Learning and thinking about socio-scientific issues: A multi-study examination of the role of epistemic emotions in epistemic cognition

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Table of contents

Abstract

Complex socio-scientific issues surrounding health or the environment, among others, are becoming increasingly controversial as the urgency for action increases. Learning and thinking critically about these issues requires epistemic cognition, i.e., thoughts and beliefs about the nature of knowledge, who holds knowledge, and how knowledge is justified. A review of the literature on epistemic cognition shows that epistemic cognition is a multifaceted phenomenon, including elements such as epistemic beliefs, epistemic aims, epistemic strategies, and epistemic emotions, yet many of these facets remain underexplored. The review also indicates that using more diverse and sophisticated methodologies is instrumental to advancing our understanding of epistemic cognition, as is the investigation of variables that may mediate relations between epistemic cognition and learning outcomes. Epistemic emotions are identified as one promising mediational mechanism that may explain how epistemic cognition relates to important outcomes. On the basis of this review, two manuscripts are proposed that address these issues. The first manuscript reports on two studies where a think-aloud methodology was employed to assess instances of epistemic cognition, epistemic emotions, and self-regulated learning during complex learning. Verbal data were used to examine the types of appraisals that serve as antecedents to epistemic emotions and to explore the immediate consequences of epistemic emotions for self-regulated learning. A path analysis using self-report and verbal data provided support for a model of epistemic emotions as mediators between epistemic cognition and learning processes and outcomes. The second study tested the generalizability of this model by examining the mediational role of epistemic emotions in the relationship between epistemic cognition and critical thinking. Theoretical contributions, implications, limitations, and future directions are discussed.

Résumé

Les problématiques socio-scientifiques complexes, liées par exemple à la santé ou à l'environnement, sont devenues aussi urgentes que controversées. Apprendre et avoir une pensée critique au sujet de ces questions nécessite une pensée épistémique adaptée, c'est-à-dire d'avoir une réflexion et d'adopter des croyances productives au sujet de la nature de la connaissance, à savoir qui la détient et comment elle est justifiée. Une recension des écrits sur la cognition épistémique montre que celle-ci est multiple, incluant des éléments tels que les croyances épistémiques, les objectifs épistémiques, les stratégies épistémiques et les émotions épistémiques, tout en indiquant que plusieurs de ces facettes demeurent empiriquement peu explorées. Les conclusions de cette recension indiquent également que pour améliorer notre compréhension de la cognition épistémique, il est essentiel d'utiliser des méthodologies plus diverses et sophistiquées, ainsi que d'investiguer les variables médiatrices susceptibles d'intervenir dans la relation entre la cognition épistémique et l'apprentissage. Les émotions épistémiques sont identifiées comme un mécanisme médiateur prometteur qui pourrait expliquer l'influence de la cognition épistémique sur des résultats importants. Ces lacunes font l'objet de deux articles présentés ici. Le premier article décrit deux études empiriques où la cognition épistémique, les émotions épistémiques et l'apprentissage autorégulé sont mesurés à l'aide d'un protocole de réflexion à voix haute au cours d'un épisode d'apprentissage complexe. Ces données ont été utilisées pour examiner les types d'évaluations cognitives qui servent d'antécédents aux émotions épistémiques, ainsi qu'afin d'explorer les conséquences immédiates des émotions épistémiques sur l'apprentissage autorégulé. Une analyse de trajectoire appuie un modèle prédictif où les émotions épistémiques constituent un médiateur entre la cognition épistémique et les divers processus et résultats d'apprentissage. Le deuxième article présente une deuxième étude où est testée la généralisabilité de ce modèle en examinant les effets médiateurs des émotions épistémiques dans la relation entre la cognition épistémique et la pensée critique. Les contributions théoriques et méthodologiques, les limites et les orientations futures de ces études sont discutées.

Dedication

I dedicate this dissertation to my daughter Hariette, whose endless curiosity and motivation to test hypotheses inspire me daily. Thank you for pushing me to keep moving forward every day. May this body of work one day inspire you to pursue your own ideas and dreams.

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First and foremost, I would like to extend my sincerest gratitude to my supervisor, Dr. Krista Muis, for her mentorship and encouragement over the last seven years. At each stage of this process, you have guided me with expertise, encouraged me through challenges, and celebrated every achievement. You have introduced me to a network of excellent collaborators, provided financial support and access to key resources, and have invested generous amounts of time and effort into my success. You have helped me grow into the researcher I am today and for that, I am forever grateful.

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Preface and Contributions of Authors

I am the primary author on all manuscripts included in this dissertation and I am responsible for their content. I wrote Chapter 1 and Chapter 5 independently and Dr. Krista R. Muis provided feedback. I independently wrote Chapter 2 (literature review), part of it in fulfillment of my comprehensive examination, and Dr. Krista R. Muis and Dr. Alenoush Saroyan provided feedback. The two empirical manuscripts (Chapters 3 and 4) were co-authored with Dr. Krista R. Muis and co-authors provided feedback. The specific contributions of co-authors for each manuscript are summarized below.

Chapter 3

Citation

Chevrier, M., Muis, K. R., Trevors, G. J., Pekrun, R., & Sinatra, G. M. (under review). Examining the antecedents and consequences of epistemic emotions. *Learning and Instruction*.

Contributions

The research design for this study is the result of a collaboration between Drs. Muis, Pekrun and Sinatra. The third author assisted in research design, data collection, and contributed to the development of the coding scheme used to capture variables of interest and acted as an inter-rater for coding. I was responsible for the conceptualization of research questions, the development of a coding scheme to capture variables of interest, data analysis, and writing the manuscript in its entirety. Co-authors provided expert feedback on full drafts.

Chapter 4

Citation

Chevrier, M., Muis, K. R., Pekrun, R., Sinatra, G., & Denton, C. A. (under review) Thinking critically about socio-scientific issues: The role of epistemic cognition and epistemic emotions. *Contemporary Educational Psychology*.

Contributions

The research design for this study is the result of a collaboration between Drs. Muis, Sinatra, and Pekrun. The fifth author contributed to the development of the coding scheme used to capture outcome variables of interest and acted as an inter-rater for coding. I was responsible for the conceptualization of research questions, the development of the coding scheme used to capture variables of interest, data analysis, and writing the manuscript in its entirety. Co-authors provided expert feedback.

List of Tables

List of Figures

Appendices

Chapter 1

Introduction

The digital age is changing how we relate to knowledge. The advent of the web, social media, algorithmic filtering, and the proliferation of massive amounts of data is creating a situation where knowledge is increasingly dispersed across networks, resulting in inescapable echo chambers and the deinstitutionalization of learning. Indeed, the way individuals search, vet, build, and use knowledge today is by accessing a variety of sources of information that vary in credibility and trustworthiness. The multiplicity of voices is replacing the monolithic authoritative sources of knowledge that once illuminated minds, revealing the fundamentally complex and uncertain nature of knowledge, and the challenges of knowing.

Still, traditional and mainstream educational systems, by relying on prescribed knowledge representations and enforcing an answer-oriented assessment culture, promote an understanding of knowledge as objective and factual. As a result, transitioning from learning in the "safe" educational environment into the "wild," uncertain world can pose a challenge for many. Successfully managing that transition requires epistemic cognition. Epistemic cognition refers to the process by which learners think about the forms of knowledge, its criteria and limits, to decide what to do or what to believe (Greene, Sandoval, & Bråten, 2016).

For those who are unprepared, being faced with the world's uncertainty and complexity is an experience that is likely to leave individuals feeling anxious, confused, or frustrated, among others. Throughout this dissertation, these knowledge- and knowing-related emotions are termed *epistemic emotions*. Despite long-standing calls to explore the affective facet of epistemic cognition (e.g., Mansfield and Clinchy, 2002; Pintrich, 2000), little research to date has been dedicated to addressing this matter and important questions remain unanswered. How do epistemic emotions relate to epistemic cognition? What epistemic emotions are experienced by individuals in different contexts? What role do epistemic emotions play in learning processes? And how can these emotions be leveraged to improve important educational outcomes?

The purpose of this dissertation is to theoretically and empirically address these questions by investigating the nature and function of epistemic emotions in the context of complex learning. What I intend to demonstrate with this thesis is that contending with complex and controversial knowledge elicits knowledge- and knowing-related beliefs, cognitions, and emotions that relate to learning and higher-order thinking processes such as critical thinking. In Chapter 3, I demonstrate that epistemic cognition is a significant predictor of epistemic emotions, and that epistemic emotions significantly mediate relations between epistemic cognition and self-regulated learning. Further, I demonstrate that predictable sequences of occurrences exist between epistemic emotions and learning strategies. In Chapter 4, I demonstrate that relations between epistemic cognition and epistemic emotions can be generalized to other higher-order thinking processes, namely critical thinking.

Additional themes are explored throughout this dissertation that link together the three manuscripts contained herein: (1) controversial socio-scientific issues (2) a broadened conceptualization of epistemic cognition, and (3) novel research methodologies. First, epistemic cognition is likely to be most relevant in situations where knowledge is at issue, such as when conflicting claims of varied levels of credibility exist on the same issue, or when phenomena are represented by opposing perspectives that propose seemingly irreconcilable explanations. This is the case of the topics of focus in Chapter 3 (i.e., climate change) and Chapter 4 (i.e., genetically modified foods). Second, whereas most research on epistemic cognition to date has focused solely on individuals' epistemic beliefs (Greene, Cartiff & Duke, 2018; Muis & Singh, 2018), in this dissertation, I adopt a broadened conceptualization of epistemic cognition that is better aligned with recent frameworks and which considers epistemic cognition as multifaceted, comprised not only of epistemic beliefs, but also of epistemic aims, epistemic strategies, and epistemic experiences, including epistemic emotions (Muis & Singh, 2018). This decision was made as the result of a review of the literature on the subject (see Chapter 2) which guided the experimental design and analyses of the studies contained herein. Third, I identify limitations associated with traditional research methodologies used in epistemic cognition research (Chapter 2) and adopt methodologies that are aligned with a broadened conceptualization of epistemic cognition, namely in the form of a think-aloud protocol that allowed me to operationalize distinctions between epistemic beliefs, epistemic aims, and epistemic strategies (Chapter 3). I also present an analytic technique seldom used in emotion research, namely a state-transition analysis, that allowed me to study relations between epistemic emotions and learning processes on a small timescale (Chapter 3).

Overall, the manuscripts contained in the dissertation address the following complimentary research questions:

1) What is epistemic cognition and how can it be measured? (Chapter 2)
2) What epistemic emotions are experienced during learning of complex and controversial socio-scientific topics, and what are the antecedents of these epistemic emotions? (Chapters 3 and 4)
3) What are the immediate and general consequences of epistemic emotions on processes of self-regulated learning? (Chapter 3) And do these consequences generalize to other high-order thinking processes, such as critical thinking? (Chapter 4)
4) What role do epistemic emotions play in mediating the relationship between epistemic cognition and learning processes and outcomes? (Chapters 3 and 4)

In addressing these questions, this dissertation contributes new knowledge in understanding the role of epistemic cognition in complex learning and thinking situations, and further contributes to understanding the nature and role of epistemic emotions in these contexts. As a result, this dissertation adds information that can be used to elaborate guidelines for teachers and science communicators to better leverage individuals' beliefs, cognitions, and emotions to promote greater learning and critical thinking in a complex and uncertain world.

Overview of the Chapters

To address the above-mentioned questions, Chapter 2 presents a critical and comprehensive review of the literature on epistemic cognition. The review addresses the following questions: How can epistemic cognition be conceptualized, and how can it be measured? I also highlight unresolved issues in theories of epistemic cognition and identify elements contained in current conceptualizations that are likely to form fruitful avenues to advance knowledge on epistemic cognition. These avenues for future work include the study of epistemic emotions as one mediational mechanism to explain how epistemic cognition relates to learning processes and outcomes. Further, this review provides the basis on which I critique methods typically employed to measure epistemic cognition, which guided methodological choices throughout the dissertation.

Chapter 3 presents two empirical studies that employed self-report instruments and a think-aloud protocol to gather data on the antecedents and consequences of epistemic emotions. This data collection was conducted in the context of a complex learning situation that involved learning about a controversial socio-scientific topic across multiple conflicting documents. Study 1 presents an exploration of three antecedents of epistemic emotions and the identification of sequences of transitions between epistemic emotions and learning and epistemic strategies.

Further, I empirically explore relations between offline epistemic beliefs and online epistemic cognition, which constitutes one of the unique contributions of this study. In Study 2, I use self-report and verbal data to test a predictive model of epistemic emotions as mediators between epistemic cognition and self-regulated learning processes and outcomes.

Chapter 4 further tests the generalizability of this model by examining the mediational role of epistemic emotions in the relationship between epistemic cognition and one important higher-order thinking process: critical thinking. Results from this study provide further support for the role of epistemic emotions in epistemic cognition and adds substantial nuances to our understanding of the role of several epistemic emotions.

Lastly, Chapter 5 concludes this dissertation with a summary of the theoretical and methodological contributions to the advancement of knowledge, along with a discussion of the limitations and future directions for research.

References

Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. *Journal of Educational Psychology*. Advanced online publication.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016). (Eds.). *Handbook of epistemic cognition*. New York, NY: Routledge.

Mansfield, A. F., & Clinchy, B. (2002). Toward the integration of objectivity and subjectivity: epistemological development from 10 to 16. *New Ideas in Psychology, 20*, 225-262.

Muis, K. R., & Singh, C. A. (2018). The three facets of epistemic thinking in self-regulated learning. In D. Schunk & J. Greene (Eds.), *Handbook of self-regulated of learning and performance* (pp. 434–456). New York, NY: Routledge.

Pintrich, P. (2000). An achievement goal theory perspective on issues in motivation terminology, theory, and research. *Contemporary Educational Psychology, 25*, 92-104.

Chapter 2

Conceptualizing and Measuring Epistemic Cognition: A Review of the Literature

The 21st century, marked by unprecedented access to information and the explosion of self-authored, unregulated content, poses the challenge of educating individuals who can discern useful and trustworthy contributions to knowledge from fraudulent, dogmatic, or otherwise fake claims (Sandoval, Greene, & Bråten, 2016). Thinking deeply and critically about matters of knowledge is not something that comes easily or naturally, and teaching students to think in such ways is challenging (Sinatra, Kienhues, & Hofer, 2014). As will be addressed in this chapter, there exists a growing body of literature that indicates that epistemic cognition "matters" (Kuhn & Weinstock, 2002). Broadly stated, epistemic cognition refers to how people understand, construct, and reason about knowledge, its sources and justification. Individuals engage in epistemic cognition when they are required to determine who or what to believe, problem solve, or make decisions about knowledge or information problems (Barzilai & Zohar, 2014; Greene, Sandoval, & Bråten, 2016a; Sinatra, 2016).

Empirically, epistemic cognition has been related to competent self-regulated learning, motivation, and learning achievement (Muis, 2004; 2007). However, a recent meta-analysis shows that the effect of epistemic cognition on learning achievement is significant but surprisingly small (Greene, Cartiff, & Duke, 2018). Understanding the conceptual and methodological challenges inherent to the field of epistemic cognition can help interpret this finding and illuminate paths forward to advance knowledge on epistemic cognition. As such, the goal of the present chapter is to construct a knowledge foundation that can be used to advance this promising line of research. Specifically, I ask the following questions: 1- How is epistemic cognition conceptualized? And 2- What methods can be used to examine epistemic cognition?

To answer these questions, I first review traditional and contemporary frameworks of epistemic cognition and underline their unique contributions and shortcomings. Second, I outline the challenges inherent to epistemic cognition measurement, and explore solutions.

Part 1: What is Epistemic Cognition and How Is It Conceptualized?

The study of epistemic cognition can be situated at the crossroads of psychology (e.g., Piaget's [1950] genetic epistemology), sociology (e.g., Thomas Kuhn's [1962] structures of scientific revolutions) and philosophy, reaching as far back as the works of Plato and Aristotle. In educational psychology, the interest for epistemic cognition is in understanding the nature and functions of individuals' thoughts and beliefs about how knowledge is acquired, justified and used. Throughout this chapter, I use the term *epistemic cognition* (e.g., Chinn, Buckland, & Samarapungavan, 2011; Greene et al., 2016a) to refer to this broad area of research. Other scholars have used the terms *personal epistemology* (Hofer & Pintrich, 1997), *epistemic beliefs* (e.g., Muis, Bendixen, & Haerle, 2006), and *epistemic thinking* (e.g. Barzilai & Zohar, 2014; Muis & Singh, 2018). The aim of this section is to review the frameworks that populate the field of epistemic cognition through a presentation of different perspectives' components, assumptions, contributions, and limitations. Against this backdrop, current trends and issues are discussed.

Given their conceptual importance and prominence in this chapter, it is crucial to differentiate between various "epistemic" terms. As mentioned above, I choose the term epistemic cognition to refer to both the field of investigation and the phenomenon of individuals' thoughts, beliefs, and processes that relate to the nature of knowledge and knowing. Further, *epistemological beliefs* (e.g., Schommer, 1990) or *epistemic beliefs* (e.g., Muis et al., 2006; Muis, 2007) are used to refer to individuals' tacit beliefs about the nature of knowledge and knowing.

