal AM and CM words and investigated its influence on subsequent performance on a quiz. The implicit subliminal effect of AM was observed only for individuals with lower levels of mindfulness. There is strong evidence in the literature for considering mindfulness as a higher-cognitive process that heavily relies on executive function (Chiesa, Calati, & Serretti, 2011; Lyvers, Makin, Toms, Thorberg, & Samios, 2014; Riggs, Black, & Ritt-Olson, 2015). Individuals with lower levels of mindfulness tend to use their reflective process to a lesser extent and rely more on their impulsivity (Peters, Erisman, Upton, Baer, & Roemer, 2011), which could explain why they were more heavily influenced by the priming procedure of implicit AM (Radel, Sarrazin, Legrain, et al., 2009). Interestingly mindfulness is also considered as an executive function skill described as the ability to voluntarily focus or direct our attention on specific cues (D. S. Black, Semple, Pokhrel, & Grenard, 2011; Manna et al., 2010). As such, individuals who are more mindful may be more capable to de-automatize some mental operations and dampen automaticity (Kang, Gruber, & Gray, 2013), which could explain why they were less influenced by implicit AM.

Overall, a fuller understanding of the integrative process can be gleaned when explicit and implicit assessments of AM are unified into one model. Explicit self-reported AM disposition is only one piece of the internalization process and recent research showed that convergence between explicit and implicit AM can be taken as an indicator of integration (Gareau & Gaudreau, 2017; Gareau et al., 2018; Weinstein et al., 2013). The dual-process perspective offered in the explicit-implicit model of AM appears promising to further our understanding of the SDT framework, as the general theoretical approach is centered around the determinants and consequences of motivational processes that may sometime be nonconscious (Deci & Ryan, 1980). Interestingly, past studies have demonstrated that mental representation of

AM can be activated outside of one's awareness and that the potential effects of implicit AM can be contingent on executive function.

### **The Role of Working Memory Capacity for the Integrative Process**

The *explicit-implicit model of AM* – as many dual-process models – acknowledges the role of working memory on the interplay between automatic and controlled processing. Working memory capacity (WMC) is often described as an attentional system for memory that can maintain activation of goal-relevant mental representation outside of individuals' awareness (Kane, Conway, Hambrick, & Engle, 2007). The activation of goal-relevant information is said to pass through the executive center (Baddeley, 2012) – the central component of WMC – and is described as a gateway of accessibility (Barrett et al., 2004). The initial proposition of the *explicit-implicit model of AM* was that WMC could be taken as an indicator of available cognitive resources. Given that the integrative process of SDT is posited to be cognitively challenging, individuals with higher levels of WMC should be more equipped to activate the synergistic pattern of implicit and explicit AM. Although results of past studies corroborated the initial hypothesis (Gareau & Gaudreau, 2017; Gareau et al., 2018), the role of WMC for the integrative process still deserves theory elaboration and clarification.

From a dual-process perspective, AM disposition would be said to either be guided through an automatic or a controlled cognitive process. Hence, the ability to control attention can be an important contributor on this interplay. Individual differences in WMC can enable observation of what is controllable for one individual and not controllable for another individual. In their seminal article, Barrett et al. (2004) offered an extensive discussion on how WMC is a crucial moderator for most of dual-process theories. Of most importance, it was suggested that individuals with lower levels of WMC might not be able to maintain activation of goal-related

information and thus may lack the ability to motivate their actions from a top-down cognitive process, even if their explicit motivational dispositions and intentions are set in a goal-oriented manner. Thus, it appears plausible to hypothesize that the cognitive process of bringing self-evaluation of AM into awareness is a mental operation likely to be contingent on the WMC of individuals. The studies of Gareau and his colleagues have provided initial evidence for such WMC effect. Students who reported higher explicit AM and quicker cognitive access to their implicit AM had a significantly higher GPA at the end of the semester, but only if they also had average to high levels of WMC (Gareau & Gaudreau, 2017; Gareau et al., 2018). Overall, the dual-process perspective advanced in the explicit-implicit model of AM brings together principles from implicit social cognition and motivation sciences to foster a deeper understanding of the integrative process.

### **The Present Study**

In this study, our goal was to examine the causal effect of subliminally priming participants with AM words on the relationship between self-evaluation of AM and performance on an experimental learning task. We tested the hypotheses of the *explicit-implicit model of AM* in the confines of a lab with the intention to mimic the environmental conditions of a university class. An experimental learning situation was created with specific characteristics pertaining to a typical university class. At the end of the experiment, participants completed an exam on the learned content, again with the intention to mimic a typical university class. Before starting the experimental learning situation, participants were randomly divided in three priming conditions (i.e., AM, CM, and neutral). We hypothesized that explicit self-reported AM, assessed before the prime, would influence positively the examination score of participants, but only for participants subliminally primed with AM words, as per the synergistic hypothesis of the explicit-implicit

model of AM (H1a). Within this first hypothesis, we also hypothesized that the association between prior explicit self-reported AM and examination score will be significantly lower for both the CM primed group (H1b) and the control group (H1c). Moreover, as described by the explicit-implicit model of AM, we hypothesized that differences in the association between explicit self-reported AM and examination scores across conditions should be moderated by the working memory capacity of the participants, as per the *cognitive resources hypothesis* (H2).

## Method

### Participants

One hundred and sixty-four undergraduate students ( $n = 164$ , 65.9% female) aged between 17 and 49 years old ( $M = 19.9$ ,  $SD = 4.3$ ) were recruited through an integrated research participation system. Participants were mainly full-time students (86.6%) and were either in their first (54.9%), second (25%), third (6.7%), or fourth year (7.3%) of their respective program. Students from this sample were enrolled in different programs: social sciences (34.1%), health sciences (32.3%), management (11%), sciences (10.4%), arts (3%) and other (9.1%). No restrictions were placed on participants' age, years of study, academic programs or ethnicity. Participants described themselves as Caucasian (47%), Arabic (12%), Asian (11.6%), African-American (9.8%), and other (11%). Participants received two points toward their introductory psychology class and completed an electronic informed consent at the beginning of the study. An institutional research ethics board approved the study.

### Experimental Procedures

Participants arrived at the INSPIRE lab with the instructions that they will participate in a study on cognitive ability and learning. Each participant had his/her own desk (4 desks per session) with two computer screens. One screen was used to present all of the different tasks and

on the second screen a digital clock was displayed to ensure that all participants would refer to the same time when managing their time during the experiment. At the beginning of the experiment, participants received general instructions about the whole experiment and were given a course plan detailing the procedure. They were told at the beginning that an exam would be given after the learning task at a specific time (e.g. 10 AM). The fixed sequence of the different measures was controlled via a programmed batch file on windows computers. The experimenter left the room and monitored the procedure in the control room. Participants first completed a socio-demographic questionnaire with measures of AM and CM, WMC, and math anxiety. After completing those measures, participants were randomized in the three experimental priming conditions. After the priming procedure (i.e. lexical decision task with subliminal words), all participants went through the same learning situation. The pace of the learning situation was, however, decided by each participant with only the exam time as a constraint. The exam was scheduled at a predetermined time and participants had to manage their time in order to be ready for the exam. After the exam, participants were debriefed on the nature of the prime. The whole study was 2 hours long.

### **Semantic Priming Manipulation**

Priming was done through a lexical decision task programmed in E-PRIME 2.0. Participants were presented strings of letters and asked to indicate whether the strings were words ( $n = 50$ ) or non-words ( $n = 50$ ). Participants were instructed to respond to the strings as quickly as possible and to be as accurate as possible. At each presentation, a subliminal prime was displayed according to the condition in which participants were randomized. Each stimulus was presented with this procedure: (1) Fixation (1000 ms); (2) Forward mask (34 ms) 2/60 cycles; (3) Prime (17 ms) 1/60 cycle; (4) Backward (34 ms) 2/60 cycles; stimuli (1500 ms).

Three randomized experimental conditions were created for the prime methodology: AM, CM, and control groups. For the AM primed condition the words were: *autonomous, autonomy, choiceful, enjoyable, genuine, important, interested, meaningful, pleasurable, valuable*. For the CM primed condition the words were: *ashamed, constrained, controlled, forced, imposed, must, obligation, pressured, required, should*. For the neutral primed condition the words were: *chair, color, duck, color, fish, mouth, puzzle, screen, street, sugar*.

### **The learning situation: Modular arithmetic?**

For the content of the learning situation, we decided to teach the participants about *modular arithmetic*. We selected this learning content because we thought it would be new enough for everyone, hence, controlling for the participants' baseline knowledge. None of the participants reported to have heard of modular arithmetic prior to our experiment. Modular arithmetic is a special case of arithmetic that is widely used in computer programming but never taught at elementary or high school level. This type of arithmetic is fairly simple and can be easily taught with visual representation. We created a slideshow inspired by the Khan Academy tutorial (KhanAcademy, 2018) and Beilock and Carr (2005) study in E-PRIME 2.0 with conceptual notions of modular arithmetic and exercises to practice. Below we explain the specific characteristics of the learning situation.

After being seated at their desk, participants received a course outline, a notepad, a pen, and a highlighter. Verbal information was minimal and the course outline contained information on the estimated time to complete each task (questionnaires, WMC tasks, lexical decision task, learning situation), the exact scheduled time of the exam, the content of the exam (slideshow, math resolution, supplemental reading), and the type of questions asked in the exam (multiple choices, true or false, short answers). When a participant finished the learning task, he/she

received information regarding a supplemental reading that could be done. The course outline clearly indicated that the exam would contain questions from the supplemental reading material. Between the end of the learning task and the start of the exam, participants were free to decide what they wanted to do. Through the programmed batch file on the computer, participants could open the supplemental reading, do extra exercises online, open the slideshow that was just presented to them, or go on the internet. Five minutes before the exam, an experimenter entered the room, closed the computer screens, took all of the notepads back, and distributed the exam. Participants had 20-minutes to complete the exam. All of the materials and measure are accessible on the OpenScienceFramework website at [osf.io/u86hw](https://osf.io/u86hw).

## Measures

**Explicit autonomous motivation for learning.** Self-reported AM and CM were assessed through a questionnaire that evaluates the five regulations of SDT with two items per regulations. Participants were asked to indicate to which extent each item corresponded to the reasons they invest themselves in learning new knowledge on a scale of 1 (not at all) to 7 (totally). An exploratory factor analysis, estimated with principal axis factoring, revealed a two-factor solution that explained 65.1% of the variance. All items primary loadings were on the theoretical construct that they were supposed to measure (i.e. AM or CM). Cross-loadings were all smaller than  $|.203|$ . Correlation between AM and CM factor was small ( $r = .06$ ). This questionnaire went through many confirmatory factor analysis with ample evidence for its reliability, concurrent/divergent validity and predictive validity (Brunet, Gunnell, Gaudreau, & Sabiston, 2015; Gareau & Gaudreau, 2017; Gareau et al., 2018; Gaudreau, 2015). In this study reliability estimate for the intrinsic ( $\alpha = .816$ ), integrated ( $\alpha = .752$ ), identified ( $\alpha = .777$ ), introjected ( $\alpha = .645$ ) and external regulation ( $\alpha = .835$ ) were all deemed satisfactory.

**Working memory capacity.** In this study we used two computerized tasks programmed in E-PRIME 2.0 by the Attention and Working Memory Lab (OSPAN and RSPAN; Unsworth, Heitz, Schrock, & Engle, 2005). Both tasks are short-term memory tasks paired with a processing task. The scores of WMC ranged from 0 to 75, reflecting the total number of the remembered elements (partial-credit load scoring, see Conway et al. (2005)). This scoring method has been shown to hold good psychometric properties: test-retest, internal consistency, construct validity, and convergent validity (Redick et al., 2012). The two tasks were aggregated to form an overall indicator of WMC. According to Eisinga, Grotenhuis, and Pelzer (2013) reliability was calculated with the spearman-brown coefficient and was found to be acceptable ( $\rho = .692$ ).

**Math anxiety (control variable).** The abbreviated math anxiety scale (AMAS; Hopko, Mahadevan, Bare, & Hunt, 2003) was used to assess the anxiety level of the participants when faced with a mathematical event. Participants were asked to rate each item in terms of how anxious they feel during a specific event of mathematical nature (e.g., listening to a lecture in math class). Items were answered on a 5-point likert scale (low anxiety, some anxiety, moderate anxiety, quite a bit of anxiety, high anxiety). Previous validation demonstrated that the AMAS had good reliability, test-retest stability and convergent/divergent validity (Hopko et al., 2003). In this study, a one-factor-solution was estimated with principal axis factoring and explained 53.5% of variance. Moreover, reliability estimate for the 9-items scale was acceptable ( $\alpha = .89$ ).

**The learning situation exam.** An exam was created to assess the extent to which participants have learned during the experimental learning task. The exam had multiple choices (6), true or false (14), short answers (9), and modular arithmetic resolutions (11). There were two main components in this exam, a verbal and a math component. The verbal component had all of

the multiple-choice questions, the short answers, and four of the true or false questions. In the true or false questions, 10 questions were taken from Beilock and Carr (2005) modular arithmetic task, and thus were aggregated to the math component. The math component also had modular arithmetic resolutions taken from the Khan Academy's website (KhanAcademy, 2018). The two exam scores were calculated with a proportional approach to ensure that each question type (i.e., multiple choices, true or false, short answers and math resolution) had the same influence on the final scores aggregation. The bivariate association between the two exam components was small ( $r = .206, p < .05$ ), thus revealing that the exam components were measuring different aspects of the learning task. Descriptive statistics are shown in Table 1.