Greene, Azevedo, and Torney-Purta (2008) aptly argued that the term "epistemological" refers to the study of epistemology, whereas the term "epistemic" evokes more accurately what is concerned with knowledge and knowing per se. As such, students are much more likely to hold "epistemic beliefs" (beliefs about knowledge and knowing) than "epistemological beliefs" (beliefs about the study of epistemology). Epistemic cognition, on the other hand, can be seen as a situated, dynamic process of thinking, used to reason, problem solve, or make decisions about information problems (Hofer, 2016; Sinatra, 2016). The content of epistemic cognition draws upon more stable cognitive and metacognitive structures such as knowledge, beliefs, and strategies. In the ensuing pages, I respect and use the terminology employed by authors when discussing their work.

Perspectives in Epistemic Cognition

The field of epistemic cognition comprises various frameworks that have frequently been grouped into three distinct perspectives (e.g., Hofer, 2001): the developmental, multidimensional, and epistemological resources perspectives. For the purpose of this review, recent frameworks have been grouped into a fourth perspective that I call "new conceptualizations."

The developmental perspective. The major tenet of the developmental perspective is that epistemic cognition develops throughout the lifespan, and that epistemic development is a crucial part of education. The developmental perspective is largely derived from the work of Perry (1970), who proposed a sequence of stages of epistemic growth that characterize the intellectual development of university students during their college years. Many scholars have endeavored to refine and extend Perry's developmental sequence. Each framework introduces a sequence of developmental phases that reflect qualitative changes in epistemic cognition.

Notable frameworks that have adopted a developmental perspective include Belenky and colleagues' (Belenky, Clinchy, Goldberger, & Tarule, 1986) "ways of knowing" framework, Baxter Magolda's (1992; 2004) epistemological reflection framework, King and Kitchener's (1994; 2004) reflective judgment framework, and Kuhn and colleagues' framework of epistemological understanding, more aptly labelled argumentative reasoning (Kuhn, 1991; Kuhn, Cheney & Weinstock, 2000; Kuhn, & Park, 2005; Kuhn & Weinstock, 2002). I next elaborate on Kuhn and colleagues' framework, as the developmental sequence they proposed consolidates previous conceptual efforts, and as such, has gained prominence that still holds to date.

Kuhn et al. (2000) proposed a sequence of three developmental phases that reflect a progressive integration and coordination of the objective and subjective dimensions of knowing. These levels of development include (1) absolutism, (2) multiplism, and (3) evaluativism. Individuals who embrace an *absolutist* view believe that assertions are either correct or incorrect, and that facts represent reality, such that knowledge is objective and certain. This form of thinking often characterizes thinking in childhood but can be observed in older persons. Individuals who adopt a *multiplist* perspective view knowledge as subjective, uncertain, and idiosyncratic. This epistemic orientation is often characteristic of adolescents, who tend to view assertions as freely chosen opinions. Lastly, *evaluativists* reconcile the objective and subjective aspects of knowledge and knowing. Evaluativists acknowledge that certain opinions are more justified than others, based on the evaluation of arguments and evidence via norms of inquiry. This perspective is more likely to develop in late adolescence or adulthood, if ever.

Taken together, the developmental frameworks include a number of assumptions. The central assumption of this perspective is that the development of epistemic cognition is characterized by a sequence of one-dimensional, qualitatively different stages, and consists of fully abandoning one stage to enter a more advanced one. This assumption has been challenged by Schommer (1990), among others, who proposed that epistemic development should instead be conceived as multidimensional, where different dimensions develop at various rates. A second important assumption of the developmental frameworks is that individuals' stages of development are not specific to a particular field or domain of knowledge. This assumption has been challenged namely by Hofer (2000), and later by Muis et al. (2006), who showed that patterns in epistemic development vary across domains. A last key assumption is that the development of epistemic cognition beyond the initial positions (e.g., absolutist stage) does not begin until learners reach college. This assumption has been challenged by results obtained by others (see Chandler, Hallett & Sokol, 2002; Kuhn et al., 2000, Mason & Scirica, 2006), who found that younger students are capable of displaying more advanced epistemic cognition.

Aside from the challenged assumptions mentioned above, the developmental frameworks have been criticized for their lack of consideration for the cultural specificity of epistemic cognition and its development. For instance, do children adopt an absolutist view of knowledge as a result of an inevitable developmental pattern, or due to the influence of beliefs conveyed in the home environment? To this point, Muis et al. (2006) suggested that epistemic beliefs are socially constructed and context-bound, and that epistemic beliefs conveyed at home are likely to influence the beliefs a child adopts before entering the educational system.

In sum, the epistemic developmental theories have made important contributions to the epistemic cognition literature, first by proposing a developmental sequence of personal epistemology that is still widely referred to these days. Another notable contribution has been to establish the importance of epistemic cognition in educational psychology by connecting facets of epistemic cognition to other skills such as argumentation (Kuhn, 1991; 1993), critical thinking (Kuhn, 1999), self-reflection, and justification (King & Kitchener, 1994; 2004).

The multidimensional perspective. Researchers who assume a multidimensional perspective have focused on identifying the underlying dimensions of epistemic cognition, as well as identifying how variations on these dimensions can be more or less availing for learning processes and outcomes. The central assumption is that epistemic cognition draws from epistemic beliefs, and that the way learners apprehend and contend with knowledge is influenced by these beliefs (Hofer, 2001). This line of research was initiated by Schommer (1990), who questioned the assumption that epistemic cognition is one-dimensional. Schommer proposed a multidimensional framework of *epistemological beliefs* that includes five independent but related dimensions to epistemic beliefs. She stipulated that beliefs develop alongside each dimension from a basic or “naïve” position to a more mature or “sophisticated” position (Schommer, 1994).

Building from Schommer’s framework, Hofer and Pintrich (1997) later proposed a four-dimensional framework of epistemic beliefs. The first dimension, the *certainty of knowledge,* refers to beliefs about the nature of knowledge, from the belief that truths are fixed and unchanging to the belief that knowledge is tentative and evolving. The *simplicity of knowledge* also concerns the nature of knowledge, ranging from the belief that knowledge is best described as an accumulation of independent and concrete facts, to the belief that knowledge consists of a complex structure of interrelated propositions. The *source of knowledge* concerns the process of knowing and refers to the role of the self and others as sources of knowledge. A less constructivist view is that knowledge originates outside of the self and resides in experts or other authorities. A more constructivist view conceptualizes the self as a knower who has the ability to generate knowledge via active construction. The last dimension, the *justification for knowing* concerns how individuals evaluate knowledge claims, from an unquestioning reliance on authorities (e.g., experts, teachers, textbook authors) to the examination, evaluation, and integration of evidence, reasons, and arguments from various perspectives. Presumably, as epistemic beliefs develop into more constructivist forms, individuals become better able to detect and address incongruent knowledge representations, questionable sources, and unjustified knowledge claims.

The multidimensional frameworks first assumed the domain generality of epistemic beliefs. Later, at the outcome of an extensive review of theoretical and empirical literature, Muis et al. (2006) proposed that epistemic beliefs are both domain-general and domain-specific. Muis et al. proposed the Theory of Integrated Domain in Epistemology (the TIDE framework) which stipulates that individuals first develop general epistemic beliefs, then academic epistemic beliefs, and later, domain-specific epistemic beliefs, as individuals deepen their understanding of certain academic or professional domains. Muis and colleagues explained that these beliefs are mutually influential.

In terms of assumptions, the multidimensional frameworks assume that epistemic beliefs do not develop homogeneously, indicating that a learner can simultaneously espouse more *and* less constructivist beliefs on different dimensions. It is also assumed that epistemic beliefs develop from a "naïve" to a "sophisticated" view of knowledge. Although the terms "naïve" and "sophisticated" have been criticized for insinuating that researchers know what is best to believe (Schommer-Aikins, 2002; Muis, 2004), the terms continue to be widely used in the literature to date. Alternatively, the terms "availing and non-availing" (Muis, 2004) as well as "less and more constructivist" (e.g., Muis, 2007) have been suggested. However, the assumption that mature beliefs always align with a constructivist epistemology has been challenged by Chinn et al., (2011), and more recently by Greene and Yu (2014). In their philosophically anchored framework, Chinn et al. (2011) argued that individuals may choose to take the stance of certainty towards claims that appear to be extremely well justified. Indeed, Greene and Yu (2014) found that experts sometimes adopt the view that some form of knowledge (such as “bedrock” historical knowledge) is simple and certain, which is a belief typically associated with a naïve or less constructivist view.

Lastly, an assumption that is prevalent in multidimensional frameworks is that epistemic beliefs are amenable to change. Whereas epistemic development is viewed as the result of a maturation process, epistemic change is better described as variations in epistemic cognition that result from interactions with various contexts (Muis, Trevors, & Chevrier, 2016). Indeed, several researchers have been successful at obtaining lasting change in beliefs with short text-based interventions (Bromme, Pieschl, & Stahl, 2010; Ferguson & Bråten, 2013; Porsch & Bromme, 2011), as well as longer-term instructional interventions (Muis & Duffy, 2013). However, others have observed that text-based interventions can lead to regression towards less constructivist beliefs (Kienhues, Bromme & Stahl, 2008). Overall, empirical evidence suggests that epistemic change is arduous and unlikely to happen spontaneously without specifically targeted interventions (Sinatra, 2016).

Taken together, the multidimensional frameworks have made key contributions that still shape the field of epistemic cognition today. First, these frameworks have introduced the notion of epistemic beliefs as a system of more or less independent dimensions. Second, they brought greater emphasis to the relation between epistemic beliefs and other facets of learning, such as academic performance (Schommer, 1990), learning strategies (Schommer, Crouse & Rhodes, 1992), and motivation (Muis, 2004). Another important contribution has been to adopt a more quantitative approach to epistemic beliefs research than theretofore, triggered by the need to statistically test the multidimensionality proposed in frameworks.

The multidimensional frameworks, however, are not without limitations. These include a lack of consideration for the context specificity of epistemic cognition, a lack of integration of philosophical considerations in epistemic cognition, as well as a narrow focus on epistemic beliefs as a unique component of epistemic cognition. These limitations have been taken on by researchers who proposed alternative frameworks, which are presented next.

The epistemological resources perspective. Hammer and Elby (2002; 2003) proposed that epistemic cognition operates on the basis of fine-grained and context-specific cognitive resources that they call *epistemological resources*. The authors observed that individuals, from a very young age on, draw from a multitude of epistemological resources to apprehend knowledge and knowing. Epistemological resources refer to believed propositions about the nature of knowledge (e.g., “knowledge as direct perception”), as well as the resources used to understand epistemological activities (e.g., “accumulation” of knowledge), epistemological forms (e.g., “categories”), or epistemological stances (e.g., “doubting”). This framework challenges the idea that epistemic beliefs are stable across contexts. The authors argue that the activation of epistemological resources is context- and content-dependent, and as such, is likely to vary throughout a single learning task.

The epistemological resources perspective has contributed a greater emphasis on the context specificity of epistemic cognition, as well as the dynamic nature of belief activation. However, this perspective has limited potential for empirical research as it does not offer well-fleshed predictions with regard to relations between epistemological resources and other learning processes and outcomes and is missing a clear perspective on epistemic development.

New conceptualizations: Beyond epistemic beliefs. A broader perspective on epistemic cognition has recently emerged, one that goes beyond the sole focus on individuals' beliefs about knowledge and knowing. New frameworks take into account a wider variety of epistemic phenomena, including components borrowed from psychology and philosophy (e.g., epistemic emotions [Muis et al., 2015]), epistemic vice and virtues [Chinn et al., 2011], and ontological dimensions [Greene et al., 2008]).

***Epistemic and ontological cognition*.** Greene, Azevedo and Torney-Purta (2008) borrowed from developmental and multidimensional frameworks to propose a framework of *epistemic and ontological cognition* that emphasizes not only individuals' beliefs about knowledge and knowing, but also the *process* by which beliefs are acquired and used. Greene et al. (2008) argued that given its centrality, the justification dimension of epistemic cognition should be better elaborated, and assigned a focal role in epistemic research, namely by exploring how and when individuals rely on various means of justification (i.e., justification by authority, personal justification, multiple sources). Greene et al. further argued that the justification dimension is the only one that is rightfully epistemic. The certainty and simplicity dimensions, they argued, tap into individuals' views about the nature of reality and, as such, should be labelled *ontological cognition*.

In terms of development, Greene et al. (2008) stipulated that individuals first develop absolutist beliefs that later morph into multiplicist beliefs, and that may later turn into evaluativistic beliefs. To address the fact that not all adults reach evaluativism, the authors proposed that there exist two paths for multiplicists: Individuals either adopt a *dogmatic* position, wherein they turn to authoritative sources to know what to believe, or else they adopt a *skeptical* stance, wherein they choose to view all knowledge as subjective and personal. Depending on experiences and circumstances, individuals may finally move into evaluativism, wherein they acknowledge the need for justification, and rely on a variety of means of justification that they use discriminately, depending on the context.

New dimensions to epistemic cognition. Building from the work of Greene et al. (2008), Chinn, Buckland, and Samarapungavan (2011) presented a philosophically anchored framework that included substantial additions and extensions to previous frameworks that focused only on epistemic beliefs. The authors introduced an array of novel components: *Epistemic aims* refer to a subset of learning goals adopted by learners that relate to inquiry, and include attaining knowledge, understanding, or true beliefs. *Epistemic virtues and vices* refer to dispositions that facilitate or hinder the achievement or epistemic aims. *Epistemic virtues* are dispositions that assist individuals in accomplishing epistemic aims, and include for instance intellectual courage and open-mindedness. On the other hand, *epistemic vices* are another type of disposition that impedes the accomplishment of epistemic aims, such as close-mindedness and dogmatism. Further, *reliable and unreliable processes* refer to individuals' theories or beliefs about whether the cognitive and metacognitive processes, and methods put in place to achieve epistemic aims are reliable or unreliable under the conditions in which they are used.

Three facets of epistemic cognition. One persistent debate in the literature has been over the boundaries between cognitive and metacognitive aspects of personal epistemology. Barzilai and Zohar (2014) tackled that issue by proposing a framework that considers epistemic thinking (the term they employ) through the lens of metacognition. They proposed that epistemic thinking is multifaceted; specifically, that it includes three epistemic facets: a metacognitive, a cognitive, and an experiential facet. They define *epistemic metacognition* as the reflective level of personal epistemology. It includes *epistemic metacognitive knowledge* about persons as knowers (themselves as much as others), as well as about tasks and strategies that lead to knowledge. Epistemic metacognitive knowledge includes individuals' epistemic beliefs about knowledge and knowing. Additionally, individuals develop *epistemic metacognitive skills*, which Barzilai and Zohar define as processes of regulation and control that involve planning, monitoring, and evaluation of individuals' epistemic thinking.

Epistemic cognition, in turn, is conceptualized by Barzilai and Zohar as the operational or strategic level of personal epistemology. It involves thinking about the knowledge- and knowing-related characteristics of information, as well as engaging in *epistemic strategies* to evaluate knowledge claims. They define epistemic cognition as an inherently dynamic process that can manifest in the form of cognitive enactments. Barzilai and Zohar (2014) drew from the work of Richter and colleagues (Richter & Schmid, 2010; Schroeder, Richter, & Hoever, 2008) to define epistemic strategies as strategic cognitive activities that consider the epistemic status of information, and that are aimed at achieving reliable knowledge by evaluating knowledge claims and sources, considering multiple perspectives, and more. Epistemic strategies include, for instance, sourcing strategies (i.e., evaluating the trustworthiness of sources [Strømsø, Bråten & Britt, 2010]), knowledge validation strategies (i.e., evaluating whether knowledge claims are well justified [Richter & Schmid, 2010]), and integration strategies (i.e., providing explanations to account for differences between various perspectives [Barzilai & Zohar, 2012]).

Lastly, Barzilai and Zohar (2014) proposed an experiential facet to personal epistemology. *Epistemic experiences* refer to cognitive or affective experiences that can arise in the face of uncertainty or ambiguity. Muis, Chevrier, and Singh (2018) have elaborated upon this third facet by proposing an integrated framework that incorporates the role of epistemic emotions in epistemic cognition.

The role of epistemic emotions in epistemic cognition. Muis et al. (2018) proposed a model of epistemic cognition anchored in a self-regulated learning perspective. The model's main contribution has been to integrate the role of epistemic emotions in epistemic cognition. *Epistemic emotions* are defined as affective experiences that arise out of information-oriented appraisals related to the alignment or misalignment between incoming information and existing beliefs or knowledge structures, or when inconsistencies or other discrepancies in processing the information cause cognitive disequilibrium (D'Mello, Lehman, Pekrun, & Graesser, 2014). Epistemic emotions include, for instance, surprise, curiosity, enjoyment, confusion, anxiety, frustration, and boredom (Pekrun, Vogl, Muis, & Sinatra, 2017).

In their model, Muis and colleagues proposed that epistemic beliefs, epistemic values, and self-efficacy are activated as a task definition is produced. In turn, appraisals related to these beliefs and values predict the epistemic emotions that will arise during learning. They further suggested that epistemic emotions predict epistemic aims and other learning goals, and in turn predict learning processes and outcomes. Overall, they proposed that epistemic emotions mediate relations between epistemic beliefs and learning strategies. In other words, epistemic emotions explain in part how epistemic cognition relates to self-regulated learning (Muis et al., 2015; Trevors et al., 2016).