### **Plan of Analyses**

A SEM regression approach was used to test our hypothesis. All continuous variables were z-score transformed beforehand, in order to have a bias-free interpretation of the different interaction effects (Cohen, Cohen, West, & Aiken, 2003). Experimental conditions were thus modeled as a categorical moderator through dummy-coded contrasts. The AM primed group was coded as the reference group. The CM and neutral primed groups were thus compared through the contrasts against the AM primed group (Contrast 1: AM versus Control; Contrast 2: AM versus CM). The relationship between prior explicit AM and subsequent examination performance could thus be compared across the different experimental conditions, as per the synergistic hypothesis. This categorical moderation was further moderated by working memory, as per the cognitive resources hypothesis. We used a multivariate hierarchical regression approach to test the moderated moderation in which the verbal and math components of the exam were simultaneously included as correlated dependent variables. Each dependent variable had their own  $R^2$  estimate and a difference test across the hierarchical steps of the regression

approach. At step 1, only the main effects were estimated. At step 2, we added the first-order interaction terms. Finally, at step 3, the second-order interaction terms were added to the final model. In all models, math anxiety was added as a control variable given its prominent effect on subsequent math performance (Beilock & Maloney, 2015; Foley et al., 2017). Maximum likelihood robust estimation was used to estimate the different parameters of the model. Missing data points were handled with the full information maximum likelihood algorithm (Schlomer, Bauman, & Card, 2010). Within this algorithm for missing data, we added socio-demographic variables (i.e. sex, age, number of years at university and full-time/part-time status) that were used as missing data correlates in addition to the variables in the model (Graham, 2003). All of the analyses were performed in MPLUS 7.

## **Results**

Participants were screened for their influence on the regression coefficient in each of the experimental conditions. The standardized difference test in beta (DFBETA) was used to assess the influence of each participant. When the influence was greater than 1.0 standard error on the regression coefficient, the participant was taken out of the main analysis. Six participants were found to have sufficient influence on at least one of the regression parameters and were taken out of the analysis. Four were in the AM primed group and two were in the CM primed group. The final sample for the main analysis was of 157 participants.

### **Preliminary Analysis**

Descriptive statistics are presented in Table 1. Bivariate associations with the dummy-code can be interpreted as the differences in mean between the experimental conditions. None of the baseline assessment were significantly different between the AM primed, the CM primed, and neutral prime groups (see gray array in Table 1). Moreover, mean performance on the verbal

and math components of the exam were not significantly different across the experimental conditions. The remaining correlation coefficients should be interpreted as the mean bivariate associations across all experimental conditions. A significant positive association between explicit CM and math anxiety was observed ( $r = .289, p < .05$ ). The WMC of participants was positively associated with the verbal component of the exam ( $r = .263, p < .05$ ). The WMC tasks used in this study are based on short-term memory and it is fair to say that the verbal component of the exam is in itself of short-term memory test on the content of the class. Lastly, math anxiety was negatively associated with the verbal ( $r = -.200, p < .05$ ) and math components ( $r = -.277, p < .05$ ) of the exam.

### **Hierarchical moderated moderation regression analysis**

Even if the two dependent variables are predicted simultaneously in the regression models, two different tables are presented across the hierarchical steps with all of the regression coefficients (see Tables 2 and 3).

**Predicting the verbal component (Table 2).** The first model with all main effects predicted 10.9% of variance in the verbal component of the exam. At step 1, WMC and math anxiety were both significant predictors of the verbal component of the exam. At step 2, with the added first-order interaction terms, the model predicted 16.3% of variance ( $\Delta R^2 = 6.4\%$ ). This model revealed a significant interaction effect between explicit AM and the experimental conditions. Two significant interactive terms revealed that the effect of explicit AM significantly differed across the AM primed versus the control group (see explicit AM x c1c2) as well as across the AM primed versus the CM primed groups (see explicit AM x c1c3). More precisely, explicit AM was positively associated with the verbal component of the exam, but only for individuals who were primed with AM word ( $\beta = .308, p = .028$ ). Contrast coefficients revealed

that this effect was significantly different from the control ( $\beta = -.461, p = .015$ ) and CM primed condition ( $\beta = -.404, p = .038$ ).

At step 3, with the added second-order interaction terms, predicted 19.5% of variance ( $\Delta R^2 = 3.2\%$ ). The two triple interaction terms between explicit AM, experimental conditions and WMC were both significant (see Table 2). Simple slope analysis was performed at  $\pm 1$  SD of WMC. Results are presented in Figure 1. The association between explicit AM and the verbal component of the exam was significant for individuals who were primed with AM words, and had low ( $\beta = .352, p = .001$ ) to average levels of WMC ( $\beta = .249, p = .057$ ). These findings supported the synergistic hypothesis of the explicit-implicit model of AM. However, this effect was no longer significant for individuals with higher levels of WMC ( $\beta = .146, p = .473$ ). Contrary to our hypothesis, WMC had an opposite effect on the synergistic effect; which will be discussed further. Lastly, negative association was found between explicit AM and the verbal component of the exam for individuals with low levels of WMC in the CM primed group ( $\beta = -.457, p = .018$ ) and the control group ( $\beta = -.483, p = .066$ ).

**Predicting the math component (Table 3).** The first model, at step 1, with all of the main effects, predicted 9.6% of variance in the math component of the exam. Math anxiety was the sole significant predictor of this model. At step 2, with the added first-order interaction terms, the model predicted 12.7% of variance ( $\Delta R^2 = 3.1\%$ ). The association between explicit AM and the math component of the exam was not significant and not different across experimental conditions (see explicit AM x c1c2 and explicit c1c3 regression coefficient). At step 3, with the added second-order interaction terms, predicted 15.9% of variance ( $\Delta R^2 = 3.2\%$ ). A significant interaction between explicit AM, the contrast of AM primed vs the control group and WMC was found (see Table 3). Simple slope analysis was performed at  $\pm 1$  SD of WMC. Results are

presented in Figure 1. The association between explicit AM and math resolution was significant and negative for individuals in the control group and with low levels of WMC ( $\beta = -.520, p = .042$ ). None of the other slopes presented in Figure 1 was significant.

### **Discussion**

In this experimental study, we followed and extended a dual-process perspective of AM by testing the hypotheses presented in Gareau and Gaudreau (2017), within the confines of a lab. Accordingly, we developed an experimental learning situation to evaluate if a subliminal priming procedure of AM could enable, in a synergistic manner, explicit self-reported AM disposition to more strongly predict subsequent learning performance. On the one hand, our results corroborated the synergistic hypothesis of the *explicit-implicit model of AM*, but only for the verbal, not the math component of the exam. On the other hand, conflicting results were found for the cognitive resources hypothesis, where the synergistic effect was observed for individuals with low to average levels of WMC rather than for high levels of WMC, again only for the verbal component of the exam. Intricate and unexpected associations were found between the experimental conditions, explicit AM, WMC, and math examination performance. The differentiation between verbal and math learning processes will be discussed. Overall, the findings of this experimental study will be discussed and interpreted in light of their implication for SDT and the implicit social cognition approach.

#### **Synergistic Effect of AM and the Dual-Process Perspective of SDT**

In our experimental learning situation, subliminal activation of AM was found to moderate the association between explicit AM to learn new knowledge and examination performance on the verbal component of the exam. Consistent with the synergistic hypothesis of the explicit-implicit model of AM, students who were subliminally/implicitly primed with AM

words displayed a positive and significant association between their explicit AM and subsequent examination performance on the verbal component of the exam. Of particular importance, the size of this association was significantly different from the CM primed and control groups. As demonstrated in past studies (Gareau & Gaudreau, 2017; Gareau et al., 2018), the reflective/controlled/explicit process of AM seems to be only beneficial when accompanied with a more pronounced impulsive/automatic/implicit process of AM.

The reflective-impulsive model (RIM; Strack & Deutsch, 2004) offers useful heuristics and hypotheses to reinterpret our findings. First, the RIM assumes that behaviors are guided either solely by the impulsive system or by a combination of the impulsive and the reflective systems. Second, when these two behavioral forces work in synergy by activating the same behavioral schemata, they can enact the behavior with more ease, fluency, and increase positive affects (Winkielman & Cacioppo, 2001). The impulsive system is also said to operate through an associative network that can activate behavioral schemata through spreading activation (Krishna & Strack, 2017; Strack & Deutsch, 2004). In our study, the subliminal prime of AM words potentially increased the accessibility of those mental representations and associative cues of AM. Accordingly, if the reflective motivational process, assessed through explicit self-reporting of AM, is high enough, the two motivational processes of AM are now in synergy and can facilitate learning mechanisms. In other words, students who explicitly stated to have higher levels of AM and were subliminally primed with AM words seemed to have gained a more acute accessibility of their AM mental representations. Throughout the learning situation, they were thus able to regulate more autonomously their behavior, as demonstrated by their higher score on the verbal component of the exam.

Our results corroborated and extended past findings on the synergistic hypothesis of AM. Past studies relied on a correlation design in which individual differences in implicit AM were indirectly assessed with reaction time. As such, results from these studies should be taken as an illustration of a *person x person effect* in which personally held dispositions, measured with explicit and implicit methodologies, interacted to predict task performance. In the current study, we relied on an experimental design in which participants were randomized into conditions in which implicit AM and CM were manipulated with a subliminal priming paradigm. As such, the current findings showed that subliminal priming of AM causally moderated the association between explicit AM and task performance. This novel finding can be reinterpreted as a *person x situation effect* in which subliminal priming of AM acted as a situational cue that causally influenced the relation between one's explicit AM and task performance. These synergistic effects (person x person; person x situation) are conceptually and methodologically different but they nonetheless provide complementary and fruitful information to further our understanding of the integration process proposed in SDT. It thus appears that both implicit AM as a personal disposition and implicit AM as a situational trigger are required for explicit AM to positively predict task performance. This finding not only replicates past studies on the *explicit-implicit model of AM* but it also extends it by revealing that the synergistic effect likely operates when prompted by individual differences in implicit AM and primed by implicit situational cues in the learning environment.

The repositioning of the current findings through a *person x situation* paradigm is also consistent with a central organismic postulate of SDT that describes humans as being constantly and dynamically in interaction with their social environment. The results of this study further our understanding, within the SDT perspective, of how the social environment can shape individuals'

development of AM. Consistent with past SDT studies, when students perceived the academic context as autonomy-supportive they are more likely to develop or maintain AM, which ultimately help them reach higher performance on subsequent examination (e.g., A. E. Black & Deci, 2000; Reeve, Jang, Hardre, & Omura, 2002; Vansteenkiste et al., 2004). Overall, past SDT studies in the educational (e.g., Guay, Ratelle, Larose, Vallerand, & Vitaro, 2013), sport (e.g., Bartholomew, Ntoumanis, Ryan, Bosch, & Thogersen-Ntoumani, 2011; Gaudreau et al., 2016) parenting (e.g., Grolnick, Frodi, & Bridges, 1984; Joussemet, Landry, & Koestner, 2008) and work (e.g., Moreau & Mageau, 2012) domains have made it clear that individuals' perception in how their environment is autonomy-supportive or interpersonally controlling directly influence their need satisfaction, development of AM, well-being, persistence, and achievement. This experimental study contributes to this specific literature by revealing that unconscious subliminal AM cues stemming from the environment can also influence the motivational process of AM and its positive effect on academic achievement. As such, the socio-environmental cues that promotes AM may not need to be conscientiously processed to activate AM and the potentially positive effects of AM. This finding is important for education research and practice because students are exposed to countless subliminal socio-environmental cues capable of interacting with their own AM in ways that could influence their academic achievement and adjustment.

### **Synergistic Effect of AM is Contingent on WMC**

The *explicit-implicit model of AM* assumes that high levels of WMC enable the synergistic effect of explicit and implicit AM to yield positive influence on academic achievement. Contrary to our hypothesis and past correlational findings, the synergistic effect of AM was found to operate only for students with low to average levels of WMC (rather than high levels of WMC), and again only for the verbal component of the exam. At a first glance, this

specific finding seems to contradict the hypothesis and previous findings of the *explicit-implicit model of AM* (Gareau & Gaudreau, 2017; Gareau et al., 2018). However, it is important to reiterate that experimentally priming AM is not the same as measuring individual differences in implicit AM. Although unexpected and in contradiction to the original hypothesis, our finding appears nonetheless reinterpretable for at least two reasons.

On the one hand, past research in cognitive psychology showed that priming effects are more likely to be working for individuals with lower levels of WMC (Heyman, Van Rensbergen, Storms, Hutchison, & De Deyne, 2014; Ortells, Noguera, Alvarez, Carmona, & Houghton, 2016). In the SDT literature a similar priming contingency was found with mindfulness disposition, in which the subliminal priming of AM was found to influence the performance of students on a quiz but only for those with low levels of mindfulness (Radel, Sarrazin, Legrain, et al., 2009). Earlier we noted some interesting parallel between executive function and mindfulness (Holas & Jankowski, 2013; Riggs et al., 2015). The ability to orient our attention on the present and to be aware of the moment is the key cognitive component of the mindfulness definition. Working memory and mindfulness disposition also share a fair amount of variance that may be attributable to their shared underlying attentional ability (Riggs et al., 2015). Overall, the bolstering effect of AM priming on the association between explicit AM and learning performance seems to benefit individuals with lower to average WMC. In terms of practical implications, these results are encouraging as students with lower WMC, which are known to underperform compared to their peers (Alloway & Alloway, 2010; Rohde & Thompson, 2007), appear to benefit more from the synergistic interplay of their explicit AM and situational cues of implicit AM primed by the learning environment. If replicated outside the lab, such a finding

could highlight the importance of AM cues to reduce the achievement gap associated with lower WMC.