Taken together, the recent frameworks of epistemic cognition presented above make substantial contributions to the literature. Greene et al. (2008) contributed a framework that draws from philosophical epistemology and emphasizes the notion of epistemic cognition, as opposed to the sole notion of epistemic beliefs. One major contribution of Chinn et al.'s (2011) work has been to identify caveats in epistemic research that had not been addressed heretofore: They called upon researchers to examine how individuals' conceptions of reliable processes may vary in different contexts, and to examine how epistemic cognition may vary across various types of knowledge (e.g., declarative, procedural, principled knowledge). Barzilai and Zohar's (2014) metacognitive framework offered clear distinctions between epistemic metacognition and epistemic cognition that invite researchers to reconsider and clarify definitions. Lastly, Muis and colleagues' (2018) model has responded to a long-standing call to integrate emotions into epistemic cognition research (see Pintrich, Marx, & Boyle, 1993; Sinatra, 2005) and have proposed epistemic emotions as one important mediator in the relationship between epistemic cognition and self-regulated learning. Taken together, the recent conceptual frameworks reviewed here provide the grounds on which new research questions and hypotheses can be proposed.

Conceptual Issues

The literature review presented above has led to the identification of underlying conceptual issues that are still unresolved to date. These include: the proliferation of new terms, the specificity of epistemic cognition, the nature of advanced or sophisticated epistemic cognition, and the nature and role of justification. These issues are discussed in turn.

The proliferation of new terms. In the conclusion to their recent *Handbook of epistemic cognition*, Greene and colleagues (2016b) documented what they called "the proliferation of terms with some form of the adjective 'epistemic' attached" (p. 496). The underlying question is that of the value or usefulness of differentiating the "epistemic" version of a construct from its "non-epistemic" version. Alexander (2016) and Greene et al. (2016c) have warned against an explosion of terminology that may hurt the important principle of parsimony. Alexander (2016) called for more coherence and consistency in the language employed, and implored researchers to consider whether new terms add any explanatory power to the field before introducing them.

In order to achieve a balance between parsimony and explanatory power, I argue that a criterion or criteria should be used to differentiate what is epistemic from what is not. Traditionally, authors have defined what is epistemic by emphasizing the knowledge- or knowing-related focus of a construct. Further, Chinn and colleagues (Chinn et al., 2011; Chinn & Reinhart, 2016) proposed to consider whether epistemic aims are present in order to determine whether a cognition or enactment is epistemic in nature. Finally, Muis et al. (2015) proposed that emotions such as frustration or anxiety can be considered epistemic when the object focus of the emotion is related to knowledge, knowing, and the processing of information. These latter criteria suggest an empirical avenue to explore whether various constructs are indeed connected to individuals' epistemic cognition.

Overall, I argue that the introduction of well-defined "epistemic" terms can be beneficial, first to advance our fundamental understanding of epistemic cognition, and second, to draw attention on this important facet of learning. Indeed, in spite of 40 years of empirical efforts that demonstrate that epistemic cognition "matters" (Kuhn & Weinstock, 2002), very few educational curricula take students' (and teachers') epistemic cognition into account when designing educational environments or devising instructional interventions (Hofer, 2016; Muis et al., 2016).

It is important to note that epistemic cognition researchers are not arguing that there exist epistemic constructs that are conceptually and empirically different from other cognitive and metacognitive aspects of thinking. Rather, epistemic cognition is situated within existing structures, and can be interpreted within existing frameworks (Barzilai & Zohar, 2014; Bromme et al., 2010; Greene, Yu, & Copeland, 2014; Hofer, 2004a; Muis, 2007). In other words, what makes a construct "epistemic" is its concern, rather than its form. Distinguishing "epistemic" constructs from other motivational or contextual forces (i.e., distinguishing epistemic anxiety in the face of uncertain knowledge versus performance anxiety in the face of a test) may lead to the identification of undue conflations or unearth hidden mediators. In sum, more research will be needed to determine which epistemic mechanisms are actually in place, and to determine which terms should be retained in our common vocabulary.

It is further important to note that epistemic cognition researchers are not arguing that all learning is epistemic, nor that all learning tasks should be designed to elicit epistemic cognition. For instance, memorizing the order of the planets in the solar system is certainly an activity that requires less epistemic cognition than building an argument after having consulted multiple sources. However, by positing the existence of epistemic cognition, epistemic aims, epistemic strategies, or epistemic emotions, researchers can better explore the specific mechanisms by which epistemic cognition occurs. Ultimately, such an endeavor may help researchers, educators, and policy makers to produce more specific instructional guidelines and curricula that foster the development of deeper learning, greater disciplinary integration, as well as high-order thinking.

The specificity of epistemic cognition. The question of the contextual specificity of epistemic cognition has received much attention in recent years. One question concerns whether or not different epistemic belief dimensions should be taken into account across domains. Indeed, researchers who assume the domain-specificity of epistemic cognition also posit that underlying dimensions (i.e., simplicity, complexity, source, justification) are valid across all domains – that there are no dimensions that are unique to a particular domain. However, recent findings by Greene and Yu (2014) challenge this assumption: After having interviewed university professors in various disciplines, Greene et al. concluded to obvious similarities in less advanced, or “naïve,” beliefs across disciplines (e.g., the belief that knowledge corresponds to a list of facts) but found that advanced beliefs were much more differentiated across disciplines. For instance, biology professors referred to the importance of connected knowledge, whereas history professors focused on interpretations. In Greene and Yu's (2014) words, "it is difficult to imagine a domain-general definition of the nature of knowledge factors that could capture advanced experimentation skills in biology, as well as historical empathy skills in history" (p. 20).

The nature of sophistication. Beyond the question of the suitability of epithets such as "naïve" or "less constructivist" to qualify less developed epistemic beliefs, the question of the nature of sophistication remains a current debate. One issue concerns the assumption that mature epistemic cognition (understood as the beliefs, sources evaluations and means of justification espoused by experts) is "more constructivist". Indeed, evidence obtained by Greene and Yu (2014) indicates that experts at times espouse the belief that types of knowledge are rather simple and certain. This is the case, for example, of declarative knowledge in history, or of procedural knowledge in chemistry.

A related issue is the problematic assumption that more constructivist beliefs are superior in all situations (see Bromme, Kienhues, & Stahl, 2008, Bromme et al., 2010; Greene, Muis, & Pieschl, 2010). Indeed, in instances where prior knowledge and epistemic aims are low (i.e., where basic understanding is sufficient), it may be more adaptive to assume that knowledge is simple and that experts are trustworthy sources. Alexander and colleagues (Alexander, 2016; Alexander, Winters, Loughlin, & Grossnickle, 2012; Maggioni, Fox, & Alexander, 2010) proposed the term *epistemic competence* to refer to an adaptive and flexible form of epistemic cognition. By this definition, competent learners recognize the potential unreliability of sources and the contestable nature of knowledge, but also consider content and context when determining the level of certainty and justification that may be required to accept a knowledge claim or source as acceptable. As such, the notion of "competent belief" appears to be a more accurate way of qualifying experts' beliefs than the label "more constructivist."

The nature and role of justification. As Greene et al. (2008) have pointed out, philosophical epistemology has been concerned with the justification of knowledge as a primary focus. In multidimensional frameworks of epistemic cognition, "naïve" justification has been construed as the reliance on authorities and experts, whereas the reliance on one's own means of justification, such as rational evaluation, has been deemed "sophisticated" (Schommer, 1990; Hofer & Pintrich, 1997). However, Greene et al. (2008) argued that the way justification is defined in multidimensional frameworks fails to consider the many means of justification that are valid and acknowledged in the philosophical literature. For example, Chinn et al. (2011) pointed out that philosophers regard knowledge claimed by experts as justified, provided that those experts are properly vetted. Chinn et al. proposed to refer to this type of justification as *justification by testimony,* where testimony is defined as all social forms of sharing information and knowledge with others. The authors further argued that most of what is known is learned from others, and that no one can actually evaluate all of what is learned through their own means.

Another issue related to justification is that individuals do not always enact the evaluations that would be in accordance with their beliefs. Chinn and Brewer (1993) found that many scientists report that anomalous data should lead to model revision, yet many ignore anomalous data in their research. It might be the case that individuals' espoused beliefs may have little to do with how they actually go about justifying knowledge claims in context. Overall, more research is needed to investigate how individuals go about evaluating and justifying knowledge claims in different domains and contexts, and with different types of problems.

Conclusion

The above review provided a review of the existing theories of epistemic cognition. To this day, research on epistemic cognition continues to become richer, more diversified, and better integrated with other disciplines (e.g., philosophy, psychology). Nonetheless, the field still struggles to unify its various traditions, frameworks, and terms under a consolidated framework. Integrated theoretical frameworks like those proposed by Barzilai and Zohar (2014) or Muis and Singh (2018) appear to be a promising avenue, as future research on epistemic cognition will require rich frameworks from which to derive sophisticated research questions and hypotheses.

The above review also shows that there exist several issues left to be resolved, as well as gaps that should be addressed. For instance, despite positive associations between epistemic cognition and several educational processes and outcomes, the correlation between epistemic cognition and learning achievement tends to be small (Greene et al., 2018). As was illustrated in this review, some possible explanations for this include the need to broaden conceptual horizons to include not only tacit and stable epistemic beliefs, but more dynamic and contextually-anchored processes such as epistemic aims and epistemic strategies that may provide a fuller picture of epistemic cognition as it occurs in learning settings. Further, as argued by Bråten et al. (2011), there is a need to investigate mediational mechanisms that account for relations between epistemic cognition and important educational processes and outcomes. As exposed above, Muis and colleagues (Muis et al., 2018; Muis & Singh, 2018) advanced epistemic emotions as one such mediational mechanism; however, to date, little empirical work has been done to uncover the role that epistemic emotions may play in epistemic cognition.

One last possible explanation to the observed small effect of epistemic cognition on achievement is methodological in nature. As will be discussed in the next section, research on epistemic cognition to date has heavily relied on decontextualized self-report instruments to collect evidence of epistemic cognition. However, as the field moves towards conceptualizations where the situated and dynamic nature of epistemic cognition is taken into consideration, equally situated and dynamic research methods will be needed to further our understanding of the nature and role of epistemic cognition in learning. The next section offers a critical examination of the various methods that can be used to measure epistemic cognition.

Part 2. What Methods Can Be Used to Measure Epistemic Cognition?

Accurate measurement of epistemic cognition is crucial for many reasons. Undoubtedly, sound measurement is key to bolstering theoretical frameworks and advancing the field. But more importantly perhaps is that quick and accurate measurement is key to realizing the full educational implications of epistemic cognition, such as supporting the development and enactment of higher-order thinking skills. However, despite a number of publications dedicated to this issue, the measurement of epistemic cognition continues to be a challenge (Clarebout, Elen, Luyten, & Bamps, 2001; DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008; Wood & Kardash, 2002). Measuring epistemic cognition is arduous mainly because it is a complex and multifaceted construct. In this section, I first review how researchers from various theoretical perspectives have employed diverse methods to assess epistemic cognition and to advance knowledge in the field. Next, I identify the limitations of these methods, and offer suggestions to overcome them.

Methods Used Within Perspectives

The developmental perspective. As discussed above, developmental frameworks proposed a continuum of positions moving from absolutism, to multiplicism, to evaluativism. Historically, researchers interested in the development of personal epistemology have used qualitative methods to assign individuals a developmental position or epistemic stance. Following Perry (1970), researchers with a developmental focus have predominantly used semi-structured interviews to understand individuals' epistemic cognition. Often committing to a phenomenological approach to elicit respondents' voices, interviews have allowed researchers to obtain rich data about learners' worldviews, rapport to authority (Perry, 1970), decision-making processes (Baxter Magolda, 1992; 2004), and reasoning about ill-structured (King & Kitchener, 1994; 2004) or moral (Belenky et al., 1986) problems. Interviews have been used in longitudinal studies (Baxter Magolda, 1992; 2004; King & Kitchener, 1994; 2004; Perry, 1970) or complimented with paper-and-pencil surveys (Baxter Magolda, 1992; 2004). Given the resource-intensive nature of interviews, developmental researchers have later focused on developing scenario-based paper-and-pencil instruments (see Barzilai & Weinstock, 2015; Kuhn et al., 2000; Wood & Kardash, 2002). Vignettes with text and images have also been used with interviews to investigate children's level of epistemic development (Mansfield & Clinchy, 2002).

The multidimensional perspective. Multidimensional frameworks have conceptualized epistemic cognition as a system of more or less independent beliefs or theories that develop asynchronously. To test whether individuals espouse more or less sophisticated or constructivist beliefs on a number of dimensions, scholars have developed questionnaires where respondents self-report their level of agreement with numerous statements on Likert scales.

Early epistemic beliefs questionnaires (i.e., Epistemological Questionnaire [EBQ; Schommer, 1990]; Epistemic Beliefs Inventory [EBI; Schraw, Bendixen, & Dunkle, 2002]), Epistemological Beliefs Survey [EBS; Wood & Kardash, 2002]) assessed domain-general beliefs, with statements that referred to knowledge in general. As the debate over the domain generality of epistemic beliefs unfolded, Muis et al. (2006) called upon researchers to measure individuals' epistemic beliefs about a specific domain. Muis et al. (2006) argued that respondents presented with broadly stated items might be influenced by their domain of study or of expertise, which would compromise comparability across respondents. At first, domain-general questionnaires were turned into domain-specific versions by substituting domains of focus in items that otherwise remained the same (e.g., "Mathematics relates to day-to-day life" versus "Economics relate to day-to-day life"; Buehl, Alexander, & Murphy, 2002; see also Greene, Torney-Purta, & Azevedo, 2010; Hofer, 2000). Later, proper domain-specific questionnaires were developed, as well as topic-specific questionnaires (e.g., Topic-Specific Epistemic Beliefs Questionnaire [TSEBQ; Bråten, Gil, Strømsø, & Vidal-Abarca, 2009]). Researchers who adopted the multidimensional perspective have also used semantic differential measures (e.g., the Connotative Aspects of Epistemic Beliefs scale [CAEB; Stahl & Bromme, 2007]). Items in semantic differential instruments capture the evaluative judgments that individuals attribute to words to pairs of conflicting adjectives (e.g., "exact-vague"; "dynamic-static").

As will be discussed below, Likert-type instruments have received abundant criticism with regard to their poor psychometric properties. As a result, researchers from the multidimensional tradition have continually sought to develop alternative measures, turning to methodologies used, for instance, in self-regulated learning research. Think-aloud protocols, among others, have been successfully employed to assess epistemic cognition, including dimensions of epistemic beliefs, epistemic strategies, and epistemic aims (Chevrier et al., 2015; 2016; Hofer, 2004a; Ferguson, Bråten, & Strømsø, 2012; Greene et al., 2014; Mason, Ariasi, &

Boldrin, 2011; Mason, Boldrin, & Ariasi, (2010). Lastly, Greene et al. (2010) proposed computer-based learning environments to collect trace data (e.g., time logs, highlighting patterns, recorded notes) to infer epistemic cognition from learning behaviors.

The epistemological resources perspective. Hammer and colleagues (2002; 2003) proposed that epistemic cognition can be conceptualized as epistemological resources that individuals activate as a function of contextual demands. Interviews (Hammer & Elby, 2002; 2003) and direct observation (Louca, Elby, Hammer, & Kagey, 2004) have been the privileged methods of measurement used in this perspective. As no stability in epistemological resources is assumed across situations, contexts, or domain, only immersive measurement approaches sensitive to sociocultural variables are adequate here.

New conceptualizations. The notion that epistemic cognition encompasses much more than epistemic beliefs is common across the recent frameworks reviewed above (e.g., Barzilai & Zohar, 2014; Chinn et al., 2011; Greene et al., 2008; Muis & Singh, 2018). Models such as Greene et al.'s (2008) and Muis and Singh's (2018) assume that epistemic cognition encompasses relatively stable epistemic beliefs as well as more dynamic and context-specific components such as epistemic aims, epistemic strategies, and epistemic emotions. As such, these researchers have combined quantitative and qualitative methods to test their models. For instance, Muis and colleagues' (2018) integrated model has been tested with a combination of self-report questionnaires to capture learners' epistemic beliefs and think-aloud protocols to capture learners' epistemic aims, epistemic strategies, and epistemic emotions (see Chevrier et al., under review; Muis et al., 2015). Likewise, Greene and colleagues tested their 2008 model with a self-report instrument (Greene et al., 2010), as well as with think-aloud protocols (Ferguson et al., 2012; Greene et al., 2014).

As exposed above, the alignment between a framework's assumptions and the measurement methods used to test them is paramount. While these methods have participated to the elaboration of each framework and to the advancement of the field in general, each method comports limitations that force researchers to keep innovating. I next examine the affordances and limitations of each method.

Affordances and Limitations of Employed Methods

Likert-type self-report instruments. Likert scales are prevalent in epistemic cognition research, as in many branches of educational psychology, due to their manageable and inexpensive modes of administration. The chief advantage of these instruments is allowing individuals to report on constructs that are inherently personal and that can be hard to reveal. However, thorough examination of the psychometric properties of the most common self-report instruments used in epistemic cognition research has revealed issues of validity, reliability, and inaccuracy. In terms of validity, DeBacker et al.'s (2008) analysis of the factor structure of the Epistemic Beliefs Questionnaire (EBQ; Schommer, 1990), the Epistemic Beliefs Inventory (EBI; Schraw et al., 2002), and the Epistemic Beliefs Scale (EBS; Wood & Kardash, 2002) failed to provide support for the number of proposed epistemic belief dimensions. This is consistent with work by Hofer (2004a), who reported that certainty and simplicity did not emerge as separate factors in her Discipline-Focused Epistemic Beliefs Questionnaire (DFEBQ; Hofer, 2000). Hofer (2000) concluded that epistemic beliefs may not be as multifaceted as hypothesized, or else, be too multifaceted to be captured with Likert-scale questionnaires.

The validity of Likert-scale questionnaires has also been problematic for developmental research. As pointed by Muis et al. (2006), it is difficult to determine what should constitute the breaking point in a continuum between a belief in authorities as true sources of knowledge (an absolutist or less constructivist belief), and a belief in the active construction of knowledge (an evaluatist or more constructivist belief). Indeed, disagreeing with a less constructivist statement is not a reliable indication of espousing a more constructivist belief (Greene et al., 2008; Greene & Yu, 2014; Hofer, 2004a; Hofer & Pintrich, 1997; Mason, 2016; Schommer, 1990). In other words, Likert scales create false dichotomizations in what should be a continuum in belief.

The low reliability of Likert-scale questionnaires is another problematic issue in epistemic cognition measurement. DeBacker et al. (2008) found that the internal consistency of the EBQ was poor, whereas that of the EBS and the EBI were lower than desirable. Poor internal consistency is problematic as it indicates great proportions of measurement error, which constitutes an important threat to the reliability of instruments as well as to the replicability of results (Muis et al., 2006). A related issue is the overwhelming reliance on homogeneous samples, often composed of white, urban, undergraduate students, which threatens the reliability of self-report epistemic belief questionnaire (Greene & Yu, 2014; Mason, 2016).

Lastly, using Likert-type questionnaires for the assessment of epistemic beliefs has been criticized for its potential inaccuracy. Greene et al. (2008) pointed out that completing an epistemic belief inventories requires a level of metacognitive engagement that participants may not be willing to deploy in an experimental context. This may compromise the accuracy of their responses. Similarly, researchers have raised concerns that there may be interpretability issues with items that are too broadly stated or worded with unspecific knowledge-related words (Greene & Yu, 2014; Muis et al., 2006). For instance, the item “I am most confident that I know something when I know what the experts think” (Hofer, 2000, p. 251) can be interpreted as asking whether sole reliance on experts is sufficient justification, or whether experts are a legitimate source of knowledge. Despite these limitations, Likert-scale questionnaires continue to be prevalent in epistemic cognition research. As Greene et al. (2008) argued, self-report instruments can be adequate when used with large, heterogeneous samples, and when multiple items are used to capture one dimension from different angles.

Scholars have proposed several solutions to address these measurement issues. In response to the identification of problems with psychometric factorial structures and internal consistency of instruments (e.g., Clarebout et al., 2001; DeBacker et al., 2008; Wood & Kardash, 2002), as well as to the issue of wording in relation to domain-specificity, new instruments have been developed, such as the TSEBQ (Bråten et al., 2009) or the CAEB (Stahl & Bromme, 2007). Others have conducted qualitative investigations to assess whether there might be inherent conceptual problems with the frameworks from which self-report instruments are derived. Notably, as noted above, Greene and Yu (2014) interviewed novices and experts about their epistemic beliefs and identified various conceptual issues that might be problematic for measurement. Lastly, scholars have questioned whether self-report instruments may simply be inadequate to capture epistemic cognition (Alexander et al., 2012; Greene et al., 2010; Muis et al., 2006). This hypothesis has led to consider alternative methods, which are discussed next.

Think-aloud protocols. One methodological approach that has gained traction over the past decades is think-aloud protocols (Ericsson & Simon, 1993). Think-aloud protocols involve asking participants to verbalize their thinking as they learn or study, thus allowing researchers to capture processes that are concurrent with learning without relying on participants' memory. These verbal data are then categorized for a range of cognitive processes using coding schemes, which allows to quantify these processes. Given these characteristics, think-aloud protocols may be considered a quantitative methodology. Researchers have used think-aloud protocols to capture "epistemic beliefs in action" (e.g., Hofer, 2004a; Mason et al., 2010; 2011) as well as other contextualized aspects of epistemic cognition such as epistemic strategies and epistemic aims (e.g., Barzilai & Zohar, 2012; Chevrier et al., 2016; Greene et al., 2015)..

Contrary to Likert-type self-report questionnaires, which are completed before or after a cognitive task (i.e., offline measure), think-aloud protocols are another type of self-report measurement but offer online measurement, meaning that measures are taken as cognitive activity unfolds. Veenman, Van Hout-Wolters, and Afferbach (2006) have argued that in the context of measuring cognitive and metacognitive processes, online methods render data that are more predictive of learning achievement than offline methods. However, an important limitation to think-aloud protocols is that they may disrupt participants' thinking process by imposing an additional cognitive demand (Veenman et al., 2006). Another issue is the resource intensiveness of think-aloud protocols, which require large investments of time (e.g., development of coding schemes, transcription and coding) and money (e.g., research assistants' salary; participant compensation). Lastly, think-aloud is a self-report methodology and is subject to the same biases are other self-report methodologies, namely in that they are limited by how much participants are aware of their own mental processes.

Qualitative methods. Qualitative methods used in epistemic cognition research have included, among others, phenomenological interviews (e.g., Baxter Magolda, 1992; Belenky et al., 1986; King and Kitchener, 1994; 2004; Perry, 1970), direct observation of classroom practices (e.g., Rosenberg, Hammer, & Phelan, 2006), multiple case study (e.g., Greene & Yu, 2014), and the analysis of artifacts (e.g., Alexander et al., 2012). Cognitive interviews have also been used to elicit respondents' interpretations of self-report items (e.g., Greene et al., 2010; Mason, 2016; Muis, Duffy, Trevors, Ranellucci, & Foy, 2014). Lastly, qualitative methods have been used to challenge some of the field's conceptual assumptions. To this end, open-ended, inductive, and exploratory work has been used to broaden the scope of dimensions, the types of justification, and the nature of sophisticated or expert epistemic cognition (Greene & Yu, 2014).

Qualitative methods, however, are not without limitations. King and Kitchener (2002) argued that their own semi-structured interview (i.e., the Reflective Judgment Interview) might have resulted in an underestimation of respondents' cognitive abilities, since it asked of students to respond to difficult questions with very little time to reflect. Another limitation comes from the fact that interview protocols are time-consuming, costly, and require specific training for research assistants, which explains why their use is typically limited to smaller samples. Lastly, when discussing the usefulness of artifacts (e.g., drawings, cognitive maps), Alexander et al. (2012) acknowledged that there is no way of knowing whether these artifacts reliably reflect students' tacit beliefs. The authors also questioned the generalizability of findings derived from qualitative analyses by concluding that, "we simply cannot divorce these data from the context in which they were generated" (Alexander et al., 2012, p. 13).

Future Directions and Conclusions

As the field of epistemic cognition moves towards new methodologies, a few considerations must be taken into account. A first consideration consists of weighing participants' lack of motivation to respond to questionnaires against maladaptive epistemic competence. If we accept the notion that epistemically competent individuals are flexible and take contextual demands into account, we can question the extent to which epistemically competent respondents would be motivated to deploy their "best" epistemic cognitive processes under experimental conditions. For instance, Hyytinen et al. (2014) found that among students who espoused more constructivist epistemic beliefs, many did not engage in thorough and effortful thinking on a reasoning task performed in an experimental context.

A second issue concerns sampling. We can wonder whether the field of epistemic cognition might have grown on the basis of evidence provided by samples that were overall too homogeneous. This concern dates back to Perry's (1970) seminal work, which was based on a sample of all-white males from an elite institution. Since, samples used in epistemic cognition research have been overwhelmingly composed of white urban female university students. Despite the well-documented influence of the socio-cultural context on epistemic cognition (Bromme et al., 2008; Hammer & Elby, 2002; Muis et al., 2016) and its development (Hofer, 2008; Muis et al., 2006), too little multicultural or socially diverse samples are used in epistemic cognition research. In addition, Hofer (2008) warns that the research conducted on cross-cultural samples has generally neglected to reconsider the assumptions, conceptualizations, and operational definitions of theories and methods used to apprehend these samples, which might not stand across cultures.

Lastly, there is a need for instruments that can assess the epistemic climate of learning environments. Drawing from Muis et al. (2016), such a tool would capture and characterize the pedagogy, authoritative style, curriculum, evaluative practices, and support styles of a learning environment. Further, if researchers are to fulfill Bromme et al.'s (2010) call for a "double-track approach" (p. 23) to epistemic cognition research, artefact analysis with coding schemes should be used to analyze the knowledge representations to which learners are exposed.

To conclude, it appears that the advancement of the quality of epistemic cognition measurement lies both in the combination of qualitative and quantitative methods (Mason, 2016), as well as in the development of new technologies (Greene et al., 2010). As new conceptualizations shed light on the many underlying facets of epistemic cognition, it is becoming increasingly important for researchers to clearly identify what is being measured, and to select methods accordingly. Indeed, instruments that have attempted to capture both the static and dynamic aspects of epistemic cognition might explain why these instruments have seldom correlated with each other (see DeBacker et al., 2008). Another promising avenue comes from technological advances, which bear the possibility of the stealth implementation of multi-modal measurement. Software such as nStudy (Winne, 2014) is promising in this regard: nStudy, is an online environment and research tool developed that allows researchers to gather traces of learners' epistemic, affective, and self-regulated processes as they occur in real time. However, as new technologies become the new center of interest, the resource intensivity of these sophisticated methods must be taken into consideration. As long as the field does not suggest methods that are non-invasive, inexpensive, and rapid to use, self-report instruments stand little chance of being replaced.

In sum, accurate measurement of epistemic cognition is crucial for many reasons. Crucially, quick and non-invasive measurement of the components of epistemic cognition is key to realizing its full educational implications. On the other hand, precise measurement is key to advancing the field by relating epistemic cognition to other psychological and educational constructs, such construct is epistemic emotions.

General Conclusion

In a context of proliferating information and viewpoints, competent epistemic cognition is becoming a necessity for citizens of all ages. In the first section of this chapter, I have shown that the field of epistemic cognition has proposed frameworks that are increasingly specific, expansive, interdisciplinary, and integrated with other learning processes and outcomes, offering a fruitful avenue to better understand the nature and role of epistemic cognition for important educational processes and outcomes. Specifically, I have articulated conceptual distinctions between various epistemic terms (e.g., epistemic cognition, epistemic beliefs, epistemic aims, epistemic strategies, epistemic emotions) that hold the promise of providing a fuller account of epistemic cognition if duly taken into account. In the second portion of this chapter, I have further shown that the field of epistemic cognition still suffers from methodological challenges and have identified the limitations but also the affordances of methods that can guide future research on epistemic cognition.

Promising avenues for future work were also identified, including the investigation of mediation mechanisms that intervene in the relationship between epistemic cognition and important educational outcomes, as well as the use of multi-modal and dynamic measurement methods to properly operationalize the aforementioned conceptual distinctions. Overall, I have made the argument that with careful consideration for conceptual and methodological shortcomings, future research will help us understand how epistemic cognition can be profitably leveraged to educate individuals who can effectively sift through today's complex informational landscape and make adequate decisions about what to believe or what to do.

References

Alexander, P. A. (2016). The arguments for and the reasoning about epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 100-110). New York, NY: Routledge.

Alexander, P. A., Winters, F. I., Loughlin, S. M., & Grossnickle, E. M. (2012). Students' conceptions of knowledge, information, and truth. *Learning and Instruction, 22*, 1-15.

Barzilai, S., & Eshet-Alkalai, Y. (2015). The role of epistemic perspectives in comprehension of multiple author viewpoints. *Learning and Instruction, 36*, 86-103.

Barzilai, S., Tzadok, E., & Eshet-Alkalai, Y. (2015). Sourcing while reading divergent expert accounts: Pathways from views of knowing to written argumentation. *Instructional Science, 43*, 737-766.

Barzilai, S., & Weinstock, M. (2015). Measuring epistemic thinking within and across topics: A scenario-based approach. *Contemporary Educational Psychology, 42,* 141-158.

Barzilai, S., & Zohar, A. (2012). Epistemic thinking in action: Evaluating and integrating online sources. *Cognition and Instruction, 30,* 39-85.

Barzilai, S., & Zohar, A. (2014). Reconsidering personal epistemology as metacognition: A multifaceted approach to the analysis of epistemic thinking. *Educational Psychologist, 49,* 13-35.

Baxter Magolda, M. B. (1992). *Knowing and reasoning in college: Gender-related patterns in students' intellectual development*. San Francisco, CA: Jossey-Bass.

Baxter Magolda, M. B. (2004). A constructivist conceptualization of epistemological reflection. *Educational Psychologist*, *39*, 31-42.

Belenky, M., Clinchy, B., Goldberger, N., & Tarule, J. (1986). *Women's ways of knowing: The development of self, voice, and mind*. New York, NY: Basic Books.

Bråten, I., Britt, M. A., Strømsø, H. I., & Rouet, J.-F. (2011). The role of epistemic beliefs in the comprehension of multiple expository texts: Toward an integrated model. *Educational Psychologist, 46,* 48-70.

Bråten, I., Gil, L., Strømsø, H. I., & Vidal-Abarca, E. (2009). Personal epistemology across cultures: Exploring Norwegian and Spanish university students' epistemic beliefs about climate change. *Social Psychology of Education, 12*, 529-560.

Bromme, R., Kienhues, D., & Stahl, E. (2008). Knowledge and epistemological beliefs: An intimate but complicate relationship. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs* (pp. 423-441). New York, NY: Springer.

Bromme, R., Pieschl, S., & Stahl, E. (2010). Epistemological beliefs are standards for adaptive learning: A functional theory about epistemological beliefs and metacognition. *Metacognition and Learning, 5*, 7-26.

Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002). Beliefs about schooled knowledge: Domain specific or domain general? *Contemporary Educational Psychology, 27*, 415-449.

Chandler, M. J., Hallett, D., & Sokol, B. W. (2002). Competing claims about competing knowledge claims. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 145-168). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Chevrier, M., Muis, K. R., Trevors, G., Psaradellis, C., Di Leo I., & Singh, C. (2016, August). *Epistemic emotions mediate relations between epistemic beliefs and learning strategies*.

Poster presented at the annual convention of the American Psychological Association, Denver, CO.

Chevrier, M., Trevors, G. J., Muis, K. R., Psaradellis, C., & Di Leo, I., (2015, August). *Relations between epistemic beliefs and emotions when reading contradictory information.* Paper presented at the biennial conference of the European Association for Research on Learning and Instruction, Limassol, Cyprus.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*, 1-49.

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. L. A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist, 46,* 141-167.

Chinn, C. A., & Rinehart, R. W. (2016). Epistemic cognition and philosophy: Developing a new framework for epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 460-478). New York, NY: Routledge.

Clarebout, G., Elen, J., Luyten, L., & Bamps, H. (2001). Assessing epistemological beliefs: Schommer's questionnaire revisited. *Educational Research and Evaluation, 7*, 53-77.

D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29*, 153-170.

DeBacker, T. K., Crowson, H. M., Beesley, A. D., Thoma, S. J., & Hestevold, N. L. (2008). The challenge of measuring epistemic beliefs: An analysis of three self-report instruments. *The Journal of Experimental Education, 76*, 281–312.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis*. Cambridge, MA: MIT press.

Ferguson, L. E., & Bråten, I. (2013). Student profiles of knowledge and epistemic beliefs: Changes and relations to multiple-text comprehension. *Learning and Instruction, 25*, 49-61.

Ferguson, L. E., Bråten, I., & Strømsø, H. I. (2012). Epistemic cognition when students read multiple documents containing conflicting scientific evidence: A think-aloud study. *Learning and Instruction, 22,* 103-120.

Greene, J. A., Azevedo, R., & Torney-Purta, J. (2008). Modeling epistemic and ontological cognition: Philosophical perspectives and methodological directions. *Educational Psychologist, 43,* 142-160.

Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. *Journal of Educational Psychology*. Advanced online publication.

Greene, J. A., Muis, K. R., & Pieschl, S. (2010). The role of epistemic beliefs in students' self-regulated learning with computer-based learning environments: Conceptual and methodological issues. *Educational Psychologist, 45*, 245-257.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016a). *Handbook of epistemic cognition*. New York, NY: Routledge.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016b). Introduction to epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 1-16). New York, NY: Routledge.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016c). Reflections and future directions. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 495-511). New York, NY: Routledge.

Greene, J. A., Torney-Purta, J., & Azevedo, R. (2010). Empirical evidence regarding relations among a model of epistemic and ontological cognition, academic performance, and educational level. *Journal of Educational Psychology, 102,* 234.

Greene, J. A., & Yu, S. B. (2014). Modeling and measuring epistemic cognition: A qualitative re-investigation. *Contemporary Educational Psychology, 39,* 12-28.

Greene, J. A., & Yu, S. B. (2016). Educating critical thinkers: The role of epistemic cognition. *Policy Insights from the Behavioral and Brain Sciences*. Advanced online publication.

Greene, J. A., Yu, S. B., & Copeland, D. Z. (2014). Measuring critical components of digital literacy and their relationships with learning. *Computers and Education, 76*, 55-69.

Hammer, D., & Elby, A. (2002). On the form of personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 169-190). Mahwah, NJ: Lawrence Erlbaum Associates.

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences, 12,* 53-90.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, *25*, 378-405.

Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review, 13*, 353-383.

Hofer, B. K. (2004a). Epistemological understanding as a metacognitive process: Thinking aloud during online searching. *Educational Psychologist, 39,* 43-55.

Hofer, B. K. (2004b). Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology, 29*, 129-163.