On the other hand, the subliminal priming of AM may have encountered serious roadblocks because individuals with higher levels of WMC are known to be more efficient in enacting controlled and goal-directed processing (Barrett et al., 2004; Conway, Cowan, & Bunting, 2001). Concordantly, in another study, when participants were encouraged to use controlled strategies, semantic priming effects were greatly reduced when imposing a high WMC load (Heyman et al., 2014). Overall, semantic priming effect seems to be moderated by the WMC of individuals. Based on this, it is reasonable to assume that students with higher levels of WMC may have been more focused on the lexical decision task itself (i.e., deciding if the stimuli presented is a word or not) with a more controlled mode of processing. Hence, their automatic/impulsive process may have been activated to a lesser extent, which could explain why students with higher levels of WMC were not affected by the AM priming procedures. Contrariwise, students with lower levels of WMC benefited from the priming procedures of AM, as they were more susceptible to be influenced by the subliminal priming of AM. Altogether, the results of the three-way interaction are not directly contradicting the previous results of the explicit-implicit model of AM. When it comes to individual differences in implicit AM, people with higher levels of WMC benefit more from expressing synergistic pattern of explicit and implicit AM (Gareau & Gaudreau, 2017; Gareau et al., 2018). However, when it comes to implicit situational cues of AM, such as the subliminal priming used in this study, people with lower levels of WMC benefit more from their synergy between their explicit self-reported AM and the implicit situational cues of AM. These findings complement the explicit-implicit model

of AM by highlighting the different, yet determining, moderating role of WMC on the synergistic interplay of explicit and implicit AM.

### **Learning to Do Mathematical Operations Require Different Motivational Processes**

Academic evaluations, at all educational stages, are often quite specific to the studied subject (e.g. science, math, language, etc.). In this study, even if the core content of the learning situation was of mathematical nature (i.e. modular arithmetic), the learning situation was also designed to verbally inform participants with facts about modular arithmetic and general rules of appliances. Therefore, some of the exam questions were not math resolution per se but were direct questions of the presented facts (i.e. verbal component). The other questions were modular arithmetic resolutions. Hence, in order to have more precise account of what was learned by the participants, we decided to split the exam in two components for the same reason educational institution separate mathematics from language skills.

We tested the synergistic and cognitive resources hypothesis of the explicit-implicit model of AM on the math component of the exam. However, we found a completely different portrait of this three-way interaction. First, the subliminal priming effect of AM on the association between explicit self-reported AM and math performance was not significant (Figure 1, Panel B2), thus no synergistic effect was found between explicit AM and the experimental conditions. However, the experimental condition interaction with WMC was oddly significant for the comparison of the control group and AM primed group. It appears that students explicit AM predicted negatively math examination score, but only for students who did not receive any subliminal motivational prime and had lower levels of WMC. Interestingly, the subliminal prime of AM significantly alleviated this negative effect found at lower levels of WMC.

The striking difference between the findings of math versus verbal examination scores clearly demonstrates how two different learning processes seem to be at play. Past educational psychology research has shown that learning mathematics requires different cognitive skills (Peterson et al., 2017), can create different anxiety symptoms (Foley et al., 2017), and that students have specific self-concept (Arens et al., 2017) and academic motivation (Wang et al., 2015) about math. On another note, pressure to perform during math examination was found to be moderated by WMC, as only individuals with higher levels of WMC were found to be harmed by a pressure manipulation (Beilock, 2008; Beilock & Carr, 2005). Concordantly, a study also revealed an intricate interaction with math anxiety and WMC, where the math anxiety was found to deplete the working memory resources of participants when performing a mathematical task (Ashcraft & Kirk, 2001). Overall, the role of WMC, math anxiety, motivation, and their potential interaction appear far more complex when it comes to predict math skills versus verbal skills. Future research investigating the explicit-implicit model of AM on math learning mechanisms should carefully examine the potential interaction role of math anxiety to better explicate the unexpected findings reported in this study.

### **Strengths, Limits and Future Directions**

In this experimental study, we developed an in-lab learning situation designed to mimic the academic environment in which university students are often exposed. For instance, the learning situation was self-paced, students received a course plan with a schedule to follow and a notepad, they also received a supplemental reading that was not part of the learning situation, and the exam had typical university questions format (e.g. multiple choices, short answers, true or false). We believe that all those different features augment the ecological validity of this experimental study. Accordingly, for an experimental lab study, our findings are more

representative of what could happen in the academic environment. In this learning situation developed for this study, our results were unexpectedly different for the verbal and mathematical components of the exam. Future studies should try to replicate these findings of the explicit-implicit model of AM across different learning situations and type of exams (e.g., multiple-choice, essays, oral) to examine in more details how implicit and explicit AM plays similar or different roles in verbal and math learning processes often encountered by students from primary to tertiary education.

Even if the statistical analyses reported in this study converged with maximum likelihood robust estimation, the results should be interpreted with caution. Detecting interaction effects in moderation analyses requires larger sample size than multiple regression analyses (Dawson & Richter, 2006). In this study, the categorical experimental moderator created a statistical condition that can be viewed as three separate simple interactions. Interaction effect size found in this study ranged from moderate to large, accordingly, to detect such effect it is recommended to have more than 100 participants (Cohen et al., 2003; Dawson & Richter, 2006). In addition, reliability of the variable used to create the interaction terms can greatly influence the detection of interaction effect. Nonetheless, lab studies are advantaged over field study in the detection of interaction effect (McClelland & Judd, 1993) given that high reliability is not an issue for categorical moderator like the experimental conditions used in this study. Future studies should nonetheless maximize the reliability of their measures and aim at recruiting a larger sample to properly estimate the effects obtained in the current study.

For the development of SDT, this experimental study offers complementary findings to the implicit approach that is growing at much larger pace since the advent of cognitive methodologies. Adopting a dual-process perspective with SDT brings new research avenues to

the research problem of finding for whom and under which circumstances autonomous self-regulation can be effectively bolstered (Levesque, Copeland, & Sutcliffe, 2008). Implicit motivational processes of the mind are not to be ignored, as the implicit social cognition approach revealed, our behaviors are not entirely controlled by our own will at all time (Bargh, 2017). Nonetheless, humans have the reflective ability to have control over their actions, thus the conscious processes that underlies AM should remain the main determinant of autonomous self-regulation, as we are not just mere automata who accumulate knowledge from the environment. In our view, automatic/impulsive processing does not conflict with SDT concept of freedom and will, but expand our understanding of how adaptive unconscious (Bargh & Morsella, 2008; Wilhelm Hofmann & Wilson, 2010) and conscious processes are inevitably intertwined in the prediction of social behavior.

### **Conclusion**

Does the effect of explicit self-reported AM on a learning task performance can be bolstered by subliminal AM cues? In all, the findings of this experimental priming study extend the previous findings of the explicit-implicit model of AM by demonstrating that implicit situational environmental cues can causally influence the relationship between explicit self-reported AM and verbal learning performance. Synergy between individuals' dispositions of AM and subliminal priming of AM was a determining factor in the prediction of subsequent learning performance. Contrary to the initial cognitive resources hypothesis, individuals with average to low levels of WMC were the ones affected the most by the subliminal priming procedure of AM. Overall, students' evaluation of their own AM needs to be accompanied with an environment that fosters the sustainment of AM for them to perform adequately, even if that environment is not consciously perceived.

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Table 1

*Descriptive statistics and bivariate associations between all of the studied variables*

Variables	M	SD	1	2	3	4	5	6	7
1. Explicit AM	4.523	1.187							
2. Explicit CM	2.632	1.198	.040						
3. c1c2	0.345	0.477	-.060	-.076					
4. c1c3	0.314	0.467	.096	-.072	<b>-.495*</b>				
5. WMC	58.075	11.771	-.045	.113	.008	.054			
6. Math anxiety	2.431	0.784	.052	<b>.289*</b>	-.134	.084	-.033		
7. Verbal exam	0.626	0.134	-.002	.003	.062	-.038	<b>.263*</b>	<b>-.200*</b>	
8. Math exam	0.708	0.219	-.127	-.058	.087	-.027	.064	<b>-.277*</b>	<b>.206*</b>

Note. \*  $p < .05$ . AM = autonomous motivation, CM = controlled motivation, c1c2 = AM primed vs neutral primed, c1c3 = AM primed vs CM primed, WMC = working memory capacity. In grey are the mean differences with AM primed group as the reference group.

Table 2

*Hierarchical moderated regression analysis for the three-way interaction model when predicting verbal component*

Variables	Step 1		Step 2		Step 3	
	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>
Main effects						
Explicit autonomous motivation (AM)	.026	.732	<b>.308</b>	<b>.028</b>	<b>.249</b>	<b>.057</b>
Working memory capacity (WMC)	<b>.257</b>	<b>.001</b>	<b>.313</b>	<b>.026</b>	<b>.376</b>	<b>.003</b>
AM primed vs control group (c1c2)	.054	.790	.021	.915	.029	.881
AM primed vs CM primed (c1c3)	-.049	.787	-.056	.751	-.027	.8
Interaction terms						
Explicit AM × c1c2			<b>-.461</b>	<b>.015</b>	<b>-.446</b>	<b>.017</b>
Explicit AM × c1c3			<b>-.404</b>	<b>.038</b>	<b>-.407</b>	<b>.020</b>
WMC × c1c2			-.205	.287	-.267	.143
WMC × c1c3			.003	.988	-.092	.593
Explicit AM × WMC			.096	.274	-.103	.282
Explicit AM × c1c3 × WMC					<b>.389</b>	<b>.042</b>
Explicit AM × c1c2 × WMC					<b>.403</b>	<b>.015</b>
Control variables						
Explicit CM	.030	.706	.007	.934	.025	.750
Math anxiety	<b>-.197</b>	<b>.019</b>	<b>-.189</b>	<b>.022</b>	<b>-.196</b>	<b>.017</b>
Variance explained $R^2$ ( $\Delta R^2$ )	10.9%		16.3% (5.4%)		19.5% (3.2%)	

*Note.* AM = autonomous motivation, CM = controlled motivation, c1c2 = AM primed vs neutral primed, c1c3 = AM primed vs CM primed, WMC = working memory capacity. In bold are the effects that are worth examining.

Table 3

*Hierarchical moderated regression analysis for the three-way interaction model when predicting math component*

Variables	Step 1		Step 2		Step 3	
	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>	<i>B</i>	<i>p</i>
<b>Main effects</b>						
Explicit autonomous motivation (AM)	-.112	.142	-.076	.610	-.114	.464
Working memory capacity (WMC)	.045	.622	-.133	.391	-.096	.531
AM primed vs control group (c1c2)	.137	.501	.156	.443	.176	.379
AM primed vs CM primed (c1c3)	.082	.677	.109	.574	.108	.582
<b>Interaction terms</b>						
Explicit AM × c1c2			-.032	.875	-.080	.692
Explicit AM × c1c3			-.068	.176	-.010	.960
WMC × c1c2			<b>.390</b>	<b>.049</b>	<b>.352</b>	<b>.059</b>
WMC × c1c3			.101	.618	.062	.761
Explicit AM × WMC			-.043	.625	-.165	.224
Explicit AM × c1c3 × WMC					<b>.491</b>	<b>.017</b>
Explicit AM × c1c2 × WMC					.052	.779
<b>Control variables</b>						
Explicit CM	.030	.729	.051	.539	.074	.367
Math anxiety	<b>-.274</b>	<b>.002</b>	<b>-.265</b>	<b>.004</b>	<b>-.269</b>	<b>.003</b>
Variance explained $R^2$ ( $\Delta R^2$ )	9.6%		12.7% (3.1%)		15.9% (3.2%)	

*Note.* AM = autonomous motivation, CM = controlled motivation, c1c2 = AM primed vs neutral primed, c1c3 = AM primed vs CM primed, WMC = working memory capacity. In bold are the effects that are worth examining.

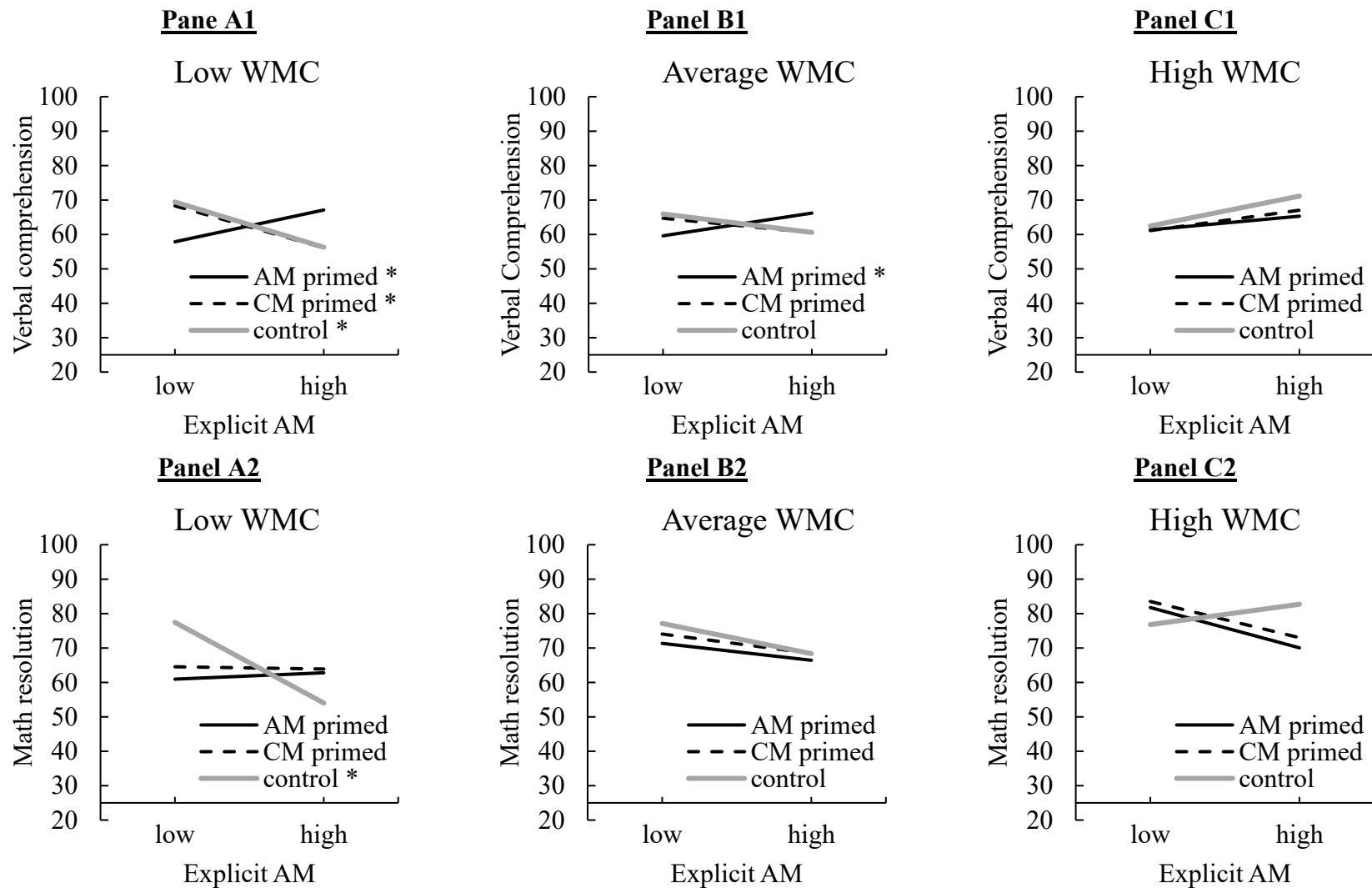


Figure 1. Simple slope analysis for the three-way interactions predicting verbal comprehension and math resolution examination  
\*  $p < .05$ , AM = autonomous motivation, CM = controlled motivation, WMC = working memory capacity.