Hofer, B. K. (2008). Personal epistemology and culture. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs* (pp. 3-22). New York, NY: Springer.

Hofer, B. K. (2016). Epistemic cognition as a psychological construct: Advancements and challenges. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 19-38). New York, NY: Routledge.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 6*, 88-140.

Hofer, B. K., & Pintrich, P. R. (2002). *Personal epistemology: The psychology of beliefs about knowledge and knowing*. Mahwah, NJ: Lawrence Erlbaum Associates.

Kienhues, D., Bromme, R., & Stahl, E. (2008). Changing epistemological beliefs: The unexpected impact of a short-term intervention. *British Journal of Educational Psychology*, *78*, 545-565.

King, K. S., & Kitchener, K. S. (2002). The reflective judgment model: Twenty years of research on epistemic cognition. In Hofer, B. K., & Pintrich, P. R. (eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 37-61). Mahwah, NJ: Erlbaum.

King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco, CA: Jossey-Bass.

King, P. M., & Kitchener, K. S. (2004). Reflective judgment: Theory and research on the development of epistemic assumptions. *Educational Psychologist, 39*, 5-18.

Kitchener, K. S., & King, P. M. (1985). *Reflective judgment scoring rules*. Unpublished manuscript, Bowling Green State University and University of Denver.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*, 319-337.

Kuhn, D. (2001). How do people know? *Psychological Science, 12*, 1-8.

Kuhn, D., Cheney, R., & Weinstock, M. (2000). The development of epistemological understanding. *Cognitive Development, 15,* 309-328.

Kuhn, D., & Crowell, A. (2011). Dialogic argumentation as a vehicle for developing young adolescents' thinking. *Psychological Science, 22*, 545-552.

Kuhn, D., & Park, S. H. (2005). Epistemological understanding and the development of intellectual values. *International Journal of Educational Research*, *43*, 111-124.

Kuhn, D., & Weinstock, M. (2002). What is epistemological thinking and why does it matter? In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing*. (pp. 121-144). Mahwah, NJ: Erlbaum.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Louca, L., Elby, A., Hammer, D., & Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist*, *39*, 57-68.

Maggioni, L., Fox, E., & Alexander, P. A. (2010). The epistemic dimension of competence in the social sciences. *Journal of Social Science Education, 9,* 15-23.

Mansfield, A. F., & Clinchy, B. M. (2002). Toward the integration of objectivity and subjectivity: Epistemological development from 10 to 16. *New Ideas in Psychology*, *20*, 225-262.

Mason, L. (2016). Psychological perspectives on measuring epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 375-392). New York, NY: Routledge.

Mason, L., Ariasi, N., & Boldrin, A. (2011). Epistemic beliefs in action: Spontaneous reflections about knowledge and knowing during online information searching and their influence on learning. *Learning and Instruction, 21*, 137-151.

Mason, L., Boldrin, A., & Ariasi, N. (2010). Epistemic metacognition in context: Evaluating and learning online information. *Metacognition and Learning, 5*, 67-90.

Mason, L., & Boscolo, P. (2004). Role of epistemological understanding and interest in interpreting a controversy and in topic-specific belief change. *Contemporary Educational Psychology, 29*, 103-128.

Mines, R. A., King, P. M., Hood, A. B., & Wood, P. K. (1990). Stages of intellectual development and associated critical thinking skills in college students. *Journal of College Student Development, 31*, 538−547.

Mintchik, N. M., & Farmer, T. A. (2009). Associations between epistemological beliefs and moral reasoning: Evidence from accounting. *Journal of Business Ethics, 84*, 259-275.

Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Educational Research, 74,* 317–377.

Muis, K. R. (2007). The role of epistemic beliefs in self-regulated learning. *Educational Psychologist, 42*, 173-190.

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review, 18,* 3-54.

Muis, K. R., & Duffy, M. C. (2013). Epistemic climate and epistemic change: Instruction designed to change students' beliefs and learning strategies and improve achievement. *Journal of Educational Psychology, 105*, 213-225.

Muis, K. R., Duffy, M. C., Trevors, G., Ranellucci, J., & Foy, M. (2014). What were they thinking? Using cognitive interviewing to examine the validity of self-reported epistemic beliefs. *International Education Research, 2*, 17-32.

Muis, K. R., Pekrun, R., Sinatra, G. M., Azevedo, R., Trevors, G., Meier, E., & Heddy, B. C. (2015). The curious case of climate change: Testing a theoretical model of epistemic beliefs, epistemic emotions, and complex learning. *Learning and Instruction, 39*, 168-183.

Muis, K. R., & Singh, C. A. (2018). The three facets of epistemic thinking in self-regulated learning. In D. Schunk & J. Greene (Eds.), *Handbook of self-regulated of learning and performance* (pp. 434–456). New York, NY: Routledge.

Muis, K. R., Trevors, G., & Chevrier, M. (2016). Epistemic climate for epistemic change. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 331-359). New York, NY: Routledge.

Pekrun, R., & Stephens, E. J. (2012). Academic emotions. In K. R. Harris, S. Graham, T. Urdan, S. Graham, J. M. Royer, & M. Zeidner (Eds.), *APA educational psychology handbook* (Vol. 2, pp. 3-31). Washington, DC: American Psychological Association.

Pekrun, R., Vogl, E., Muis, K. R., & Sinatra, G. M. (2017). Measuring emotions during epistemic activities: The Epistemically-Related Emotion Scales. *Cognition and Emotion, 31*, 1268-1276.

Perry, W. G. Jr. (1970). *Forms of intellectual and ethical development in the college years: scheme.* New York, NY: Holt, Rinehart and Winston.

Piaget, J. *Introduction à l'épistémologie génétique*. Paris, France: Presses Universitaires de France.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*, 167-199.

Pintrich, P. R., Smith, D. A., Garcia, T., & McKeachie, W. J. (1991). *A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ)*. Ann Arbor, MI: University of Michigan.

Porsch, T., & Bromme, R. (2011). Effects of epistemological sensitization on source choices. *Instructional Science*, *39*, 805-819.

Richter, T., & Schmid, S. (2010). Epistemological beliefs and epistemic strategies in self-regulated learning. *Metacognition and Learning*, *5*, 47-65.

Rosenberg, S., Hammer, D., & Phelan, J. (2006). Multiple epistemological coherences in an eighth-grade discussion of the rock cycle. *The Journal of the Learning Sciences, 15,* 261-292.

Sandoval, W. A., Greene, J. A., & Bråten, I. (2016). Understanding and promoting thinking about knowledge: Origins, issues, and future directions of research on epistemic cognition. *Review of Research in Education, 40,* 457–496.

Schommer, M. (1990). Effect of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, *82*, 498–504.

Schommer, M. (1994). An emerging conceptualization of epistemological beliefs and their role in learning. In R. Garner & P. A. Alexander (Eds.), *Beliefs about text and instruction with text* (pp. 25-40). Hillsdale, NJ: Erlbaum.

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology*, *84*, 435.

Schommer-Aikins, M. (2002). An evolving theoretical framework for an epistemological belief system. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 103-118). Mahwah, NJ: Erlbaum.

Schommer-Aikins, M., & Hutter, R. (2002). Epistemological beliefs and thinking about everyday controversial issues. *The Journal of Psychology, 136*, 5-20.

Schraw, G., Bendixen, L. D., & Dunkle, M. E. (2002). Development and validation of the Epistemic Belief Inventory (EBI). In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 103-118). Mahwah, NJ: Erlbaum.

Schroeder, S., Richter, T., & Hoever, I. (2008). Getting a picture that is both accurate and stable: Situation models and epistemic validation. *Journal of Memory and Language*, *59*, 237-255.

Sinatra, G. M. (2005). The "warming trend" in conceptual change research: The legacy of Paul R. Pintrich. *Educational Psychologist*, *40*, 107-115.

Sinatra, G. M. (2016). Thoughts on knowledge about thinking about knowledge. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 479-492). New York, NY: Routledge.

Sinatra, G. M., Kienhues, D., & Hofer, B. K. (2014). Addressing challenges to public understanding of science: Epistemic cognition, motivated reasoning, and conceptual change. *Educational Psychologist, 49*, 123-138.

Stahl, E., & Bromme, R. (2007). The CAEB: An instrument for measuring connotative aspects of epistemological beliefs. *Learning and Instruction, 17*, 773-785.

Strømsø, H. I., & Bråten, I. (2014). Students' sourcing while reading and writing from multiple web documents. *Nordic Journal of Digital Literacy, 2*, 92-111.

Strømsø, H. I., Bråten, I., & Britt, M. A. (2010). Reading multiple texts about climate change: The relationship between memory for sources and text comprehension. *Learning and Instruction*, *20*, 192-204.

Strømsø, H. I., Bråten, I., & Britt, M. A. (2011). Do students' beliefs about knowledge and knowing predict their judgment of texts' trustworthiness? *Educational Psychology, 31,* 177-206.

Strømsø, H. I., Bråten, I., Britt, M. A., & Ferguson, L. E. (2013). Spontaneous sourcing among students reading multiple documents. *Cognition and Instruction, 31*, 176-203.

Trevors, G. J., Muis, K. R., Pekrun, R., Sinatra, G. M., & Winne, P. H. (2016). Identity and epistemic emotions during knowledge revision: A potential account for the backfire effect. *Discourse Processes, 53,* 339-370.

Veenman, M. V., Van Hout-Wolters, B. H., & Afflerbach, P. (2006). Metacognition and learning: Conceptual and methodological considerations. *Metacognition and Learning, 1*, 3-14.

Winne, P. H. (2014). Issues in researching self-regulated learning as patterns of events. *Metacognition and Learning, 9*, 229-237.

Wood, P., & Kardash, C. (2002). Critical elements in the design and analysis of studies of epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 231-260). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Bridging Text

Chapter 2 presented a comprehensive and critical review of the literature on epistemic cognition. The objectives that guided that review were (1) to identify contemporary and integrated conceptualizations of epistemic cognition that best describe the phenomenon of epistemic cognition in complex informational situations, and (2) to identify affordances and limitations of methods employed to measure epistemic cognition that can best guide future research in advancing knowledge on epistemic cognition. On the basis of this review, it was identified that epistemic cognition is multifaceted and includes, in addition to epistemic beliefs, underexplored facets such as epistemic aims, epistemic strategies, and epistemic experiences, including epistemic emotions. Further, to advance research on epistemic cognition, two promising avenues were suggested. These included the investigation of mediation mechanisms to explain how epistemic cognition relates to important educational outcomes, and the use of sophisticated measurement methods to properly operationalize the aforementioned conceptual distinctions.

The following chapter presents two empirical investigations that follow these avenues. For these studies, a think-aloud protocol was used to collect verbal data on epistemic cognition, epistemic emotions, and learning strategies. These verbal data were used to assess a novel set of cognitive appraisals that are proposed to serve as antecedents to epistemic emotions (Study 1), and to assess the immediate (Study 1) and general (Study 2) consequences of epistemic emotions on self-regulated learning strategies. In doing so, I sought to address the conceptual and methodological limitations identified above, namely in operationalizing the distinction between the different facets of epistemic cognition, thus making it possible to empirically examine the relationship between epistemic beliefs and epistemic cognition, which constitutes one of the unique contributions of this chapter.

Chapter 3

Manuscript 1

Exploring the Antecedents and Consequences of Epistemic Emotions

Chevrier, M., Muis, K. R., Trevors, G. J., Pekrun, R., & Sinatra, G. M. (under review). Exploring the antecedents and consequences of epistemic emotions. *Learning and Instruction*.

Abstract

Across two studies, we evaluated a model that proposed relations between epistemic cognition, epistemic emotions, self-regulatory strategies, and learning of complex contradictory content. For Study 1, to capture epistemic cognition, epistemic emotions, and self-regulatory strategies, 114 undergraduate students thought out loud while reading conflicting texts about climate change. Protocol analysis revealed that epistemic aims, epistemic congruity, and appraisals of novelty and complexity of information served as antecedents to epistemic emotions. State-transition analyses revealed that curiosity increased the likelihood of metacognitive self-regulation, and that surprise decreased the likelihood of rehearsal and increased the likelihood of critical thinking. For Study 2, participants reported epistemic beliefs, read contradictory texts about climate change, reported emotions experienced while reading, and completed a knowledge assessment task. Path analyses revealed full mediation between epistemic beliefs, epistemic emotions, learning strategies and learning achievement. More constructivist beliefs about the complexity, uncertainty and justification of knowledge predicted more curiosity, less surprise, and less boredom. Curiosity, in turn, predicted critical thinking, knowledge elaboration and rehearsal strategies. Finally, critical thinking and rehearsal positively predicted learning achievement. Implications for research on epistemic cognition, epistemic emotions, and self-regulated learning are discussed.

Keywords: epistemic emotions, epistemic cognition, learning strategies, learning achievement.

1. Introduction

Understanding the socio-scientific issues we face today is of critical importance, as citizens are called upon to make decisions about these increasingly pressing matters. Issues such as the benefits of genetically modified organisms, the risks associated with childhood vaccines, or the causes and consequences of climate change have emerged as some of the most complex and controversial topics (Funk & Kennedy, 2016; Hulme, 2009; Kata, 2012; Weber & Stern, 2011). In educational settings, students' understanding of socio-scientific topics is complicated by a set of social and psychological factors. First, such topics are often challenging to understand given their complex nature (e.g., Weber & Stern, 2011). To successfully learn about socio-scientific topics, learners need to engage in skilled *self-regulated learning*, which includes setting learning goals, using strategies, and closely monitoring progress towards learning goals. Second, the falsely balanced media coverage of socio-scientific topics (Boykoff & Boykoff, 2004) can result in erroneous conceptions about these topics, like the belief that there exists a connection between vaccination and autism (Kata, 2012) or the belief that climate change is not caused by mankind's activities (Corbett & Durfee, 2004). As such, individuals need to engage in *epistemic cognition* to evaluate and select reliable sources of information, judge knowledge claims, and integrate divergent perspectives.

Third, socio-scientific topics are often rife with *emotions*, especially when students are confronted with learning content that exposes uncertainty and controversy about these topics (Broughton, Pekrun, & Sinatra, 2012; Heddy, Danielson, Sinatra, & Graham, 2017). Previous research has shown that when learning about a topic such as climate change, students can be driven more by affect and values than by evidence (Slovic, 1987) and respond to uncertainty in ways that are more emotional than analytic (Loewenstein, Weber, Hsee, & Welch, 2001). An emerging body of literature suggests that emotions are a critical component of learning about controversial socio-scientific topics (Muis et al., 2015; Muis & Singh, 2018). Recently, Muis et al. (2015) put forth a framework of epistemic emotions where they propose that individuals' epistemic beliefs, i.e., beliefs about knowledge and knowing, predict the kinds of epistemic emotions (emotions that arise as a function of the cognitive qualities of information and the processing of that information [Pekrun & Stephens, 2012]) experienced during complex learning. For example, learners who espouse epistemic beliefs that are different from the epistemology of science (e.g., who believe that knowledge is simple and certain) may experience confusion, anxiety, or frustration when they encounter complex and conflicting scientific knowledge. In contrast, those who believe that knowledge is complex and evolving may experience curiosity and enjoyment. These epistemic emotions may then facilitate or constrain self-regulated learning. Given these implications, there are pressing questions with regard to the impact of epistemic emotions when learning about complex socio-scientific topics, particularly when knowledge is presented as controversial or contradictory.

Bieg, Goetz, and Hubbard (2013) argued that one productive way to advance this line of research is by investigating the antecedents of emotions, as they can inform the development of interventions designed to foster positive emotions in the classroom. Further, to fully understand the role of epistemic emotions in self-regulated learning, Muis and colleagues (2015) recommended examining how learners immediately attend and respond to emotions as learning unfolds. As such, the primary purpose of this research was to respond to these calls and extend Muis et al.'s (2015) framework by investigating the antecedents and consequences of epistemic emotions on learning processes and outcomes during complex learning. In the following section, we review relevant theoretical and empirical work that guided the hypotheses of the current study.

2. Theoretical Frameworks

2.1. Epistemic Cognition

Individuals' thoughts and beliefs about knowledge and knowing have been a popular line of inquiry among educational psychologists. Research in this field has largely focused on individuals' beliefs about knowledge and knowing, i.e., *epistemic beliefs*. Epistemic beliefs are typically described as multidimensional and ranging from a less constructivist viewpoint to a more constructivist viewpoint along four dimensions. Hofer and Pintrich (1997) defined four dimensions of epistemic beliefs: (1) the *certainty* of knowledge, ranging from the belief that knowledge is certain to the belief that knowledge is tentative; (2) the *simplicity* of knowledge, ranging from the belief that knowledge is as simple as a list of facts, to the belief that knowledge is more like a complex network of interrelated propositions; (3) the *source* of knowledge, ranging from the belief that knowledge is handed down by authority, to the belief that knowledge is actively constructed through reason and logic; and, (4) the *justification* for knowing, ranging from the belief that knowledge is unquestionably justified through authoritative or expert sources, to the belief that knowledge is justified by rules of inquiry, including the critical evaluation of claims and the integration of multiple perspectives. Typically, more constructivist epistemic beliefs have been empirically linked to greater academic performance compared to less constructivist epistemic beliefs (Schommer, Crouse, & Rhodes, 1992) via use of learning strategies (Schommer, 1990). Specifically, learners who espouse more constructivist epistemic beliefs are more likely to use deep learning strategies, such as knowledge elaboration and critical thinking, whereas those who espouse less constructivist epistemic beliefs are more likely to resort to shallow learning strategies, such as rehearsal (Muis, 2007).

A growing body of literature emphasizes a wider set of cognitive processes associated with the nature of knowledge and the process of knowing that help to deal with controversial information. These include processes such as setting *epistemic aims* for learning, as well as using *epistemic strategies* to evaluate and integrate sources of information or establish justification for knowing. Together with epistemic beliefs, these processes constitute facets of *epistemic cognition* (Greene, Azevedo, & Torney-Purta, 2008; Greene, Sandoval, & Bråten, 2016; Kitchener, 1983; Muis & Singh, 2018). Specifically, Chinn, Buckland and Samarapungavan (2011) define epistemic aims as learning goals related to knowledge construction or problem solving that range from the aim to obtain simple and certain answers to the aim to acquire justified beliefs. Epistemic aims are attained via the use of epistemic strategies. Similar to learning strategies described in models of self-regulated learning (Greene & Azevedo, 2009; Winne & Hadwin, 1998), epistemic strategies are a subcategory of learning strategies that draw on epistemic beliefs and prior knowledge to address knowledge- and knowing-related issues (Richter & Schmid, 2010). Epistemic strategies include, for instance, sourcing strategies (i.e., evaluating the trustworthiness of sources [Barzilai & Zohar, 2012; Strømsø, Bråten, & Britt, 2010]), justification strategies (i.e., evaluating whether knowledge claims are well justified; providing reasons for evidence [Greene et al., 2014; Richter & Schmid, 2010]), and integration strategies (i.e., comparing and contrasting multiple sources; providing explanation for differences between various perspectives [Barzilai & Zohar, 2012; Bråten, Britt, Strømsø, & Rouet, 2011; Kienhues, Stadler, & Bromme, 2011]). As such, epistemic cognition draws on epistemic beliefs to deploy epistemic strategies directed at epistemic aims.

There is a growing body of evidence attesting to the importance of adaptive epistemic cognition for learning outcomes, including multiple-text comprehension (Bråten, Britt, Strømsø,

& Rouet, 2011), digital literacy (Strømsø & Kammerer, 2016), and critical thinking (Greene & Yu, 2016), among others. However, a recent meta-analysis by Greene, Cartiff and Duke (2018) has shown that the effect of epistemic cognition (measured predominantly as epistemic beliefs) on learning achievement is significant but small, $r = .162$. One possible explanation for this small effect may be the existence of mediators that intervene in the relationship between epistemic cognition and learning. Indeed, as Bråten et al. (2011) argued, much more research is needed to understand the mediational mechanisms by which epistemic cognition relates to learning processes and outcomes. They further note that emotions may be one such mediator. If researchers are to expand conceptualizations of epistemic cognition to include a broader range of epistemic processes, it is imperative that we also consider the emotions that directly relate to knowledge and knowing, such as curiosity or confusion (Pintrich, Marx, & Boyle, 1993). As such, Muis et al. (2015) proposed that epistemic emotions may mediate relations between epistemic cognition and self-regulated learning. We next delineate the construct of epistemic emotions.

2.2. Epistemic Emotions

Emotions are pervasive in academic contexts and are posited to affect individuals' learning and achievement (Op't Eynde, De Corte, & Verschaffel, 2007; Perkun & Perry, 2014). In his control-value theory of achievement emotions, Pekrun (Pekrun, 2006; Pekrun & Perry, 2014) proposed that appraisals of perceived control and subjective task value serve as antecedents to emotions in academic contexts. Within this framework, emotions are categorized according to their valence and level of activation. In terms of valence, positive (i.e., pleasant) emotions such as enjoyment or pride can be distinguished from negative (i.e., unpleasant) emotions such as anxiety or frustration. Further, the level of activation generated by emotions also serves as an important distinction, which contrasts activating emotions, such as anxiety and anger, with deactivating emotions, such as contentment or boredom. Academic emotions can further be grouped according to their object focus (Pekrun, 2006): achievement emotions relate to success or failure of an achievement task; topic emotions relate to the content of what is being learned; social emotions are turned towards others and include, for instance, envy and admiration. Recently, educational psychologists have taken interest in a fourth category of academic emotions, that is, epistemic emotions. We define epistemic emotions as emotions that have, as an object focus, the knowledge-generating aspects of learning that arise as a result of cognitive and epistemic qualities of information and the processing of that information (Brun & Kuenzle, 2008; Morton, 2010; Muis, Chevrier, & Singh, 2018; Muis et al., 2015; Pekrun & Stephens, 2012). In the context of complex and conflicting knowledge, epistemic emotions may include surprise, curiosity, enjoyment, confusion, frustration, anxiety, and boredom (Muis et al. 2015; Pekrun, Vogl, Muis, & Sinatra, 2017).

Surprise involves the perception of a discrepancy between incoming information and prior knowledge, expectations, or beliefs (Scheffler, 1977). Discrepancies are events that cause cognitive disequilibrium, which D'Mello and Graesser (2012) define as a state of uncertainty that occurs when individuals are confronted with impasses, contradictions, anomalous events, dissonance or incongruities. Individuals may experience surprise when they encounter information that they did not expect (Meyer, Reisenzein, & Schützwhol, 1997; Reisenzein & Studtmann, 2007) or that they cannot explain (Foster & Keane, 2015). According to Munnich and Ranney (2018), surprise serves as a metacognitive signal of the level of difficulty of integrating surprising information to an existing mental representation. They suggest that when surprise has a low intensity, individuals may readily assimilate new information into current mental structures. However, when surprise is high, discrepant information may be treated as an anomaly or regarded as implausible, possibly resulting in a rejection of the information. Low-intensity surprise may be experienced as pleasant whereas high-intensity surprise may be experienced as unpleasant; as such, surprise is considered a neutral emotion.

Curiosity, on the other hand, arises out of an information gap or a discrepancy between what one knows and what one wants to know, and may motivate individuals to seek, obtain, and make use of new knowledge (Berlyne, 1954; Litman, 2005; Loewenstein, 1994). Silvia (2010) proposed that curiosity arises when discrepant information is perceived as highly novel and complex, yet comprehensible. Litman and colleagues (Litman, 2005; 2008; Lauriola, Litman et al., 2015) describe two types of dispositional tendencies to experience and express epistemic curiosity: an interest type and a deprivation type. Interest-type curiosity is described as a desire for new information that is expected to increase pleasant feelings of situational interest, whereas deprivation-type curiosity is defined as a motive to reduce the unpleasant experience of uncertainty or knowledge deprivation. As such, curiosity can be experienced as either pleasant or unpleasant and therefore, like surprise, can be considered a neutral emotion. Empirical studies have systematically found that curiosity positively relates to learning, including exploratory behaviors and greater learning (Berlyne, 1954; Litman, 2005; Loewenstein, 1994; Lowry & Johnson, 1981), with deprivation-type curiosity leading to even higher levels of exploration than interest-type curiosity (Litman, Hutchins & Russon, 2004). While calls have been made to include and distinguish both interest-type and deprivation-type curiosity in emotion research (e.g., Jirout & Klahr, 2012), for the current study, we conceptualize and measure the interest type of curiosity.

Confusion is conceived as resulting from appraisals of uncertainty stemming from novelty, complexity, conflict, or unfamiliarity (Ellsworth, 2003). When discrepant information is highly novel and complex, and also highly incomprehensible, confusion may arise (Silvia, 2010). D'Mello and Graesser (2012) argue that confusion is central to complex learning activities such as problem-solving and generating cohesive arguments. Confusion is expected to be beneficial to learning because it can help individuals focus attention on the anomaly or discrepancy, and motivate learners to effortfully deliberate, problem solve, and restructure their cognitive structures to resolve the confusion.

When confusion is resolved, epistemic enjoyment may ensue (D'Mello & Graesser, 2012). Enjoyment is a positive emotion that can further be experienced when curiosity is satisfied (Litman & Jimerson, 2004), problems are solved, or inductively formed hypotheses are successfully validated (Brun & Kuenzle, 2008). When problems cannot be solved, lasting confusion may transition into epistemic frustration if the focus is on the lack of resolution (D'Mello & Graesser, 2012). Similar to confusion, frustration is a negative activating emotion, but is unlikely to yield any of the learning benefits associated with confusion (D'Mello & Graesser, 2012). Indeed, frustration is an intense emotion that can overtake the cognitive system (Rosenberg, 1998), leaving learners with little cognitive energy for deep or creative problem solving. Another negative activating emotion is anxiety. Epistemic anxiety can arise when new information is highly inconsistent with prior knowledge or with one's beliefs. When individuals begin to doubt their beliefs, epistemic anxiety may ensue. High anxiety can be detrimental to learning, but philosophers argue that doubt about one's propositions is necessary to motivate learners to "struggle after belief" and into inquiry (Pierce, 1992, p. 115; see also Hookway, 2008). Lastly, boredom is a negative deactivating emotion related to low arousal, low motivation, and a desire to escape the situation (Hubbard, 2019). Different types of boredom are described by Goetz, Frenzel, Hall, Nett, Pekrun, and Lipnevich (2014), including indifferent, calibrating, searching, reactant, and apathetic boredom, which reflect not only different intensities of boredom, but also a different motivational experience associated with coping with boredom. Epistemic boredom, specifically, is likely to arise when unsuccessful attempts at problem-solving turn persistent frustration into disengagement (D'Mello & Graesser, 2012).

Epistemic emotions represent a type of emotion that is understudied relative to other academic emotions such as test anxiety (Zeidner, 1998). However, epistemic emotions are posited to serve important functions in learning, as delineated above. Given these implications, it is crucial to better understand the role that epistemic emotions may play in facilitating or constraining learning, and how these emotions relate to other facets of epistemic cognition, such as epistemic beliefs. Muis and colleagues (2015) proposed a model that threads together theories of self-regulated learning, epistemic beliefs, and epistemic emotions. We next present Muis et al.'s (2015) integrated model.

2.3. Muis et al.'s (2015) Cognitive Incongruity Model

To explain the role of epistemic emotions in epistemic cognition and self-regulated learning, Muis et al. (2015) proposed a theoretical model that situates epistemic emotions as a mediational mechanism between epistemic beliefs and self-regulated learning. The model described by Muis et al. (2015) applies to complex learning situations, that is, situations that require a complex coordination of cognitive, metacognitive, affective and motivational processes to reason, problem solve, integrate information, or draw reasonable conclusions. Adding to perceived control and task value as antecedents to emotions (Pekrun, 2006; Pekrun & Perry, 2014), Muis and colleagues (2015) proposed that epistemic beliefs may be a logical antecedent to epistemic emotions given the focus of these emotions on knowledge and knowing. Broadly, Muis and colleagues' model embeds two chief hypotheses: first, that epistemic beliefs, serve as one antecedent to epistemic emotions; and second, that epistemic beliefs predict self-regulated learning via epistemic emotions. Muis et al.'s (2015) predictive model is illustrated in Figure 1. Muis et al. (2015) proposed that learning about a complex and controversial socio-scientific topic that presents conflicting claims is a context that can make salient the complex and uncertain nature of scientific knowledge. Engaging in such a context activates learners' epistemic beliefs (Muis, 2007) and triggers appraisals of epistemic congruity whereby learners evaluate the characteristics of information against the backdrop of their epistemic beliefs. For example, a learner who believes that knowledge is complex, tentative, actively constructed, and justified via critical thinking (i.e., more constructivist epistemic beliefs) should experience epistemic congruity[1] when presented with multiple or seemingly divergent perspectives on an issue. Muis et al. (2015) proposed that epistemic congruity contributes to the arousal of positive epistemic emotions like interest-type curiosity and enjoyment. Inversely, an individual who believes that knowledge is simple, certain, passively constructed and justified via personal experience or unevaluated evidence (i.e., less constructivist epistemic beliefs) should experience epistemic incongruity when encountering conflicting claims and perspectives. Epistemic incongruity is a state of dissonance that may pose a threat to a learner's epistemic identity (Bendixen & Rule, 2004) and trigger surprise and negative emotions like confusion, anxiety, frustration, or boredom. To illustrate, a learner who believes that knowledge is simple and certain, and that knowledge claims are justified via direct observation or handed down from authorities may be surprised or confused when presented with complex and conflicting scientific claims on a scientific topic. The incongruence between beliefs and context may be ignored at first; however, if the learner is repeatedly exposed to discrepant information, the learner's beliefs may be shaken and anxiety may arise (Bendixen & Rule, 2004). Frustration may occur when an epistemic perspective is perceived as unacceptable, and boredom may ensue when prolonged frustration turns into disengagement (D'Mello et al., 2014). Inversely, an individual who believes that knowledge is complex and tentative, and that knowledge claims are formed of multiple perspectives and justified via an inquiry process, is likely to experience epistemic congruence when reading complex and conflicting scientific information. They may feel curious when encountering new information or experience joy when epistemic aims are achieved.

Muis et al. (2015) proposed that epistemic emotions predict learning strategies and, in turn, learning achievement. On the basis of prominent models of self-regulated learning (Winne, 2001; Muis, 2007) and empirical research on learners' self-regulated learning strategies during complex learning (Azevedo, Cromley, & Seibert, 2004; Greene & Azevedo, 2009), we consider deep learning strategies as those that involve learners' attempts to integrate new ideas with prior knowledge (i.e., knowledge elaboration), evaluate and integrate ideas (i.e., critical thinking), or metacognitively engage (e.g., self-questioning, making judgments of learning, monitoring strategy use) in flexible and creative ways. In contrast, we consider shallow learning strategies as more rigid strategies that lead to superficial processing of information, like simple rehearsal for memorization. This classification is consistent with Muis et al.'s (2015) work and other empirical work on self-regulated learning and conceptual change (e.g., Dole & Sinatra, 1998; Franco et al., 2012; Pintrich et al., 1991; Stathopoulou & Vosniadou, 2007). For relations between epistemic emotions and learning strategies, Muis et al. (2015) proposed that curiosity and enjoyment facilitate the use of deep learning strategies, whereas negative activating emotions such as anxiety and frustration lead to shallow learning strategies (see Pekrun &

Stephens, 2012 for a review of supporting evidence). Further, surprise and confusion should relate to metacognitive self-regulation, and a deactivating emotion like boredom should impair the use of any learning strategies. Finally, for relations between learning strategies and learning achievement, following previous research (Franco et al., 2012; Greene & Azevedo, 2009), Muis et al. (2015) proposed that deep learning strategies are more likely to positively predict learning outcomes, whereas shallow learning strategies are more likely to negatively predict learning outcomes.

Muis et al. (2015) conducted an empirical study to test their theoretical framework. Four hundred thirty-nine undergraduate students from large universities across three countries first took a prior knowledge test on climate change, reported their epistemic beliefs about climate change on the Topic-Specific Epistemic Beliefs Questionnaire (TSEBQ; Bråten & Strømsø, 2009), then read four conflicting texts on the topic of climate change. After reading each text, learners reported emotions experienced during reading on the Epistemic Emotions Scales (EES; Pekrun, Vogl, Muis, & Sinatra, 2017). After studying all texts, participants reported learning strategies used on the Motivated Strategies for Learning Questionnaires (MSLQ: Pintrich, Smith, Garcia, & McKeachie, 1993), and then completed a knowledge verification task to measure learning achievement. Results showed that a belief in complex knowledge predicted lower levels of confusion, anxiety, and boredom, and a belief in tentative knowledge predicted lower levels of anxiety and frustration. Further, a belief in the active construction of knowledge predicted lower levels of confusion. Lastly, a belief in the justification for knowing via critical evaluation predicted higher levels of enjoyment and curiosity, and lower levels of boredom. Counter to their hypotheses, surprise was not predicted by any belief dimension. For relations between epistemic emotions and learning strategies, results showed that curiosity and enjoyment predicted critical thinking, knowledge elaboration, and metacognitive self-regulation, and anxiety and frustration predicted simple rehearsal. Boredom was negatively related to all learning strategies.

However, a few counter-hypothetical results were observed, namely that confusion positively predicted metacognitive self-regulation and that surprise negatively predicted critical thinking. In terms of relations between learning strategies and learning achievement, both critical thinking and knowledge elaboration positively predicted learning achievement. Counter to predictions, metacognitive self-regulation negatively predicted learning achievement. Overall, results showed that epistemic beliefs served as antecedents to epistemic emotions and these, in turn, mediated relations between epistemic beliefs and learning strategies. Moreover, unexpectedly, results showed that curiosity, enjoyment, and confusion predicted lower learning achievement via metacognitive self-regulation. Given a number of unexpected results, further empirical investigation into Muis et al.'s (2015) model is warranted.