## CHAPTER 5: General discussion

The main goal of my thesis was to investigate the association between students' AM for their school activities and academic achievement. Given that the literature portrayed a somehow weaker than anticipated association, I adopted a dual-process perspective to explore the implicit/unconscious motivational process of AM within the SDT framework. Accordingly, I developed the *explicit-implicit model of AM* for predicting academic achievement in samples of university students that incorporates notions of the implicit social cognition approach. The dual-process perspective developed in this thesis was built around the integrative process described by SDT. In past studies, the integrative process was never truly measured, but mostly used as a heuristic to create empirical investigation and interpret the results of studies. As a consequence, propositions were made to circumvent this particular issue, which included the idea of incorporating reaction-time based measures of implicit motivation (Levesque et al., 2008; Weinstein et al., 2013). In this thesis, I expanded on this methodological idea to develop an implicit measure of AM and tested a *synergistic hypothesis* and a *cognitive resource hypothesis* within the explicit-implicit model of AM. I tested these two central hypotheses of the explicit-implicit model of AM in three original studies using prospective designs (Study 1 and Study 2) and an experimental design (Study 3). The main findings of my thesis, which are summarized in Table 1, will be discussed according to their implications for SDT, implicit social cognition approach, and educational institutions.

Table 1

*Summary of findings across the three articles*

Articles	Central thesis findings		Supplementary findings
	Synergistic hypothesis	Cognitive resources hypothesis	
Chapter 2: First exploration of the explicit-implicit model of AM	When in synergy, explicit and implicit AM interacted together and predicted higher SGPA. This synergistic pattern paralleled the integrative process assumption of SDT, by demonstrating that internalization is a key ingredient for the achievement of students.	The synergistic effect of explicit and implicit AM was found to be present only for students with average to high levels of WMC. As the integrative process is theorized to be anchored in the biology of individuals, this study revealed that internalization is dependent on the cognitive resources of students.	Past studies revealed that the direct association between WMC and academic achievement was moderate for elementary and high school students. This study complemented the literature by revealing a smaller association between WMC and SGPA.
Chapter 3: Reciprocal effect of AM and replication of study 1	As it was revealed in study 1, explicit and implicit AM interacted together to predict SGPA. This second study used a Bayesian approach stemming from the reproducibility crisis in psychology, to replicate the findings of study 1.	The Bayesian approach replicated the moderating role of WMC on the synergistic effect of explicit and implicit AM. For students to benefit from having a synergistic pattern of AM, sufficient cognitive resources are needed.	A reciprocal association between students' explicit AM and their academic achievement was revealed. This was the first study to reveal this effect in a sample of university students.
Chapter 4: Priming effect of AM on the association between explicit AM and task performance	In an experimental learning situation, explicit AM for learning was found to positively predict verbal examination performance, but only for students who were subliminally primed with AM words.  Activating mental representation of AM had a bolstering effect on the association between explicit AM and examination performance.	WMC was found to moderate the experimental synergistic effect of explicit AM and subliminally primed AM. However, the priming procedure was found to be contingent on WMC with an opposite effect in comparison with studies 1 and 2. Students with average to low levels of WMC were the ones mostly affected by the subliminal prime, and displayed synergistic effect of explicit and implicit AM in the prediction of verbal examination.	WMC had a different role in this experimental study compared to the correlational study 1 and 2. This difference demonstrates how WMC is an important cognitive variable that can explain for whom and under which situation the synergistic effect of AM can operate more efficiently.  On a different note, the resolution of math problems the exam was found not to be affected by the priming manipulation, and exposed how much mathematics should be explored separately.

Note. AM = autonomous motivation, SGPA = semester grade point average, WMC = working memory capacity.

## Key Findings and Contributions from Study 1

The association between academic AM and subsequent academic achievement has been found to be relatively small (Cerasoli et al., 2014; Richardson et al., 2012; Taylor et al., 2014). Empirical investigations on this association have mostly relied on self-report assessment of academic AM. Even if those assessments have been proven to be robust predictors of social behavior and many consequential life outcomes, they are nonetheless limited (Guay et al., 2008). When students are asked, via a self-report measure, to answer questions about their motivational dispositions they might not be willing to share such information, but more importantly they might not have access or be aware of their own internal motivational dispositions (Wilson, 2003). For SDT, internalization is the process through which individuals regulate their behaviors more autonomously, but self-report measure of dispositional AM might not fully account for the actual level of internalization of those regulations. Hence, I proposed that the assessment of AM through self-report measure only assesses a *declarative form of self-knowledge* one has about his or her AM. These self-reported measures, although reliable and valid, are offering little perspective to capture the extent to which such declarative knowledge has been fully processed and integrated within a broader network of mental representations about the *self* (Gawronski & Bodenhausen, 2006; Hofmann et al., 2005; Kuhl, Quirin, & Koole, 2015). In the first study of my thesis, I proposed a dual-process investigation of AM to solve this conundrum and hypothesized that the synergistic interplay between explicit self-reported AM and implicit AM should be considered as an indicator of better well integrated AM within the *self* (Weinstein et al., 2013).

Previous work in SDT have provided initial evidence for a synergistic effect of explicit and implicit AM when predicting academic achievement (Burton et al., 2006). Although highly

important for the literature, this preliminary work had noticeable limitations. On the one hand, the sample size ( $n = 53$ ) was relatively low for testing an interactive effect, and the decomposition of the interaction was done through a median-split procedure. On the other hand, the aggregated dimension of AM was not analyzed, as separate analyses were performed for the intrinsic and identified regulations. Thus, *study 1* of this thesis provided an upgraded analysis of this preliminary work by enlarging significantly the sample size ( $n = 272$ ), using proper moderated regression analysis for decomposing interactive effect and by evaluating AM as a whole (rather than intrinsic and/or identified regulations). The results of this first exploration revealed a significant interaction between the two theorized motivational processes. Explicit academic AM was found to positively predict SGPA but only for students with higher levels of implicit AM ( $\beta = .313$ ). The dual-process perspective of AM does seem to better capture how well AM is internalized across students and significantly enhances the prediction of explicit AM on academic achievement, from a small to a moderate effect. For students to fully integrate their AM and reach higher academic achievement, they seemed to need easily accessible mental representations of AM and to explicitly declare high levels of AM.

Moreover, in this first exploration of the *explicit-implicit model of AM*, I proposed that the synergistic effect of explicit and implicit AM, which denotes proper internalization, should depend on the available cognitive resources of students. WMC was thus hypothesized to moderate the synergistic effect of explicit and implicit AM. The three-way interaction of explicit, implicit AM, and WMC was found to be significant when predicting subsequent academic achievement. Efficient autonomous functioning, characterized by the synergistic effect of explicit and implicit AM, was only found in students with sufficient cognitive resources. In the SDT view, the integrative process is not just a psychological process but is also highly tied to the

neurological functioning of the human brain. Recent neuroscience studies are starting to converge on this particular idea that the brain has some inherent intrinsic qualities that are essential for healthy self-functioning (W. Lee, Reeve, Xue, & Xiong, 2012; Murayama et al., 2013). Moreover, internalization processes were found to have most of its activities in the prefrontal cortex (Kuhl et al., 2015), an area of the brain that is associated with general executive functions (Miller & Cohen, 2001). The contingency of the synergistic effect of AM on WMC might have been observed in this study because of this incidental overlap between the neural basis of autonomous self-regulation and general executive function. In sum, this first empirical exploration of the explicit-implicit model of AM contributes to the development of SDT by providing a new cognitive perspective on the integrative process and its consequence for academic achievement.

### **Key Findings and Contributions from Study 2**

To expand on *study 1*, and further the development and predictive validity of the *explicit-implicit model of AM*, the investigation of *study 2* had several objectives to address methodological and theoretical gaps. On the one hand, I developed an improved version of the LDT measure of implicit AM by adding motivational words in order to increase the preciseness of the aggregated implicit score. Also, I embarked on the current replication paradigm that was highly advocated in the recent years (Nelson, Simmons, & Simonsohn, 2018), to respond to the, still occurring, reproducibility crisis in psychological science (Simmons, Nelson, & Simonsohn, 2011; Simmons, Nelson, & Simonsohn, 2018). Bayesian analysis was thus deemed the appropriate method of analysis to replicate the main results of *study 1* (Kruschke & Liddell, 2017). On the other hand, investigations on the association between academic AM and subsequent academic achievement have largely ignored the inevitable bidirectional dynamic

between past academic achievement, present academic AM, and future academic achievement. Hence, in *study 2*, I also examined the reciprocal effect of AM and academic achievement with a second sample of university students.

First, it is important to recognize that university students do not arrive on campus with a blank slate over their academic achievements. Before entering their university program, they were in high school, and before that, in elementary school. University students have accumulated enough knowledge to be accepted in a university program, but their past academic achievements can reveal more than just, how good academic performers they are. Their past academic achievements are also a direct reflection of how well they coped, motivated themselves, self-regulated and felt competent over the years. Throughout their academic career, they have also developed psychological skills that brought them where they are now. This assertion is reflected in studies that revealed that the selection process of tertiary education seems to reduce the observed variance in cognitive factors (i.e. intelligence, cognitive ability, etc.). Concordantly allowing for non-cognitive factors - like motivation, self-efficacy or self-regulation skills - to be more predictive of academic achievement at tertiary level of education (Ackerman, 1994; Chamorro-Premuzic & Furnham, 2003; Furnham, Chamorro-Premuzic, & McDougall, 2003; Kappe & Van der Flier, 2012; Richardson et al., 2012)

Therefore, in *study 2*, the admission GPA of university students was hypothesized to act as a motivational factor that influence the development of present academic AM. As predicted, the mediation analysis revealed that students' admission GPA was indeed a significant positive predictor of explicit self-reported AM at university. Then, explicit self-reported AM also predicted future academic achievement at university. Students who performed better during their last high school year were found more likely to have higher levels of explicit self-reported AM,

thus providing evidence that past academic achievements are a factor to be considered in the development of future academic AM.

In our modern educational systems, grading systems in itself have been associated with lower academic achievement, reduced intrinsic motivation, and diminished deep conceptual learning, in samples of elementary students (Grolnick & Ryan, 1987; Klapp, 2015). However, the results of *study 2*, seems to propose that the sum of all grades accumulated in the last year of high school (i.e. admission GPA), can act like a relevant competence feedback that benefits the development of future AM. According to SDT, students all strive to satisfy their need for competence, autonomy, and relatedness. Those basic psychological needs are theorized as being the nutriments for the development and sustainment of AM. The students thus probably perceive their successes and failures as a direct feedback of their competence, which can later promote or hinder the development of AM. University students are nonetheless unique, because they all succeeded in being accepted in a university program, and their grades were deemed sufficient for post-secondary education. Overall, taking into account the reciprocal nature of motivation and achievement portrayed a more precise estimation of future academic achievement.

The explicit self-reported AM for university studies was positively associated with SGPA ( $\beta = .163$ ), but as revealed in *study 1*, this association was relatively small. The results of *study 1* indicated that adopting a dual-process perspective can explain why this effect is smaller than expected in the literature. Through a Bayesian analytical approach, the findings of *study 1* were included in the analysis as informative prior. The data of the explicit-implicit model of AM collected in *study 2* was thus tested against the prior findings of *study 1*. The synergistic effect was successfully replicated, as demonstrated by the sensitivity analysis of the informative prior. Moreover, the cognitive resources hypothesis was also replicated, however, this three-way

interaction effect was more sensible to the informative prior. Nonetheless, Bayesian estimation allows for a more intuitive interpretation of the results, given that each parameter are presented in an actual distribution, thus the probability of a null result (region of practical equivalence  $\leq \pm .05 = \text{ROPE}$ ) can be directly assessed. In this particular study, the three-way interaction depicting the cognitive resources hypothesis was outside of the pre-established ROPE across the different sensitivity level on the prior, with 99.2% to 77.5% of the distribution not within the ROPE.

In sum, *study 2* provided additional evidence for the explicit-implicit model of AM and the adoption of a dual-process perspective of AM in the prediction of academic achievement. *Study 2* main contributions to the literature are twofold. On the one hand, this is the first study to demonstrate that past academic achievement can positively predict explicit self-reported AM for university studies, and that academic AM and achievement have a dynamic positive reciprocal relationship. On the other hand, by replicating the previous findings of *study 1*, this second study reinforces the plausibility of the synergistic effect of AM and the cognitive resources contingency on the prediction of academic achievement. Still, more research is needed to further our understanding of how dual-process models and hypotheses can be better integrated to SDT.

### **Key Findings and Contributions from Study 3**

In the last study of this thesis, my goal was to test the hypotheses of the *explicit-implicit model of AM* in the laboratory. An experimental design was created to investigate the causal properties of the implicit process of AM on the association between AM for learning and achievement, while examining the contingencies of this effect on WMC. Within the confines of a lab, participants were surveyed on their explicit dispositional motivation to learn new knowledge and randomly assigned to a subliminal priming condition. Through a lexical decision task, participants were thus primed with either AM, CM or neutral words. Afterward, participants

went into learning about modular arithmetic, in a learning situation designed to be relatively similar to the academic environment faced by university students on a daily basis. Students were informed that the end goal of the learning situation was to perform an exam on the learned content. Overall, this experimental study aimed at investigating the causal influence of the subliminal priming procedure of AM words, and its contingency on WMC, on the association between explicit AM to learn and examination performance.

According to the reflective-impulsive model (RIM; Strack & Deutsch, 2004) impulsive processes can be activated either by perceptual input or directly in combination with the reflective process itself. In this experimental study, mental representations of AM were implicitly activated via perceptual input with a subliminal priming procedure. Results of the moderation analysis revealed that explicit self-reported AM to learn positively predicted verbal examination performance, but only for the students who were subliminally primed with AM words. As previously found in *studies 1* and *2* of this thesis, the reflective/explicit process of AM seem to gain strength when accompanied with higher levels of implicit AM. In this experimental study, implicit AM was subliminally activated to elicit this synergistic effect. As described in the RIM, behaviors that are generated by the reflective process are a consequence of a decision process that is certainly volitional, but when this specific process is paired with compatible impulsive processes, the resulting behavioral regulations are more fluent. In this study, the subliminal activation of AM contributed to the autonomous behavioral regulations that were explicitly measured through self-reported AM. The results of this study corroborated the RIM proposition that a synergistic interplay between reflective and impulsive processes should facilitate the appearance of the specific behavioral regulation.

The interpretation of the findings within the RIM also resonates with the theoretical propositions of SDT. As previously discussed in *studies 1* and *2*, the synergistic effect of explicit and implicit AM can be taken as an indicator of integration. The first two studies, which relied on a correlational design, depicted a *person x person effect*, where individual difference measures of dispositional AM interacted in the prediction of academic achievement. However, in this experimental study (*study 3*), the subliminal prime of AM created a condition in which, the effect of students' explicit AM was bolstered by implicit situational cues of AM. This experimental synergistic effect should thus be interpreted as a *person x situation effect*, where the subliminal prime acted as a situational cue that causally influenced the strength of the association between explicit AM and examination score. As predicted by the synergistic hypothesis, in *study 3*, explicit self-reported AM was a positive predictor of examination performance (for the verbal component), but only for students who were subliminally primed with AM words. For SDT, this bolstering role of implicitly activating AM can be interpreted as a situational factor that fosters the internalization of AM and enable the students to enact the full potential of their AM disposition. However, the internalization process is known to be facilitated by a social environment that is autonomy supportive, in opposition to controlling, as demonstrated by ample empirical evidence (e.g., Black & Deci, 2000; Grolnick & Ryan, 1989; Moreau & Mageau, 2012; Reeve et al., 2014; Vansteenkiste et al., 2004). Nonetheless, even if in this experimental study socio-contextual factors were absent of the analysis, the unconsciously perceived situational cues of AM were still able to facilitate the enactment of AM and ultimately help those students perform better on the verbal component of the exam. Overall, it seems that socio-environmental cues that promotes AM might not need to be consciously perceived by the students to facilitate the expression of explicit AM. For SDT, this opens a new research avenue because implicit cues

in the social context – even those that are not always conscientiously perceived – can sometime accentuate the association between explicit self-declared AM and academic achievement.

The positive role of WMC on the synergistic effect of explicit and implicit AM was revealed in *study 1* and replicated *study 2*. Individuals with higher levels of WMC seem to benefit from displaying a synergistic pattern of AM between the two motivational processes. However, in this experimental study, the synergistic effect was operational for students with low to average levels of WMC, thus contradicting the initial hypothesis of the explicit-implicit model of AM. The experimental synergistic effect was observed only in students with low to average levels of WMC. Although surprising at first glance, insight from cognitive psychology can be drawn to interpret this particular result. First of all, semantic priming effect, like the one use in this study, has been found to be more likely to happen when individuals have lower levels of WMC (Heyman, Van Rensbergen, Storms, Hutchison, & De Deyne, 2014; Ortells, Noguera, Alvarez, Carmona, & Houghton, 2016). Secondly, individuals with higher levels of WMC are known to use more controlled processing (Barrett et al., 2004; Conway, Cowan, & Bunting, 2001), and might have been performing the LDT with such controlled that the subliminal prime could not affect them as much. Overall, this experimental study complement the findings of *studies 1* and *2* on the role of WMC for the synergistic effect of explicit and implicit AM. For an implicit situational cue of AM to influence explicit AM, students with lower levels of WMC can benefit to a greater extent from the implicit situational cues.

### **Limitations and Future Research Directions**

As demonstrated above, this thesis made a significant contribution to the study of motivation in the educational context. Nevertheless, several limitations should be acknowledged to facilitate the development of future studies.

### **Generalization of the Synergistic Effect to Other Educational Levels**

In this thesis, I selected undergraduate students as the target population of my research program and collected samples of university students at a large Canadian university. Of particular concern, the results of this thesis should not be generalized beyond the university context and the cultural background of North America. The results are also limited to tertiary education, and more specifically to the demographic age groups of young adults. Future work will be needed with younger students in high school as well as adult learners. For what we know, the synergistic effect of explicit and implicit AM might operate differently with younger populations of students in high school or elementary school. The cognitive process of internalizing autonomous behavioral regulation might be contingent on the normal maturation process of the frontal cortex. Therefore, I suspect that the findings or the *explicit-implicit model of AM* might bear different internalization patterns earlier in the human development.

Does the integrative process operate the same way in infants, children, adolescents and adults? Most likely, I suspect that our intrinsic motivational capacities have developmental stages, and an underlying maturation process that is embedded in the development of our brain. A similar proposition has been made by Ryan and Deci (2017), which expect that the process of autonomously internalizing behavioral regulations might require a certain level of cognitive maturation. Intrinsic motivation is the most self-determined form of AM and is defined by the actions of an individual that are pursued for the inherent satisfaction and pleasure that is derived from a given activity. Feelings of pleasure directly comes from the limbic system and can motivate our future actions when the feelings of pleasure are associated with our behaviors (Berridge & Kringelbach, 2013). Even in infants, intrinsic behaviors like exploration, curiosity, and play can be elicited and maintained in the absence of external rewards (Harter, 1978, 1981;

Lepper, 1981; Lepper, Greene, & Nisbett, 1973). Humans are thus equipped with an internal rewarding system that is deployed through simple pleasure-seeking behavior. However, as children grow, their frontal lobe will naturally develop and allow them to cognitively evaluate their social environment and their actions with more nuance and complexity. Yet, few studies have explored the developmental mechanisms of academic AM in children and adolescents (A. E. Gottfried, 1985; A. E. Gottfried, Fleming, & Gottfried, 1998, 2001; A. E. Gottfried, Marcoulides, Gottfried, & Oliver, 2009; A. W. Gottfried, Cook, Gottfried, & Morris, 2005). In those studies, results have mainly revealed that the students' intrinsic motivation to study diminish overtime within the educational context. However, as this thesis demonstrated, self-reported evaluations of academic motivation might not precisely represent the level through which autonomous regulation have been integrated in the *self*. In addition, the natural cognitive development of children has been proposed to be associated with the emergence of the explicit system through which children may reflect and evaluate their own mental content (Olson & Dunham, 2010). Therefore, it could be proposed that the synergistic interplay between explicit and implicit AM, and the development of efficient AM is tied to the normal cognitive maturation process

Moreover, this thesis revealed that internalization in young adults is contingent on their working memory capacities – an indicator of executive function. If the integrative process is inherent, thus “anchored in the biology of individuals” (Ryan & Deci, 2017, p. 50), the developmental pattern of internalization should follow the normal brain maturation process. Is the normal development of executive functions, and working memory capacities, follows the development of autonomous functioning in parallel, or do executive functions directly influence the development of efficient AM? Interestingly, as the development of working memory

capacities has been found to follow the general trend of brain maturation from childhood to late adolescence (Conklin, Luciana, Hooper, & Yarger, 2007), we could expect the integrative process to follow the same maturation process. Overall, the findings of this thesis have given insight into the integrative process of SDT with samples of young adults with matured brain and cognitive capacities above the general population. Future studies should examine the hypotheses of the *explicit-implicit model of AM* by decreasing the age of the samples one study at the time. As a result, those studies would allow to observe more easily the developmental patterns both AM and executive functions, and their emerging co-occurrence across time

### **Gender Representation and Differences in Academic Motivation**

All the samples recruited in this thesis had a larger proportion of females (86%, 74.8%, and 65.9%). Therefore, the findings of this thesis are also limited by this sample characteristic. However, the disproportion of female students in undergraduate programs is not too surprising for those samples of undergraduate students. Considering that, since 1990, in Canada, the percentage of women enroll full-time in undergraduate university programs has always been larger than men with a high of 57.9% in 2007 (Turcotte, 2011). In addition, even if the samples of this thesis had students from a variety of programs, most of the participants were coming from humanities and social and health science programs. In those programs, the proportion of women is even larger (64.3%, 67%, 77%) than the average proportion census in 2008 (Turcotte, 2011). Overall, the samples of this thesis were not exactly representative of the Canadian student population on gender and type of programs. As such, the results of this thesis might thus be more generalizable to the female student population. Future studies should address this issue by recruiting participants using a stratification recruitment procedure to allow a breakdown of males and females closely aligned to the general population of students registered in tertiary education.

On another note, the association between academic intrinsic motivation and academic achievement in university has sometime been found to be moderated by the students' gender (Vecchione, Alessandri, & Marsicano, 2014). The association was stronger for the female students and non-significant for the male students. In the same study, extrinsic motivation was a positive predictor of academic achievement for male students but a non-significant predictor for female students. Moreover, gender differences in the mean-level of AM and CM have been revealed in the literature (Grouzet, Otis, & Pelletier, 2006; Ratelle, Guay, Vallerand, Larose, & Senecal, 2007; Vallerand, Blais, Lacouture, & Deci, 1987). Females have been found to have higher levels of AM than males, and males have been found to have higher levels of CM than females. Nevertheless, revealing and exploring gender differences in psychology should follow the same theoretical rigour than any psychological effect. Within the SDT framework, gender differences hypotheses have not been readily developed, hence, the results of those past studies should be interpreted cautiously. In addition, recently the *gender similarity hypothesis* (Hyde, 2005), which proposes that men and female are alike on most psychological variables, has gained traction through entire psychological field (Brannon, 2016). Future theoretical work on gender differences within SDT should also be developed to consider the growing reality that many students on our campus are not adhering to a dichotomous male versus female definition of their gender. Overall, careful theoretical elaboration on gender and its role in human motivation should precede future work examining the specific role(s) of gender in the *explicit-implicit model of AM*.

### **What about controlled motivation?**

SDT describes the advantages that come with internalizing behavioral regulations that are more autonomous and coherent with the *self*. The benefits of AM have been clearly

demonstrated across hundreds of studies in education (Chia, Chee Keng, & Ryan, 2016; Guay et al., 2008), work (Gagné, 2014) and sports setting (Hagger & Chatzisarantis, 2007), but such this research remains an important endeavor for developing psychosocial interventions that are aligned with the inherent intrinsic function of human motivation. However, it can be argued that theorizing and research within the SDT framework still remains widely skewed toward AM. The internalization continuum of SDT describes behavioral regulation based on their perceived sources of causation – from external to internal. Through the interaction with the social environment, some individuals will more easily and deeply internalize the source of their behavior. In other cases, the internalization process will fail or remain incomplete, and those individuals will associate the cause of their behavior to external factors. This pattern of less internalized regulation is referred to as controlled motivation (CM), and empirical studies on this particular dimension of human motivation are not exactly lacking, but I would say that CM is often ignored in the interpretation of the findings. Recent empirical evidence has demonstrated the importance of examining both dimensions of the internalization continuum for their unique contribution, their interaction, and their relative agreement/disagreement to one another (Brunet, Gunnell, Gaudreau, & Sabiston, 2015). Across three studies, Brunet and her colleagues (2015) found that, participants for whom AM was relatively higher than CM were more likely to experience positive outcomes (e.g., higher goal progress, academic achievement, life satisfaction, engagement, feelings of joy, etc.). Interestingly, when AM and CM were both high, positive outcomes were also observed on academic planning, engagement, average grades, and feelings of joy. In other words, the tendency to eschew CM to focus theoretical and empirical attention to AM may limit our capacity to fully understand the respective roles of AM and CM within the SDT framework.