2.3.1 Proposed extensions to Muis et al.'s (2015) model

2.3.1.1. Antecedents of epistemic emotions. Emotion appraisal theorists (Ellsworth & Scherer, 2003; Lazarus, 1991; Moors, Ellsworth, Scherer, & Frijda, 2013) proposed that cognitive appraisals about how events in the world relate to one's beliefs, goals, values or knowledge constitute the cause of an emotion. These appraisals are often quick and unconscious, but can also be less automated (Moors et al., 2013), and explain why individuals may experience very different emotions in response to similar stimuli (Ellsworth, 2013). Muis et al. (2015) proposed that appraisals of epistemic (in)congruity serve as antecedents to epistemic emotions. Drawing from the literature on knowledge-related emotions, we propose two additional types of appraisals that may serve as antecedents to epistemic emotions: appraisals of *information novelty and complexity* and appraisals of *achievement of epistemic aims* (see Muis et al., 2018). First, when they encounter information that is discrepant with prior knowledge or recently processed information, learners may appraise the extent to which new information fits with what they know or expect (i.e., appraisal of novelty). Further, individuals may appraise the extent to which they can understand new information (i.e., appraisals of complexity). When incoming information is deemed unexpected or unexplainable, surprise may arise (Foster & Keane, 2015; Meyer et al., 1997). If learners judge that incoming information is not too complex and that they have the cognitive and metacognitive resources to resolve the discrepancy, curiosity may arise; however, if they judge that the information or task is too complex to be resolved, confusion may arise (D'Mello et al., 2014; Kang et al., 2009; Silvia, 2010). Second, following Muis (2007) and Chinn et al. (2011), individuals may set epistemic aims to apprehend to-be-learned knowledge and conduct appraisals of achievement of epistemic aims as learning unfolds. When epistemic aims are attained, enjoyment may arise (Brun & Kuenzle, 2008; Muis et al., 2018). However, if epistemic aims are blocked, individuals may experience surprise, confusion, frustration, anxiety, or boredom (D'Mello et al., 2014; Silvia, 2010). Although these mechanisms for emotional arousal have been proposed in the literature, we are the first to empirically examine whether appraisals of epistemic congruence, appraisals of information novelty and complexity, and appraisals of the attainment of epistemic aims serve as antecedents to epistemic emotions.

2.3.2.2. Consequences of epistemic emotions. Muis et al.'s (2015) model can be tested at a number of levels of granularity. Muis and colleagues tested whether epistemic beliefs reported before learning related to various epistemic emotions during learning, and to various learning strategies used over a learning session. It can be argued that this analysis constitutes a coarse level of granularity. At a finer level of granularity, the model predicts that specific cognitive appraisals serve as antecedents to specific epistemic emotions, and further predicts that these emotions have proximal consequences for the enactment of specific learning strategies. To test the model at this level, methods have to be used that allow the measurement of processes that are dynamic and changing at a fine level of granularity, such as online measures.

According to Schraw (2010), online measures are measurements taken during learning, and can be contrasted with offline measures, which are measurements taken before or after learning. Online measures can gather data unobtrusively (e.g., reading times, trace logs) or require learners' conscious attention (e.g., think-aloud protocols, inserted quiz). On the other hand, common offline measures include self-report questionnaires that use Likert-type scales to measure beliefs or behaviors. When it comes to epistemic beliefs, self-report instruments have been criticized for their low internal consistency (see DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008; Greene et al., 2008). The same can be said of self-regulated learning self-report instruments. Specifically, prior work has shown that learners are poor at reporting the actual frequency with which they use particular self-regulatory strategies (Kitchener, 1983; Winne, Jamieson-Noel, & Muis, 2002). To address these issues, researchers have suggested using trace methodologies such as think-aloud methods to capture traces of epistemic cognition and self-regulated learning (Greene et al., 2010; Winne et al., 2002). Think-aloud protocols are said to provide rich information about online processes and further reveal the temporal deployment of processes as they unfold, one after the other (Charter, 2003; Schraw, 2010; Winne et al., 2002).

There certainly exists another finer level of granularity at which Muis et al.'s (2015) model could be tested, namely by manipulating epistemic cognition and emotions to trigger the predicted transitions. However, before more systematic manipulations of antecedents can be tested, there is a need to clearly identify the antecedents of epistemic emotions and to explore transitions between emotions and cognition/metacognition as they spontaneously emerge. To fill this gap in the literature, we conducted research that we present as two studies: The first study explores the incidence of epistemic emotions as they naturally arise during learning of complex and conflicting knowledge, and the consequences of epistemic emotions for learning. The second study tests Muis et al.'s (2015) model using think-aloud data that reflects enacted self-regulatory processes during learning. We next present the research questions and hypotheses that guided our investigations.

3. The Current Studies

The purpose of the present research was to evaluate and extend Muis et al.'s (2015) integrated framework across two studies. The purpose of Study 1 was to explore the antecedents and consequences of epistemic emotions during learning of complex and conflicting knowledge. A first objective was to explore the role and relative importance of three proposed antecedents of epistemic emotions, and to assess whether variability in antecedents resulted in differential consequences for learning. A second objective was to explore the moment-to-moment consequences of epistemic emotions on learning processes by calculating the likelihood of state transitions.

3.1. Study 1 Research Questions and Hypotheses

For Study 1, we asked the following research questions: (1) What proportion of epistemic emotions are related to epistemic (in)congruity compared to information novelty and complexity, and the blockage or attainment of epistemic aims? (2) Do epistemic emotions increase the likelihood of a transition into subsequent learning strategies during learning? (3) Are there variations in these relations as a function of epistemic emotion antecedent?

For Research Question 1, on the basis of reviewed literature, we hypothesized that appraisals of epistemic congruity, appraisals of information novelty and complexity, and appraisals of the attainment of epistemic aims are antecedent to epistemic emotions. Given that no prior research has examined multiple antecedents of epistemic emotions in a single study, we did not have a specific hypothesis for the proportions in which these various antecedents may trigger epistemic emotions in the context of learning complex and conflicting knowledge. For Research Question 2, drawing from Muis et al.'s (2015) model, we hypothesized the following transitions (see Figure 1): curiosity and enjoyment will increase the likelihood of a transition into knowledge elaboration, critical thinking, or metacognitive self-regulation; frustration and anxiety will increase the likelihood of a transition into rehearsal; surprise and confusion will increase the likelihood of a transition into metacognitive self-regulation; and boredom will decrease the likelihood of a transition into any learning strategy.

For transitions between epistemic emotions and epistemic cognition, previous theoretical and empirical work suggests that epistemic cognition may occur before and after epistemic emotions (see Muis et al., 2018). Recall that we define epistemic cognition as the activation of epistemic beliefs, the setting of epistemic aims and the use of epistemic strategies. According to Muis's (2007) framework on the role of epistemic beliefs in self-regulated learning, epistemic beliefs are activated in the very first phase of self-regulated learning, as learners generate a task definition; epistemic beliefs are thus expected to arise temporally before epistemic emotions. Epistemic aims, like other learning goals, are set during the second phase of self-regulated learning, but can temporally occur at any point during learning, as phases are loosely sequenced (Muis, 2007). Given that no prior work has been conducted to examine whether epistemic emotions arise before or after epistemic aims are set, we did not have a hypothesis with regard to the temporal sequencing between epistemic aims and epistemic emotions. Lastly, like learning strategies, epistemic strategies arise during the enactment phase (third phrase) of Muis's (2007) model of self-regulated learning. By analogy, we hypothesized that epistemic emotions may have consequences for the use of epistemic strategies. For instance, a learner who has activated the belief that scientific knowledge is complex, who then encounters conflicting claims may feel curious, set the epistemic aim to form justified knowledge on the topic, and use justification strategies to generate integrated knowledge. In sum, drawing from Muis's (2007) model of epistemic beliefs and self-regulated learning, and on the basis of the reasoning elaborated above, we hypothesized that epistemic cognition would increase the likelihood of a transition into epistemic emotions, and that epistemic emotions would increase the likelihood of a transition into epistemic cognition.

Finally, for Research Question 3, we did not have a specific hypothesis, but sought to explore whether differences in subsequent states occurred as a function of epistemic emotion antecedent. This question was exploratory in nature as no prior work to date has empirically examined the relations between antecedents and consequences of epistemic emotions.

3.2 Study 2 Research Questions and Hypotheses

In Study 2, we sought to verify whether results obtained by Muis et al. (2015) could be replicated by conducting a path analysis to test relations between epistemic beliefs, epistemic emotions, learning strategies and learning achievement, using verbalized learning strategies instead of self-reported data. We formulated Research Question 4 as follows: What are the predictive relations between epistemic beliefs, epistemic emotions, self-regulatory learning strategies, and learning achievement? Figure 1 presents Muis et al.'s (2015) hypothesized model, with prior knowledge included as a covariate.

4. Study 1

4.1. Method

4.1.1. Participants

One hundred fourteen undergraduate students from multiple disciplines (mathematics, science, engineering, psychology, education, business, among others) participated in this research. Participants were recruited from a large university in Canada through a classified advertisement system. They participated on a voluntary basis and received $15 as compensation. The sample was predominantly female (66.7 %, n = 76), white (54.4 %, n = 62), and English-speaking (63.2 %, n = 72). Participants were 21.3 years of age (SD = 2.9) on average.

4.1.2. Text materials

To create a complex learning situation where issues of knowledge are at stake, we presented learners with four conflicting texts on the causes and consequences of climate change, in conflicting pairs. The four texts were adapted from Strømsø et al. (2010; see Appendix A). The first text presented climate change as manmade and was written by an academic researcher. The text contained 314 words and had a Flesch-Kincaid Grade Level[2] equivalent to grade 12. The second text presented climate change as caused by astronomical conditions and was written by a professor in astrophysics. It contained 324 words and had a Flesch-Kincaid reading level equivalent to grade 10. The third text presented negative consequences of climate change with a geopolitical perspective and was written by a scientific journalist. It contained 356 words and had a Flesch-Kincaid reading level equivalent to grade 11. Finally, the fourth text presented positive consequences of climate change from an economical perspective and was written by a newspaper journalist. It contained 272 words and had a Flesch-Kincaid reading level equivalent to grade 12. The four texts were presented in a fixed linear order, as to make salient the conflicting nature of the texts. A pilot study was conducted with a sample of over 200 lay adults (no university students participated). The pilot was conducted online using a popular survey platform and was administered in part. Pilot data analysis revealed no effect of text order on outcomes variables of interest.

4.1.3. Data sources

4.1.3.1. Epistemic emotions. A think-aloud procedure was used to capture learners' epistemic emotions in real time. Protocols were first transcribed verbatim, which resulted in 803 pages (8687 lines) of text. The first author segmented each transcript into meaningful units of analysis, which consisted of a clause or sentence that enclosed a thought or idea. Each segment was then assigned a code, according to a coding scheme developed by the first three authors. The coding scheme was tested by the first three authors using three transcripts, and inter-rater reliability for the first round was established at 83%. All disagreements were resolved through discussion and were used to update the coding scheme. The first author then coded the remainder of the protocols. The third author then independently coded 15% of the remaining protocols coded by the first author, and final inter-rater reliability based on these protocols was established at 92%.

The development of the coding scheme for epistemic emotions was based on the EES (Pekrun et al., 2017) and, as such, focused on surprise, curiosity, enjoyment, confusion, frustration, anxiety, and boredom (see Table 1 for the complete coding scheme, including definitions and examples for each code). Emotions were further coded according to their object focus: Each emotion was classified as an epistemic, topic, achievement, or social emotion, according to Pekrun and Linnenbrink-Garcia's (2012) classification. Words and sentences uttered before or after an emotion were considered to determine an emotion's object focus. For instance, "The oil and gas deposits that are concealed there are estimated to amount to 30 per cent of the earth's deposits… Great! Now we can screw over the environment even more" was coded as topic frustration. In contrast, “This is pretty absurd, trying to find the positives in global warming by saying we’ll have access to more gas which we’ll then burn which will contribute further to global warming. This is a stupid article. It’s just kind of a strange view” was coded as epistemic frustration, where the learner is frustrated that the author presents such a perspective about climate change.

Epistemic emotions were further classified according to their antecedents. Table 2 includes descriptors and examples of epistemic emotions related to each antecedent. Words or sentences uttered before or after an emotion were taken into consideration to determine the type of appraisal that led to emotion arousal. For instance, “When particles that originate from previously exploded stars penetrate the atmosphere, they could affect the formation of low clouds. That’s kind of cool to know!” was coded as enjoyment related to information novelty. In contrast, “I mean, I like to learn about a different viewpoint,” was coded as enjoyment related to epistemic congruity.

4.1.3.2. Learning strategies. Learning strategies were captured through a think-aloud procedure. Protocols were then coded for learning strategies, using a coding scheme developed for this purpose. The coding scheme incorporated the four macro-level learning strategies proposed in the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich, Smith, Garcia, & McKeachie, 1993), which Muis et al. (2015) had used to measure learning strategies in their original study: rehearsal, knowledge elaboration, critical thinking, and metacognitive self-regulation. We also drew from Greene and Azevedo’s (2009) coding scheme for self-regulatory processes to generate more detailed descriptions for each learning strategy. For instance, the following micro-level processes were used to describe the macro-level code “metacognitive self-regulation”: making judgments of learning, emitting feelings of knowledge, monitoring progress towards goal, and monitoring use of strategy. Lastly, we included “prior knowledge activation” and “re-reading” from Greene and Azevedo’s coding scheme as they were deemed relevant to the present learning task. The final coding scheme comprised six learning strategies, including: prior knowledge activation, rereading, rehearsal, knowledge elaboration, critical thinking, and metacognitive self-regulation (see Table 1 for the complete coding scheme, including definitions and examples for each learning strategy). For analyses, following others (e.g., Dole & Sinatra, 1998; Pintrich et al., 1993; Stathopoulou & Vosniadou, 2007; Franco, et al., 2012) we grouped together learning strategies that required little cognitive manipulation (i.e., prior knowledge activation, rereading, rehearsal) as shallow learning strategies, and learning strategies that required more extensive cognitive manipulation (i.e., knowledge elaboration, critical thinking, metacognitive self-regulation) as deep learning strategies.

4.1.3.3. Epistemic cognition. Epistemic cognition was captured via a think-aloud procedure. Protocols were coded for epistemic cognition using a coding scheme developed for this purpose. The development of the coding scheme was based on Greene et al.’s (2014) coding scheme for epistemic cognition (see Table 1 for a complete list of codes, definitions, and examples). Final categories included epistemic beliefs, epistemic aims, as well as epistemic strategies. Three classes of epistemic strategies were included: sourcing strategies, integration strategies, and justification strategies.

4.1.4. Procedure

This research was conducted in a laboratory setting, with the assistance of a trained experimenter. Participants first signed a consent form that included a statement of the purpose of research. Participants next completed a demographics questionnaire, a prior knowledge test (used as a covariate in Study 2; see section 4.3.1), and the Topic-Specific Epistemic Beliefs

Questionnaire (TSEBQ; Bråten & Strømsø, 2009) to capture learners' epistemic beliefs (see section 4.3.2). Next, participants received instructions for the think-aloud protocol, as per Ericsson and Simon's (1993) recommendations: Participants were asked to think out loud while reading and studying, that is, to say everything that they were thinking and doing. If participants remained silent for more than three seconds, they were prompted by the experimenter to keep talking. We did not specifically instruct participants to express their emotions out loud.

A think-aloud practice was conducted prior to reading the experimental texts using two unrelated texts (approximately 150 words). After the practice texts, participants proceeded to reading the experimental texts. A blank space on the computer screen was reserved for note-taking while studying; however, participants were told they would not have access to their notes during the post-test. Participants were alerted to the conflicting nature of the task contained in the texts with the following information: "Two of the texts discuss the causes of climate change and were written by science experts. One expert claims that humans are responsible for climate change, whereas the other expert claims that changes to the climate are natural. The other two texts, written by journalists, focus on the pros and cons of climate change. Whereas one journalist reports on the pros of climate change, the other journalist reports on the cons of climate change." After having read each of the first three texts, participants completed a short version of the EES (Pekrun et al., 2017). Participants then completed the full EES after having read the fourth experimental text and completed a post-test to measure learning achievement. When the study was over, participants were thanked and received compensation. Debriefing information was offered to all participants: The experimenter provided verbal definitions for epistemic beliefs and epistemic emotions as well as explanations as to the choices of text and their order of presentation. In total, the experiment lasted approximately one hour. Instructions were scripted to ensure consistency in instructions across participants. For the purpose of Study 1, self-reported emotions and epistemic beliefs were not included in any analyses but were used for Study 2.

4.1.5. Analytical approach

To examine the consequences of epistemic emotions on cognitive and metacognitive learning processes, we conducted state-transition analysis to test for the likelihood of transitioning from a given emotional state to a subsequent learning strategy. State-transition analyses have been used in quantitative research to capture the temporal deployment of affective, cognitive and metacognitive states during learning (see Azevedo et al., 2010; D'Mello & Graesser, 2012; Poitras & Trevors, 2012; Witherspoon, Azevedo, & D'Mello, 2008). State-transition analysis is performed by creating a matrix of all the possible states (here, we considered emotions, epistemic cognition, and learning strategies) and entering the number of times learners transitioned from one state to the next based on coded trace data, such as data from think-aloud protocols. This results in a state-transition table that can be used to calculate the probability of transitioning from one emotion to a subsequent state.

The underlying assumption to our investigation is that emotions have consequences for learning processes and that this can be observed immediately after an epistemic emotion arises. We assumed that emotions and follow-up learning strategies were not independent from each other, such that the frequency with which a specific learning strategy followed a specific epistemic emotion would be greater than chance (i.e., if distributed randomly). To test whether a given transition occurred at a rate higher than chance, we created 2 x 2 contingency tables to compare the frequency distribution of specific transitions against a prior distribution of variables. We then conducted chi-squared tests to determine whether the likelihood of transitions was significantly greater than chance. For instance, suppose that across all participants, critical thinking was coded 100 times whereas other learning strategies were coded 900 times (for a total of 1000 learning strategies). Let us further suppose that frustration was followed by critical thinking 10 times across all participants, whereas frustration was followed by another learning strategy 90 times overall (for a total of 100 instances of frustration). The likelihood of critical thinking following frustration would then be equal to chance, given the prior distribution of frustration in the overall sample. However, for the same distribution of critical thinking, if frustration was followed by critical thinking 50 times and followed by another emotion 50 times, a transition from frustration to critical thinking would then by significantly greater than chance, as would be reflected by a significant chi-squared test.