In this thesis, I too, deliberately focused on the AM dimension because of its presumed importance to promote optimal social functioning, well-being, and achievement in the academic context. The findings of this thesis are thus limited to the AM dimension, even though CM was properly controlled for in all statistical analyses to ensure that explicit and implicit AM dimensions were aligned with the underlying theory and psychometric properties of the construct. The polynomial regression-based approach used by Brunet et al. (2015) could be used to investigate explicit-implicit AM and CM interactions. Although highly interesting, this variable-centered approach can rapidly become computationally complex when more than two predictors are hypothesized in the model. Therefore, adopting a person-centered approach to the analysis of explicit-implicit AM and CM appears more promising to reveal different motivational profiles of internalization. As demonstrated in Ratelle et al. (2007), latent class analysis revealed that students with higher levels of both AM and CM were less absent in their class, more satisfied with school, less distracted in class, and performed better than their peers. Future studies could investigate the different within-person combination of explicit-implicit AM and CM to further our understanding of those distinct motivational dimensions on consequential educational outcomes.

### **Theoretical and Practical Implications**

The exploration of the integrative process performed in this thesis holds several theoretical and practical implications. SDT has now been developed more than 30 years ago and the field of psychology has largely grown since then (Deci & Ryan, 1985). Cognitive methodologies are now more accessible than ever. Accordingly, in this thesis, I had the opportunity to investigate the central assumption of the integrative process with insight from the implicit cognition paradigm. The three studies of my thesis have important theoretical

implications for SDT, because they are connecting two distinct theoretical traditions – humanistic and cognitive - with concordant results that are interpretable in light of both paradigms. Dual-process models are now ubiquitous in psychology and provide deeper insights into human behavior by bringing together cognitive and social psychology. In this thesis, I offered a first glance of what dual-process models can bring to the study of human motivation within the SDT framework.

The synergistic effect of explicit and implicit AM is theoretically and methodologically important for SDT. Theoretically, the empirical support for the synergistic effect of explicit and implicit AM on academic achievement is consistent with the internalization assumption of SDT: The more a behavioral regulation is internalized, the more the action of individuals should be autonomous and should lead to positive outcomes. The findings of this thesis are thus theoretically important because they are demonstrating that adopting a dual-process perspective on the internalization assumption can increase its predictive validity. Moreover, the implicit measure of AM and CM developed in this thesis brings more credibility and utility to the usage of such measure for SDT. The implicit methodologies have slowly gained attention within the SDT framework (Levesque et al., 2008; Radel, 2009; Weinstein et al., 2013), and this thesis offers valuable information for researchers wishing to investigate the influence of implicit motivational processes in their future studies.

This thesis also has practical implications for the scientific community. All of the methodological materials presented in this thesis are available online on the OpenScienceFramework servers ([osf.io/u86hw](https://osf.io/u86hw)). The implicit measure of AM and CM programmed in E-PRIME 2.0 is therefore available to researchers wishing to pursue this line of work. Moreover, MPLUS syntax for models with moderated-moderation (i.e., three-way

interaction), mediated moderated-moderation, and moderated-moderation with a categorical moderator models have been developed and are shared on the same server link. Those syntaxes are complicated to formulate. Providing those examples to the research community is also a methodological contribution of this thesis.

Lastly, this thesis also has practical implications for the educational context. As demonstrated, the measurement of academic motivation is not entirely complete when only a self-report assessment is taken into account. As such, counselors could be trained to adopt a dual-process perspective when intervening with students, or at least be informed that self-reported motivation should only be understood as the reflective/conscious part of the motivational characteristics of a student. Thus, by training them to consider the dual nature of students' motivational processes, applied psychologists could help students who are displaying deficient motivational profiles. Overall, the implication of this thesis for the scientific community is widespread. Future work unto the implicit approach of SDT might help transitioning the empirical evidence in the hand of who needs it the most – the students of tomorrow.

### **Conclusion**

This thesis investigated, through a dual-process SDT perspective, the motivational determinants of academic achievement. SDT initially proposed that students who regulate their action more autonomously should perform better academically (Deci & Ryan, 1985, 2002; Ryan & Deci, 2017). However, the literature portrayed a somehow weaker than expected association between self-reported AM and academic achievement (Richardson et al., 2012; Taylor et al., 2014). Accordingly, this thesis premise was that students are not always conscious or aware of their own motivational disposition. Therefore, self-reported academic AM is not precisely

tapping into the internalization process that is described in SDT. In this thesis, I integrated notion from the implicit social cognition paradigm to better understand for whom and under which circumstances self-reported AM can predict academic achievement. Adopting a dual-process perspective on the student's academic AM was found to be relevant for the study of academic motivation and its consequence on academic achievement. The explicit-implicit model of AM that was developed in this thesis contributed to the emerging implicit perspective within SDT (Levesque et al., 2008; Radel, 2009; Weinstein et al., 2013), by providing hypotheses and empirical evidence for the study of implicit motivational process within SDT.

In two prospective studies, the synergistic interplay of explicit and implicit AM was found to positively predict academic achievement. The combination of high levels of explicit and implicit AM seems to be a necessary condition for the internalization process. In the last study of this thesis, an experimental manipulation revealed that situational cues of implicit AM causally influenced the association between explicit AM and subsequent task performance. The support for this novel hypothesis on the synergy between explicit and implicit motivational processes of AM – across three studies – is the major contribution of this thesis and an important addition to the SDT literature. Moreover, in the two prospective studies, the synergistic effect was found to be contingent on the students' WMC. The positive interplay between the two motivational processes of AM seems to operate only for individuals who have enough cognitive resources. Internalizing one's behavioral regulation is a tedious cognitive task (Ryan & Deci, 2017; Weinstein et al., 2013), and individual-differences in WMC were found to support this proposition.

Overall, the implicit social cognition paradigm has still a lot to offer for the development of SDT. This is without a doubt exciting time for experimental social psychology researchers

interested in the unconscious aspect of self-determination, because implicit cognitive theories are blooming (Gawronski & Payne, 2011; Nosek et al., 2011) and their measurement methods are becoming more accessible to the neophyte. Recently, on the central autonomy principle within SDT concerns have surfaced over the notion that individuals are not always conscious of their actions (Bargh, 2017; Bargh, Gollwitzer, Lee-Chai, Barndollar, & Trötschel, 2001; Bargh & Morsella, 2008). However, proposing a dual-process approach like the one adopted in this thesis was a stepping stone – a significant contribution – required to provide the preliminary theory elaboration, methodological advances, and empirical evidence to inform this debate. In this thesis, I demonstrated that differentiating explicit motivational processes from their implicit counterparts in SDT can bring together, in a coherent whole, different streams of research with high heuristic value for the development of future theoretical and empirical work.

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## Appendices

### Appendix A: Explicit self-reported measure of academic motivation

This scale was used in *study 1* and *study 2*.

Indicate the extent to which each of the following items presently corresponds to one of the reasons why you study at the university.

**I study at the university because...**

1	2	3	4	5	6	7
Not at all for this reason	Very slightly for this reason	Slightly for this reason	Moderately for this reason	Strongly for this reason	Very strongly for this reason	Totally for this reason
1) Because I truly love it						
2) In order not feel ashamed						
3) It is part of who I am as a person						
4) Somebody is putting pressure on me						
5) I feel that it is important for me						
6) I do it, but it is not motivating						
7) I want to be rewarded						
8) It is intrinsically satisfying						
9) Otherwise, I would feel guilty						
10) It clearly defines me as a person						
11) I feel that others are pushing me to do it						
12) In order to pursue goals that are important to me						
13) I do it, without really knowing why I continue						
14) I do it, but for no reason						
15) It allows me to obtain something in return						
Amotivation	External regulation	Introjected regulation	Identified regulation	Integrated regulation	Intrinsic regulation	
6 – 13 – 14	4 – 11	2 – 9	5 – 12	3 – 10	1 – 8	

## Appendix B: Lexical decision task for *study 1* and *2*

### Study 1 list of stimuli

	Non-Words		Words	
			Neutral words	Motivational words
1	Vonk	Kowe	Chair	Enjoying
2	Trewf	Oque	Table	Freely
3	Fiese	Qawr	Spoon	Satisfied
4	Seeta	Lyet	Screen	Volunteer
5	Hinys	Poite	Apple	Autonomous
6	Dama	Thuof	Pencil	Rewarded
7	Bulti	Dife	Glass	Pressured
8	Yotri	Kutt	Window	Controlled
9	Ganw	Voos	Book	Constrained
10	Brisa	Vonf	Mouse	Proving

### Study 2 list of stimuli

	Non-words			Words		
				Neutral words	Autonomous words	Controlled words
1	blanked	cryshed	bicts	age	absorbed	acceptance
2	bophts	cwonzed	bloiled	agent	achieve	anxious
3	borpes	dribes	chautts	apple	autonomous	appreciated
4	brambed	fampced	chopths	behind	beliefs	approval
5	bylbed	freiggs	dooffth	beyond	beneficial	ashamed
6	claufth	ghavs	dweked	book	challenge	avoiding
7	cleinth	ghergs	fleeggs	cable	competence	competitive
8	cluves	ghlisks	ghirnds	chair	competent	comply
9	cwoves	ghwefes	glyfs	cloth	curiosity	compulsory
10	deacked	gived	greuths	color	delighted	constrained
11	doabs	gwemms	gweuved	crowd	development	controlled
12	durphth	gwetes	gwylphs	deer	discovering	criticized
13	gealts	gworps	hyped	drain	engaged	demanding
14	ghenged	kriets	jeucks	drum	enjoy	duty
15	ghyfs	megeed	jourbed	duck	enjoyable	embarrassed
16	ghylps	pasps	leems	fear	enjoying	envied
17	gwaunts	piphths	oanths	fish	enjoyment	evaluated
18	hulns	pleebs	peumms	five	exciting	expected
19	hursts	psysks	pheezed	four	fascinating	forced

20	keimbed	puippth	phoppth	future	flow	guilty
21	koabbs	raughns	pirns	glass	freedom	impress
22	kruffth	ryppth	pournts	monkey	fun	incapable
23	kweakes	sheibed	powdged	mouse	growth	must
24	kwulsed	shythed	psorged	mouth	happy	necessitate
25	ligged	skeelds	queles	orange	identity	obliged
26	nanked	skrirls	raimbth	over	immersed	pointless
27	noovvs	skwyggs	rhirls	pencil	important	praise
28	nygued	slirved	rulphed	pipes	integral	pressured
29	phelcks	sonksed	sciles	plant	interested	prestigious
30	phylns	sproved	scymmth	puzzle	Interesting	privileges
31	plorbes	starnts	skwigs	screen	involved	proving
32	quavved	stroats	smegeg	seed	joy	punished
33	rhamed	talsed	smeicks	shark	like	recognition
34	sheefed	threuds	storsts	signal	love	recognized
35	shigs	tinched	stuvv	snake	mastering	reprimand
36	sipsed	trynged	sumth	spoon	meaningful	reputation
37	skwuls	vawmth	swaipps	state	pleasure	required
38	snalmed	voffth	sweags	strong	satisfied	respected
39	squeds	wescks	swemms	sugar	spontaneous	responsible
40	stansed	yaged	tryvs	table	stimulating	restricted
41	stauths	yeammed	tyves	time	thrill	rewards
42	suls	yinzed	webed	total	usefulness	rule
43	swuymed	yirthed	whumbed	warm	values	shame
44	swylnd	zambv	yencked	weak	volunteering	should
45	wherbed	zoakked	yimms	window	wellbeing	supposed
46	whunced	zulced	zelbs	world	worthwhile	wasting

Non-words were generated in ARC nonword database (Rastle, Harrington, & Coltheart, 2002) 46 autonomous and 46 controlled words were administered.

In GREY are the theoretically-selected words, as described in the method section of *study 2*.

### Appendix C: The math anxiety scale (*study 3*)

The abbreviated math anxiety scale (AMAS; Hopko, Mahadevan, Bare, & Hunt, 2003)

*Please rate each item below in terms of how anxious you would feel during the event specified*

1	2	3	4	5
Low anxiety	Some anxiety	Moderate anxiety	Quite a bit of anxiety	High anxiety

1. Having to use the tables in the back of a mathematics book.
2. Thinking about an upcoming mathematics test one day before.
3. Watching a teacher work an algebraic equation on the blackboard.
4. Taking an examination in a mathematics course.
5. Being given a homework assignment of many difficult problems which is due the next class meeting.
6. Listening to a lecture in mathematics class.
7. Listening to another student explain a mathematics formula.
8. Being give a pop quiz in a mathematics class.
9. Starting a new chapter in a mathematics book.

## Appendix D: Explicit self-reported measure of motivation for learning new knowledge

This scale was used in *study 3*

### The context of today's study

During your time with us you will go through a virtual class where you will be taught new knowledge as you would in a regular university class.

Indicate the extent to which each of the following items corresponds to one of the reasons why you participate in learning activities in which you are exposed to new school-related material.

*I invest myself in learning new material because...*

1	2	3	4	5	6	7
Not at all for this reason	Very slightly for this reason	Slightly for this reason	Moderately for this reason	Strongly for this reason	Very strongly for this reason	Totally for this reason

- 1) Because I truly love it
- 2) In order not feel ashamed
- 3) It is part of who I am as a person
- 4) Somebody is putting pressure on me
- 5) I feel that it is important for me
- 6) I do it, but it is not motivating
- 7) I want to be rewarded
- 8) It is intrinsically satisfying
- 9) Otherwise, I would feel guilty
- 10) It clearly defines me as a person
- 11) I feel that others are pushing me to do it
- 12) In order to pursue goals that are important to me
- 13) I do it, without really knowing why I continue
- 14) I do it, but for no reason
- 15) It allows me to obtain something in return

Amotivation	External regulation	Introjected regulation	Identified regulation	Integrated regulation	Intrinsic regulation
6 – 13 – 14	4 – 11	2 – 9	5 – 12	3 – 10	1 – 8

## Appendix E: All of experimental material for *study 3*

### List of experimental material for the learning situation

- Lexical decision task list of stimuli + prime stimuli of AM and CM
- Course plan provided at the beginning
- POWERPOINT presentation of the learning situation on modular arithmetic
- Supplemental reading provided at the end of the learning situation
- Exam with correct answers

### Lexical decision task list of stimuli + prime stimuli of AM and CM

Neutral words		Non-words	
age	beyond	blanked	freiggs
agent	book	bophts	ghavs
apple	cable	borpes	ghergs
behind	chair	brambed	ghlisks
beyond	cloth	bylbed	ghwefes
book	color	claufth	gived
cable	crowd	cleinth	gwemms
chair	deer	cluves	gwetes
cloth	drain	cwoves	gworps
color	drum	deacked	krixts
crowd	duck	doabs	megeg
deer	fear	durphth	pasps
drain	fish	gealts	piphts
drum	five	ghenged	pleebs
duck	four	ghyfs	psysks
fear	future	ghylps	puippth
fish	glass	gwaunts	raughns
five	monkey	hulns	ryppth
four	mouse	hursts	sheibed
future	mouth	keimbed	shythed
glass	orange	koabbs	skeelds
monkey	over	kruffth	skirls
mouse	pencil	kweakes	skwyggs
mouth	pipes	kwulsed	slirved
orange	plant	ligged	sonksed
over	puzzle	nanked	sproved

pencil	screen	noovvs	starnts
pipes	seed	nygued	stroats
plant	shark	phelcks	talsed
puzzle	signal	phlylns	threuds
screen	snake	plorbes	tinched
seed	spoon	quavved	trynged
shark	state	rhamed	vawmth
signal	strong	sheefed	voffth
snake	sugar	shigs	wescks
spoon	table	sipsed	yaged
state	time	skwuls	yeammed
strong	total	snalmed	yinzed
sugar	warm	squeds	yirthed
table	weak	stansed	zambs
time	window	stauths	zoakked
total	world	suls	zulced
warm	duck	swuymed	bicts
weak	fear	swylned	bloiled
window	fish	wherbed	chautts
world	five	whunced	chopths
age	four	cryshed	dooffth
agent	future	cwonzed	dweked
apple	glass	dribes	fleeggs
behind	monkey	fampced	ghirnds

Autonomous prime	Controlled prime	Neutral prime
achieve	anxious	color
autonomous	appreciated	duck
enjoy	approval	four
freedom	ashamed	mouth
love	controlled	screen
pleasure	expected	sugar
important	forced	window
meaningful	pressured	puzzle

At each presentation of a word or a non-word a random PRIME word was presented from on the prime list, according to the experimental group randomization.

**Course plan provided at the beginning of the learning situation**

**Today's schedule**

*During the whole experiment you are not allowed to leave the room or talk with the other participants.  
Here is how the next 2-hours will unfold...*

- 1. Consent form and short questionnaire (10min)**
- 2. You will perform different tasks on the computer**
  - 2.1. Memory task ( $\approx 18$ min)
  - 2.2. Memory task ( $\approx 13$ min)
  - 2.3. Reaction time task ( $\approx 5$ min)
  - 2.4. Learning task ( $\approx 20$ min)
    - 2.4.1. You can use the notepad for this task
- 3. Wait until the exam starts at 10 AM**
  - 3.1. Follow the instructions in the BLACK window during your wait.
- 4. A short bathroom break will take place just before the exam**

**Information for the exam**

The exam will be paper-pencil and will be performed at your desk. The exam will have different types of question (multiple choices, true or false, short answers and comprehension questions). The exam will have questions on the class PowerPoint, the class exercises and on the supplemental reading.

You will have **20-minutes** to complete the exam.

Follow the instructions in the BLACK window for accessing the class material

- POWERPOINT presentation
- Supplemental reading: Article on modular arithmetic called *Fun with modular arithmetic*.
- Extra online exercises

POWERPOINT presentation of the learning situation on modular arithmetic



**Welcome in class!**

**Today you will learn about  
MODULAR ARITHMETIC...**

**The class will take about 20 minutes  
to complete.**

**After the class you will have some  
time for yourself until 10am.**

**At 10am you will have to complete  
an exam on MODULAR ARITHMETIC**



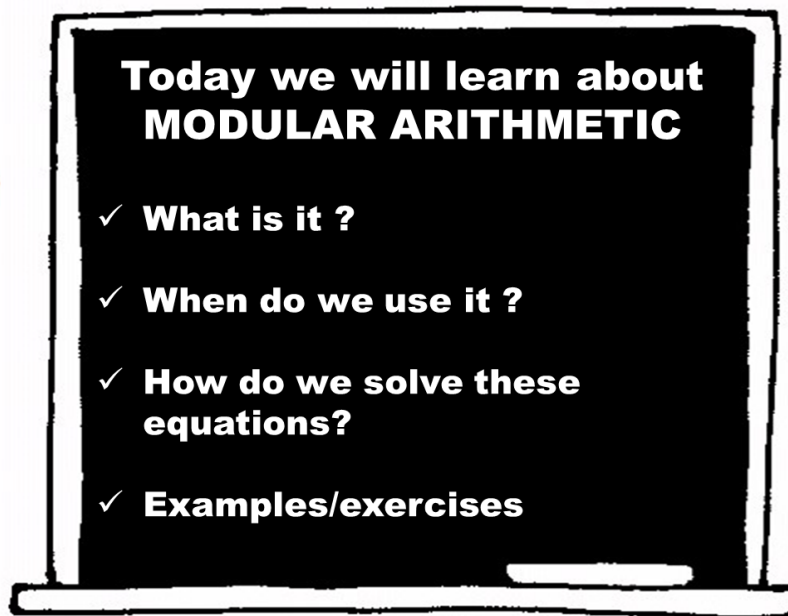
**Welcome in class!**

**During the class you can take notes  
in the provided notepad**

**Please WRITE your ISPR number on  
the first page of the notepad**

**Also you are free to go at your own  
pace while learning about MODULAR  
ARITHMETIC**

**Don't forget that the exam starts at  
10am... so be ready ☺**



---

What is modular arithmetic?

In mathematics, modular arithmetic is a system of arithmetic for integers, where numbers "wrap around" upon reaching a certain value—the modulus (plural moduli). The modern approach to modular arithmetic was developed by Carl Friedrich Gauss in his book *Disquisitiones Arithmeticae*, published in 1801. Modular arithmetic is a method for finding remainders where all the possible numbers (the numbers less than the divisor) are put in a circle, and then by counting around the circle the number of times of the number being divided, the remainder will be the final number landed on.

---

### When do we use modular arithmetic ?

The truth is that modular arithmetic should be in our mental toolbox next to addition and multiplication. We do this intuitively, but it's nice to give it a name. The sneaky thing about modular math is that we've already been using it for keeping time — sometimes called “clock arithmetic”. Using clocks as an analogy, we can figure out whether the rules of modular arithmetic “just work” (they do).

### How?

When we divide two integers we will have an equation that look like the following:

$$\frac{A}{B} = Q \text{ remainder } R$$

$A$  is the dividend

$B$  is the divisor

$Q$  is the quotient

$R$  is the remainder

Sometimes, we are only interested in what the **remainder** is when we divide **A by B**.

For these cases there is an operator called the modulo operator (abbreviated as mod).

## How?

$$\frac{A}{B} = Q \text{ remainder } R$$

$A$  is the dividend  
 $B$  is the divisor  
 $Q$  is the quotient  
 $R$  is the remainder

Using the same **A**, **B**, **Q**, and **R** as above, we would have: **A mod B =R**. We would say this as **A modulo B** is congruent to **R**. Where B is referred to as the modulus.

For example:

$$\frac{13}{5} = 2 \text{ remainder } 3$$

$$13 \bmod 5 = 3$$

## Visualize modulus with clocks

Observe what happens when we increment numbers by one and then divide them by 3.

$$\frac{0}{3} = 0 \text{ remainder } 0$$

$$\frac{1}{3} = 0 \text{ remainder } 1$$

$$\frac{2}{3} = 0 \text{ remainder } 2$$

$$\frac{3}{3} = 1 \text{ remainder } 0$$

$$\frac{4}{3} = 1 \text{ remainder } 1$$

$$\frac{5}{3} = 1 \text{ remainder } 2$$

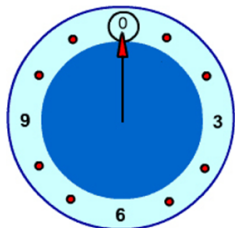
$$\frac{6}{3} = 2 \text{ remainder } 0$$

The remainders start at 0 and increases by 1 each time, until the number reaches one less than the number we are dividing by. After that, the sequence **repeats**

By noticing this, we can visualize the modulo by using circles...

We write 0 at the top of a circle and continuing clockwise writing integers 1, 2, ... up to one less than the modulus.

For example, a clock with the 12 replaced by a 0 would be the circle for a modulus of 12.



To find the result of  $A \bmod B$  we can follow these steps:

1. Construct this clock for size  $B$
2. Start at 0 and move around the clock  $A$  steps
3. Wherever we land is our solution.

(If the number is positive we step clockwise, if it's **negative** we **step counter-clockwise**.)

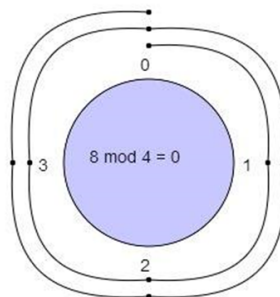
### Examples

$$8 \bmod 4 = ?$$

With a modulus of 4 we make a clock with numbers 0, 1, 2, 3.

We start at 0 and go through 8 numbers in a clockwise sequence 1, 2, 3, 0, 1, 2, 3, 0.

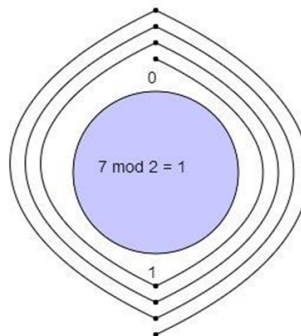
We ended up at **0** so  $8 \bmod 4 = 0$ .



### Examples

## $7 \bmod 2 = ?$

With a modulus of 2 we make a clock with numbers 0, 1.  
 We start at 0 and go through 7 numbers in a clockwise sequence 1, 0, 1, 0, 1, 0, 1



We ended up at **1** so  $7 \bmod 2 = 1$ .

### Examples

Let's say two times look the same on our clock ("2:00" and "14:00"). If we add the same "x" hours to both, what happens? Well, they change to the same amount on the clock!  $2:00 + 5 \text{ hours} \equiv 14:00 + 5 \text{ hours}$  — both will show 7:00. Why? Well, we never cared about the excess "12:00" that the 14 was carrying around. We can just add 5 to the 2 remainder that both have, and they advance the same. For all congruent numbers (2 and 14), adding and subtracting has the same result.



**Now, let's do some little exercises to make sure you understand how modular arithmetic works.**

**If you are ready, press the SPACEBAR !**



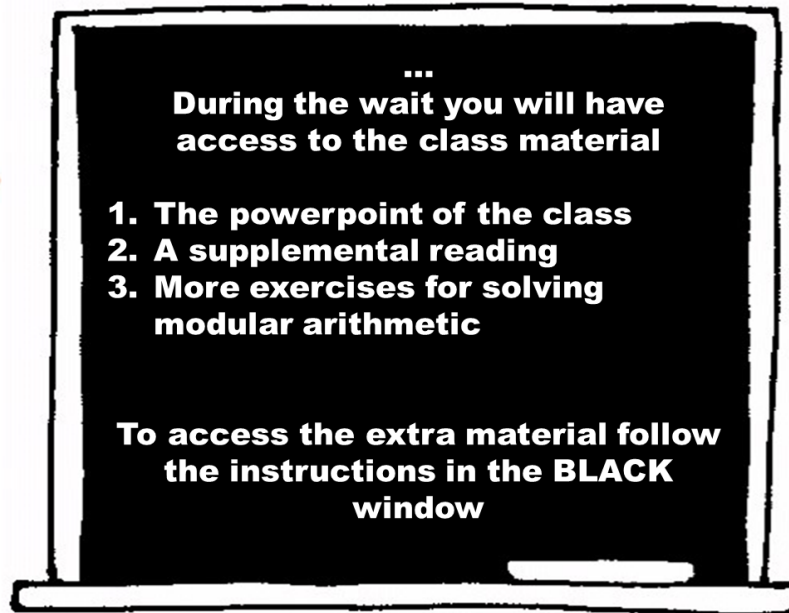
**Congratulations!**

**You have done the first part of the modular arithmetic exercises. That wasn't so bad ?**

**Now let's learn another way to solve these equations.**

**Are you ready ?**

**Press the spacebar.**





**The exam will have  
question on...**

- **The class**
- **Different equations to solve**
- **The supplemental reading (.pdf)**

*Press SPACEBAR to continue*



**The exam will start at  
10am**

**Press Q (quit) to exit  
Follow the instruction in the  
black WINDOW**

**Supplemental reading provided at the end of the learning situation**

### ***Fun With Modular Arithmetic***

A reader recently suggested I write about modular arithmetic (aka “taking the remainder”). I hadn’t given it much thought, but realized the modulo is extremely powerful: it should be in our mental toolbox next to addition and multiplication.

Instead of hitting you in the face with formulas, let’s explore an idea we’ve been subtly exposed to for years.

#### ***Odd, Even and Threeven***

Shortly after discovering whole numbers (1, 2, 3, 4, 5…) we realized they fall into two groups:

- Even: divisible by 2 (0, 2, 4, 6..)
- Odd: not divisible by 2 (1, 3, 5, 7…)

Why’s this distinction important? It’s the beginning of abstraction — we’re noticing the *properties* of a number (like being even or odd) and not just the number itself (“37”).

This is huge — it lets us explore math at a deeper level and find relationships between *types* of numbers, not specific ones. For example, we can make rules like this:

- Even x Even = Even
- Odd x Odd = Odd
- Even x Odd = Even

These rules are general — they work at the property level. (Intuitively, I have a [chemical analogy](#) that “evenness” is a molecule some numbers have, and cannot be removed by multiplication.)

But even/odd is a very specific property: division by 2. What about the number 3? How about this:

- “Threeven” means a number is divisible by 3 (0, 3, 6, 9…)
- “Throdd” means you are *not* divisible by 3 (1, 2, 4, 5, 7, 8…)

Weird, but workable. You’ll notice a few things: there’s two types of throdd. A number like “4” is 1 away from being threeven (remainder 1), while the number 5 is two away (remainder 2).

Being “threeven” is just another property of a number. Perhaps not as immediately useful as even/odd, but it’s there: we can make rules like “threeven x threeven = threeven” and so on.

But it’s getting crazy. We can’t make new words all the time.

**Enter the Modulo**

The modulo operation (abbreviated “mod”, or “%” in many programming languages) is the remainder when dividing. For example, “ $5 \text{ mod } 3 = 2$ ” which means 2 is the remainder when you divide 5 by 3.

Converting everyday terms to math, an “even number” is one where it’s “ $0 \text{ mod } 2$ ” — that is, it has a remainder of 0 when divided by 2. An odd number is “ $1 \text{ mod } 2$ ” (has remainder 1).

Why’s this cool? Well, our “odd/even” rules become this:

- Even x Even =  $0 \times 0 = 0$  [even]
- Odd x Odd =  $1 \times 1 = 1$  [odd]
- Even x Odd =  $0 \times 1 = 0$  [even]

Cool, huh? Pretty easy to work out — we converted “properties” into actual equations and found some new facts.

What’s even x even x odd x odd? Well, it’s  $0 \times 0 \times 1 \times 1 = 0$ . In fact, you can see if there’s an even being multiplied *anywhere* the entire result is going to be zero... I mean even :).

**Clock Math**

The sneaky thing about modular math is we’ve already been using it for keeping time — sometimes called “clock arithmetic”.

For example: it’s 7:00 (am/pm doesn’t matter). Where will the hour hand be in 7 hours?

Hrm.  $7 + 7 = 14$ , but we can’t show “14:00” on a clock. So it must be 2. We do this reasoning intuitively, and in math terms:

- $(7 + 7) \text{ mod } 12 = (14) \text{ mod } 12 = 2 \text{ mod } 12$  [2 is the remainder when 14 is divided by 12]

The equation “ $14 \text{ mod } 12 = 2 \text{ mod } 12$ ” means, “14 o’clock” and “2 o’clock” look the same on a 12-hour clock. They are **congruent**, indicated by a triple-equals sign:  $14 \equiv 2 \text{ mod } 12$ .

Another example: it’s 8:00. Where will the big hand be in 25 hours?

Instead of adding 25 to 8, you might realize that 25 hours is just “1 day + 1 hour”. So, the clock will end up 1 hour ahead, at 9:00.

- $(8 + 25) \text{ mod } 12 \equiv (8) \text{ mod } 12 + (25) \text{ mod } 12 \equiv (8) \text{ mod } 12 + (1) \text{ mod } 12 \equiv 9 \text{ mod } 12$

You intuitively converted 25 to 1, and added that to 8.

***Fun Property: Math just works*****Addition/Subtraction**

Let's say two times look the same on our clock ("2:00" and "14:00"). If we add the same "x" hours to both, what happens?

Well, they change to the same amount on the clock!  $2:00 + 5 \text{ hours} \equiv 14:00 + 5 \text{ hours}$  — both will show 7:00.

Why? Well, we never cared about the excess "12:00" that the 14 was carrying around. We can just add 5 to the 2 remainder that both have, and they advance the same. For all congruent numbers (2 and 14), adding and subtracting has the same result.

***Uses Of Modular Arithmetic***

Now the fun part — why is modular arithmetic useful?

**Simple time calculations**

We do this intuitively, but it's nice to give it a name. You have a flight arriving at 3pm. It's getting delayed 14 hours. What time will it land?

Well,  $14 \equiv 2 \pmod{12}$ . So I think of it as "2 hours and an am/pm switch", so I know it will be "3 + 2 = 5am".

This is a bit more involved than a plain modulo operator, but the principle is the same.

**Putting Items In Random Groups**

Suppose you have people who bought movie tickets, with a confirmation number. You want to divide them into 2 groups.

What do you do? "Odds over here, evens over there". You don't need to know how many tickets were issued (first half, second half), everyone can figure out their group instantly (without contacting a central authority), and the scheme works as more people buy tickets.

Need 3 groups? Divide by 3 and take the remainder (aka mod 3). You'll have groups "0", "1" and "2".

In programming, taking the modulo is how you can fit items into a hash table: if your table has N entries, convert the item key to a number, do mod N, and put the item in that bucket (perhaps keeping a linked list there). As your hash table grows in size, you can recompute the modulo for the keys.

### Picking A Random Item

I use the modulo in real life. Really. We have 4 people playing a game and need to pick someone to go first. *Play the mod N mini-game!* Give people numbers 0, 1, 2, and 3.

Now everyone goes “one, two, three, shoot!” and puts out a random number of fingers. Add them up and divide by 4 — whoever gets the remainder exactly goes first. (For example: if the sum of fingers is 11, whoever had “3” gets to go first, since  $11 \bmod 4 = 3$ ).

It’s fast and it works.

### Running Tasks On A Cycle

Suppose tasks need to happen on a certain schedule:

- Task A runs 3x/hour
- Task B runs 6x/hour
- Task C runs 1x/hour

How do you store this information and make a schedule? One way:

- Have a timer running every minute (keep track of the minute as “n”)
- 3x / hour means once every  $60/3 = 20$  minutes. So task A runs whenever “ $n \% 20 == 0$ ”
- Task B runs whenever “ $n \% 10 == 0$ ”
- Task C runs whenever “ $n \% 60 == 0$ ”

Oh, you need task C1 which runs 1x per hour, but not the same time as task C? Sure, have it run when “ $n \bmod 60 == 1$ ” (still once per hour, but not the same as C1).

Mentally I see a cycle I want to “hit” at various intervals, so I insert a mod. The neat thing is that the hits can overlap independently. It’s a bit like XOR in that regard (each XOR can be layered — but that’s another article!).

Similarly, when programming you can print every 100th log item by doing: `if (n % 100 == 0){ print... }`.

It’s a very flexible, simple way to have items run on a schedule. In fact, it’s the way to answer the [FizzBuzz sanity check](#). If you don’t have the modulo operation in your batbelt the question becomes much more tricky.

**Exam with correct answers****Modular arithmetic — Final Exam**

ISPR number: \_\_\_\_\_

**MULTIPLE CHOICE (1 point per question)**

1. The modern approach to modular arithmetic was developed by:
  - a) Isaac Newton
  - b) Carl Friedrich Gauss**
  - c) Leonard Euler
  - d) Arthur Dedekind
  
2. In which year did the developer of modular arithmetic publish his book on this new approach to arithmetic?
  - a) 1901
  - b) 1810
  - c) 1801**
  - d) 1910
  
3. What is the plural of “modulus”?
  - a) Moduli**
  - b) Modula
  - c) ~~Moduluses~~
  - d) Modulus (there is no plural)
  
4. What are we interested in when doing modular arithmetic?
  - a) The dividend
  - b) The divisor
  - c) The remainder**
  - d) The quotient
  
5. On a clock, 0 coincides with...
  - a) 0
  - b) 12
  - c) 36
  - d) B and C**
  - e) None of these responses
  
6. What is the symbol used in programming language for the modulus operator?
  - a. \$
  - b. %**
  - c. !
  - d. \*

## TRUE or FALSE (1 point per question)

1. It is possible to add and subtract in modular arithmetic.  
\_TRUE\_\_\_\_\_
2. Modular arithmetic is sometimes referred to as clock arithmetic.  
\_TRUE\_\_\_\_\_
3. Modular arithmetic is an alternative to division.  
\_FALSE\_\_\_\_\_
4. For all the incongruent numbers, adding and subtracting have the same results.  
\_FALSE\_\_\_\_\_
5.  $19 = 7 \pmod{7}$   
\_FALSE\_\_\_\_\_
6.  $6 = 3 \pmod{3}$   
\_TRUE\_\_\_\_\_
7.  $5 = 2 \pmod{3}$   
\_TRUE\_\_\_\_\_
8.  $36 = 12 \pmod{7}$   
\_FALSE\_\_\_\_\_
9.  $8 = 5 \pmod{3}$   
\_TRUE\_\_\_\_\_
10.  $9 = 3 \pmod{5}$   
\_FALSE\_\_\_\_\_
11.  $7 = 2 \pmod{5}$   
\_TRUE\_\_\_\_\_
12.  $19 = 12 \pmod{7}$   
\_TRUE\_\_\_\_\_
13.  $16 = 11 \pmod{4}$   
\_FALSE\_\_\_\_\_
14.  $62 = 14 \pmod{9}$   
\_FALSE\_\_\_\_\_

## SHORT ANSWERS

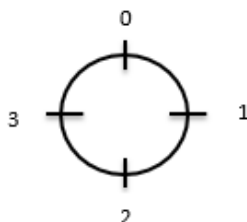
1. Complete this sentence. (2 points)  
 a. The truth is that modular arithmetic should be in our mental toolbox next to **addition and multiplication** \_\_\_\_\_

2. Why do we call modular arithmetic like that? (2 points)  
 \_\_\_\_\_

3. How can we visualize the modulo? (1 point)

**using a clock** \_\_\_\_\_

4. Draw a clock with a modulus of 4. (1 point)



5. Where would we end up on this clock if we used  $8 \bmod 4$ ? (1 point)

**on the "0"** \_\_\_\_\_

6. What is the mathematical symbol for modular congruence? (1 point)

**$\equiv$**  \_\_\_\_\_

7. Give us an example of a congruent modular equation. (2 points)

**$14 \equiv 2 \pmod{12}$**  \_\_\_\_\_

8. People use modular arithmetic every day without knowing it. On which task do they do modular arithmetic? (1 point)

**Keeping time, scheduling over 12 hours, using mental mathematics on a clock** \_\_\_\_\_

9. Name 3 different uses of modular arithmetic. (3 points) (4 answers in the READING)

1. **Picking a random item** \_\_\_\_\_
2. **Running tasks on a cycle** \_\_\_\_\_
3. **Putting items in random groups, (4) simple time calculation** \_\_\_\_\_

10. You are at the airport. You are doing a trip to your parents' house after a long semester at school. You were supposed to leave at 10 o'clock in the morning and be there at 2 o'clock. Unfortunately, your flight is delayed because of a snow storm. Your flight is at 12 o'clock. At what time are you going to arrive? And how did you proceed to get that result? (3 points)

$$\text{Difference between } 10 \bmod 12 - 2 \bmod 12 = 4 \bmod 12$$

$$12 \bmod 12 + 4 \bmod 12 = 4 \text{ o'clock}$$

Or

$$12 + 4 = 16$$

$$16 \bmod 12 = 4 \text{ o'clock}$$

#### SOLVING EQUATION (1 point per question)

1. What is  $-29 \bmod 3$  ?

1

2. What is  $-49 \bmod 5$  ?

1

3. What is  $13 \bmod 1$  ?

0

4. What is  $29 \bmod 4$  ?

1

5. What is  $7 \bmod 6$  ?

1

6. What is  $-29 \bmod 4$  ?

3

7. What is  $14 \bmod 2$  ?

0

8. What is  $17 \bmod 7$  ?

3

9. What is  $-7 \bmod 6$  ?

5



## Appendix F: Ethic approbation for *study 1* and *2*

File Number: 02-13-30

Date (mm/dd/yyyy): 04/10/2013



**Université d'Ottawa**  
Bureau d'éthique et d'intégrité de la recherche

**University of Ottawa**  
Office of Research Ethics and Integrity

### Ethics Approval Notice Social Science and Humanities REB

#### Principal Investigator / Supervisor / Co-investigator(s) / Student(s)

<u>First Name</u>	<u>Last Name</u>	<u>Affiliation</u>	<u>Role</u>
Patrick	Gaudreau	Social Sciences / Psychology	Principal Investigator
Alexandre	Gareau	Social Sciences / Psychology	Co-investigator

**File Number:** 02-13-30

**Type of Project:** Professor

**Title:** Working memory as a key to understand the equivocal relation of motivation and academic performance

<b>Approval Date (mm/dd/yyyy)</b>	<b>Expiry Date (mm/dd/yyyy)</b>	<b>Approval Type</b>
04/10/2013	04/09/2014	Ia

(Ia: Approval, Ib: Approval for initial stage only)

**Special Conditions / Comments:**  
N/A

## Appendix G: Ethic approbation for *study 3*

File Number: H06-16-39

Date (mm/dd/yyyy): 09/19/2016



**Université d'Ottawa**  
Bureau d'éthique et d'intégrité de la recherche

**University of Ottawa**  
Office of Research Ethics and Integrity

### Ethics Approval Notice Health Sciences and Science REB

#### Principal Investigator / Supervisor / Co-investigator(s) / Student(s)

<u>First Name</u>	<u>Last Name</u>	<u>Affiliation</u>	<u>Role</u>
Patrick	Gaudreau	Social Sciences / Psychology	Principal Investigator
Alexandre	Gareau	Social Sciences / Psychology	Co-investigator

**File Number:** H06-16-39

**Type of Project:** Professor

**Title:** Exploring the implicit process of motivation and its effect on learning and achievement in school

<b>Approval Date (mm/dd/yyyy)</b>	<b>Expiry Date (mm/dd/yyyy)</b>	<b>Approval Type</b>
09/19/2016	09/18/2017	Approved

#### Special Conditions / Comments:

N/A