4.2. Results

4.2.1. Antecedents of epistemic emotions

Prior to addressing Research Question 1, which concerned the antecedents of epistemic emotions, we first identified segments that represented meaningful emotions, epistemic cognition, or learning strategies, which resulted in 3301 coded segments. We then examined the object focus of each emotion to determine its type (i.e., achievement, social, epistemic, or topic). As shown in Table 3, think-aloud protocols contained a total of 267 instances of emotions: 77.53 % (n = 207) were epistemic emotions, 19.48 % (n = 52) were topic emotions, and 3 % (n = 8) were achievement emotions. Emotions with an epistemic focus included surprise (n = 86; 41.55 %), curiosity (n = 92; 44.44 %), enjoyment (n = 7; 3.38 %), confusion (n = 16; 7.73 %), and frustration (n = 6; 2.89 %). No instances of epistemic anxiety or epistemic boredom were identified; all instances of anxiety were topic anxiety, and all instances of boredom were achievement boredom.

We further classified epistemic emotions according to their antecedents (i.e., type of appraisal) and calculated the proportions in which each type of appraisal related to epistemic emotions. Table 4 shows that across 207 instances of epistemic emotions, 22.22 % (n = 46) were related to appraisals of epistemic (in)congruity, 76.81 % (n = 159) were related to appraisals of information novelty and complexity, and .97 % (n = 2) were related to the attainment of epistemic aims. Specifically, 10.46 % (n = 9) of instances of surprise related to epistemic (in)congruity, as did 31.52 % (n = 29) of instances of curiosity, 12.50 % (n = 2) of instances of confusion, and 100 % (n = 6) of instances of epistemic frustration. Moreover, 89.53 % (n = 77) of instances of surprise were related to information novelty and complexity, as were 68.48% (n = 63) of instances of curiosity and 87.50% (n = 14) of instances of confusion. Lastly, 28.57 % (n = 2) of instances of enjoyment related to epistemic aims. In response to our first research question, results showed that a greater proportion of epistemic emotions related to information novelty and complexity than to epistemic (in)congruity, and only a small proportion of epistemic emotions related to epistemic aims.

4.2.2. Transitions between epistemic emotions and learning strategies

To address Research Question 2, which concerned the sequential dynamics between epistemic emotions and other cognitive and metacognitive learning processes, we conducted state-transition analyses on the basis of the distribution of epistemic emotions, learning strategies, and epistemic cognition across think-aloud protocols. Table 5 presents the frequency of epistemic emotions, learning strategies, and epistemic cognition in think-aloud protocols. Table 6 presents the frequency of transitions from an epistemic emotion to all possible follow-up states. We considered learners' continued engagement with the learning material as a valid subsequent state ("continues to read"). To examine transitions from epistemic emotions to a subsequent learning strategy, we created multiple 2 x 2 contingency tables (Tables 7, 8, and 9) to test for statistical differences between observed frequencies and expected frequencies (see Section 4.1.5). Because chi-squared tests assume at least five cases in each cell, we could only test the statistical significance of transitions from curiosity and surprise to subsequent learning strategies. For transitions from curiosity to a subsequent learning strategy, we identified a trend that was approaching statistical significance that showed that curiosity was followed by metacognitive self-regulation more often than statistically expected, $\chi^2(1) = 3.62$, $p = .057$, as displayed in Table 7. Examples of this sequence included: “That’s interesting [*curiosity*]. I didn’t know that temperature dropping was a concern of global warming [*metacognitive self-regulation*]”, and “I find this really interesting [*curiosity*], because I never really hear about positive effects of global warming, I always hear about the negative effects [*metacognitive self-regulation*]”. These results are aligned with our hypothesis.

For transitions from surprise to a subsequent learning strategy, results showed that surprise was followed by rehearsal significantly less often than statistically expected, $\chi^2(1) = 4.54$, $p = .033$, as displayed in Table 8. Further, results showed that surprise was followed by critical thinking significantly more often than statistically expected, $\chi^2(1) = 14.56$, $p < .001$, as displayed in Table 9. An example of this sequence included: “Wow… [*surprise*] It’s putting people in danger basically more… And it’s probably going to keep rising as we go along if nothing really changes [*critical thinking*]” and “[A number of oceanographers fear highly uncomfortable side effects due to global warming…] What? Haha! [*surprise*] I think ‘highly uncomfortable’ is an understatement. People are going to die and like entire places where people live are going to be like under the ocean soon. I think that’s more than uncomfortable [*critical *thinking*].” Although this finding was unexpected, it is consistent with previous research, as will be discussed later.

4.2.3. Transitions between epistemic emotions and epistemic cognition

As part of Research Question 2, we explored how epistemic emotions sequentially related to epistemic cognition during learning. Epistemic cognition was meaningfully related to epistemic emotions in 13 cases, out of the 366 instances of epistemic emotions. For all 13 instances, epistemic cognition followed epistemic emotions. Two recurrent patterns were identified: an epistemic emotion was followed by a source evaluation (e.g., “Oh wow [*surprise*], another journalist [*source evaluation*]”), and an epistemic emotion was followed by an epistemic aim (e.g., “I find this very surprising [*surprise*] and I say I want to learn a lot more about it [*epistemic aim*]”). As will be elaborated in the discussion, this result suggests that epistemic strategies may be consequences of epistemic emotions, whereas epistemic beliefs and epistemic aims may be better construed as antecedents of epistemic emotions.

4.2.4. Variations in subsequent state as a function of epistemic emotion antecedent

To address Research Question 3**,** we explored whether the consequences of epistemic emotions on learning strategies varied as a function of antecedent. For curiosity to metacognitive self-regulation transitions, we identified 11 occurrences. Of the 11 instances, curiosity related to appraisals of information novelty and complexity nine times, versus two instances where curiosity related to appraisals of epistemic (in)congruity. In total, curiosity was related to information novelty and complexity 68.48 % (n = 63) of the time, whereas it was related to epistemic (in)congruity 31.52 % (n = 29) of the time. This difference was non-significant, $\chi^2(1) = .91$, $p = .340$. For surprise to rehearsal strategies transitions, we identified six occurrences. Of these six instances, surprise related to appraisals of information novelty and complexity five times whereas surprise was related epistemic (in)congruity only once. In total, surprise was related to information novelty and complexity 89.53 % (n = 77) of the time, whereas surprise related to epistemic (in)congruity 10.47 % (n = 9) of the time. This difference was non-significant, $\chi^2(1) = 2.46$, $p = .620$. For surprise to critical thinking transitions, we identified 18 occurrences. Of the 18 instances, surprise was related to appraisals of information novelty and complexity 14 times, whereas surprise was related to epistemic (in)congruity four times. This difference was also non-significant, $\chi^2(1) = 2.67$, $p = .102$, based on the distribution of surprise per antecedent in total. In light of these results, we inferred that the consequences of epistemic emotions on learning strategies were not a function of the type of appraisal that served as antecedent. These results are discussed in detail in the Discussion section.

5. Study 2

5.1. Method

5.1.1. Participants

The same sample was used for Study 2 as from Study 1 (see section 4.1.1.).

5.1.2. Text materials

All text materials were identical to Study 1 (see section 4.1.2.).

5.1.3. Data sources

5.1.3.1. Prior knowledge. Given established relations between prior knowledge and topic-specific epistemic beliefs (Bråten & Strømsø, 2009), we assessed learners' prior knowledge about climate change to use as a covariate. A 15-item multiple-choice test was adapted from Bråten, Strømsø, and Samuelstuen (2008) to assess participants' knowledge of content covered in the texts (see Appendix B). An example item was: "The greenhouse effect is due to (a) holes in the ozone layer, (b) increased use of nuclear energy, (c) increased occurrence of acidic precipitation, (d) streams of heat that do not get out of the atmosphere, or (d) the pollution of the oceans." One point was awarded for each correct answer. The final score consisted of a sum out of a maximum of 15. Given that the prior knowledge test covered a range of topics, an exploratory factor analysis (EFA) was conducted on the 15 items. Byrne (2005) recommends using EFA when researchers have no prior knowledge of the underlying factor structure of a measure, as opposed to a confirmatory factor analysis (CFA), which is appropriate to use when a factor structure is hypothesized a priori on theoretical grounds. Maximum likelihood with varimax rotation was conducted. Four dimensions were identified, which accounted for 42.89% of the variance. The four dimensions resulted in Cronbach's alphas of .63 (two items), .71 (four items), .73 (four items) and .76 (five items). Correlations between each of the four dimensions of prior knowledge and the variables in the model were very similar (i.e., within one one-hundredth). As such, to simplify tables and figures, only one coefficient is reported but note that all four dimensions were used in the analyses as covariates.

5.1.3.2. Epistemic beliefs. The TSEBQ was used to measure learners' epistemic beliefs about climate change (see Appendix C). Six items assessed beliefs about the simplicity/complexity of climate change knowledge (e.g., "Knowledge about climate change consists of highly interrelated concepts rather than an accumulation of facts"); six items assessed beliefs about the certainty/uncertainty of climate change knowledge (e.g., "The results of climate research are preliminary"); five items assessed beliefs about the source of knowing about climate change (e.g., "When I read about climate problems, I only stick to what the text expresses" [reversed]); and seven items assess beliefs about the justification for knowing about climate change (e.g., "To be able to trust knowledge claims in texts about issues concerning climate, one has to check various knowledge sources"). Participants rated items on a 10-point Likert scale, where a score of 1 (“I completely disagree”) indicates less constructivist epistemic beliefs and a score of 10 (“I completely agree”) indicates more constructivist epistemic beliefs.

Confirmatory factor analyses (CFA) using M*plus* 7.4 (Muthén & Muthén, 2012) revealed a poor fit of the data to the model (CFI = .87, RMSEA = .12, χ^2 = 613.49, df = 246, p < .001). Based on item loadings of less than |.30|, two items were removed from the simplicity/complexity scale, one was removed from the certainty/uncertainty scale, one was removed from the source scale, and one was removed from the justification scale. A second CFA revealed a good model fit (CFI = .94, RMSEA = .08, χ^2 = 377.89, df = 146, p < .001) (see Byrne, 2011). Standardized factor loadings for all dimensions ranged from .31 to .85, with the majority above .54. Cronbach’s alphas were as follows: .76 for the uncertainty subscale, .74 for the complexity subscale, .78 for the justification subscale, and .74 for the source subscale.

5.1.3.3. Epistemic emotions. The EES was used to measure participants’ epistemic emotions (see Appendix D). This questionnaire consisted of 21 items. Each item consisted of a single word describing one emotion, with three descriptors per emotion: surprise (e.g., “astonished”), curiosity (e.g., “inquisitive”), enjoyment (e.g., “happy”), confusion (e.g., “muddled”), frustration (e.g., “irritated”), anxiety (e.g., “nervous”), and boredom (e.g., “monotonous”). Participants were instructed to report emotions experienced while reading the texts. Participants rated each item on a 5-point Likert scale, ranging from 1 (“Not at all”) to 5 (“Very strong”). The descriptors of each emotion were averaged to represent each emotion overall. Cronbach’s alpha for subscales (i.e., individual emotions) ranged from .73 to .87.

5.1.3.4. Learning strategies. Learning strategies were captured via a think-aloud procedure[3]. Protocols were coded for learning strategies using a coding scheme developed for this purpose (see section 2.3.2).

5.1.3.5. Learning achievement. To parallel Muis et al.'s (2015) study, we focused on text comprehension as a measure of learning achievement. Text comprehension of the four experimental texts was assessed with a 21-item intra-text inference verification task (Royer, Carlo, Dufresne, & Mestre, 1996) adapted from Strømsø et al. (2010; see Appendix E). Because this task requires that learners construct an accurate mental model of the content, it can be used to distinguish deeper situational understanding from mere text retention (Royer et al., 1996). Each item consisted of a sentence constructed by combining information from two or more sentences in an experimental text to form a valid or invalid inference. For example, the sample item "Global warming may result in both cooling in Northern Europe and a higher average temperature on the earth" was constructed by combining the following sentences from the third text: "Global warming may also weaken the Gulf Stream and result in serious cooling in Northern Europe" and "[…] namely that global warming will raise the earth's average temperature." Learners were instructed to evaluate whether each item represented a valid or invalid inference by indicating "Yes" or "No." The test included 12 valid items and 9 invalid items that could be grouped into four subsets of questions that each related to one experimental text. One point was attributed for each correct answer, for a maximum of 21 points (scores were transformed into percentages for ease of interpretation). Reliability values were calculated for each subset of questions, and Cronbach's alpha values ranged from .70 to .73.

5.1.4. Procedure

The procedure for Study 2 was the same as for Study 1.

5.1.5. Analytical approach

To test the mediation model presented in Figure 1, we used Hayes and Preacher's (2013) PROCESS SPSS macro[4]. This macro is recommended for complex models as it controls for

Type I errors while maintaining high levels of power with smaller sample sizes (see Preacher & Hayes, 2008). Additionally, the bootstrap sampling method has no underlying distributional assumptions and, as such, is appropriate with our data (i.e., the think-aloud data were skewed) (see Hayes, 2013). Path analyses with 10,000 bootstrap resamples were performed in two steps with 90% confidence intervals, as they are considered appropriate for tests of mediation (Preacher, Zyphur, & Zhang, 2010).

5.2 Results

5.2.1. Preliminary analyses

Prior to conducting full analyses, each variable was examined for skewness, kurtosis, and outliers. All self-reported variables (i.e., epistemic beliefs and epistemic emotions) were within normal range, with absolute values of less than 3 for skewness and kurtosis (see Tabachnick & Fidell, 2013). However, all learning strategies variables (collected via think-aloud protocols) were positively skewed. Further, rehearsal and metacognitive self-regulation data were leptokurtic. Given that these variables represent behavioral frequencies with meaningful zero points, no transformations were performed. Means and standard deviations for all self-report variables and knowledge assessments are reported in Table 10. Correlations between variables are presented in Table 11.

5.2.2. Predictive relations between epistemic beliefs, epistemic emotions, learning strategies, and learning achievement

5.2.2.1 Effects of epistemic beliefs on epistemic emotions and learning strategies. To test for relations between epistemic beliefs, epistemic emotions, enacted learning strategies (as gathered via think-aloud protocol) and achievement as depicted in Figure 1 (Research Question 4), we conducted path analyses (see section 5.1.5) with the four prior knowledge subscales included as covariates for all variables. The final path model with significant standardized estimates is presented in Figure 2 (for simplicity, only one box is drawn for prior knowledge as path coefficients for all four subscale scores were equivalent). The first step in the analysis tested whether epistemic beliefs predicted epistemic emotions and learning strategies, with prior knowledge used as a covariate. The total effects model for this analysis was significant, $F(5, 101) = 3.45$, $p < .007$, $R^2 = .15$. As expected, belief in justification via inquiry positively predicted curiosity, $\beta = .24$, $t = 2.51$, $p = .007$, and enjoyment, $\beta = .27$, $t = -2.85$, $p = .003$, and negatively predicted frustration, $\beta = -.16$, $t = -1.64$, $p = .05$, and boredom, $\beta = -.24$, $t = -2.48$, $p = .005$. Further, a belief in the source of knowledge via active construction negatively predicted anxiety, $\beta = -.15$, $t = -1.74$, $p = .05$. However, counter to predictions, results revealed that belief in complex knowledge negatively predicted surprise, $\beta = -.17$, $t = 1.71$, $p = .05$, uncertain knowledge positively predicted boredom, $\beta = .21$, $t = 2.02$, $p = .023$, and justification via inquiry positively predicted surprise, $\beta = .17$, $t = 1.72$, $p = .04$.

For relations between epistemic beliefs and learning strategies, as expected, a belief in the complexity of knowledge positively predicted knowledge elaboration, $\beta = .29$, $t = 2.79$, $p = .006$, and critical thinking, $\beta = .24$, $t = 2.23$, $p = .010$, and a belief in the justification of knowledge via inquiry positively predicted knowledge elaboration, $\beta = .20$, $t = 2.16$, $p = .033$ and critical thinking, $\beta = .16$, $t = 1.69$, $p = .050$.

5.2.2.2. Mediation effects of epistemic emotions between epistemic beliefs and learning strategies. The first step in the analysis was used to test whether epistemic emotions mediated relations between epistemic beliefs and learning strategies. Mediation analyses revealed that anxiety mediated relations between beliefs about the source of knowledge and knowledge elaboration, with a standardized point estimate of .04 and a 90% confidence interval of .002 to

.127. The mediation was full, as the direct effect was no longer significant once the mediator was included in the model (see Hayes [2013]). In line with Muis et al.'s (2015) model, this indicates that beliefs about the active construction of knowledge predicted less anxiety and, in turn, more knowledge elaboration.

5.2.2.3. Effects of epistemic emotions on learning strategies and learning achievement. The second step in the analysis tested relations between epistemic emotions, learning strategies, and learning achievement. The total effects model was significant, $F(2, 104) = 9.32$, $p < .001$, $R^2 = .15$, controlling for prior knowledge. For direct effects of epistemic emotions on learning strategies, as expected, curiosity positively predicted critical thinking, $\beta = .16$, $t = 1.69$, $p = .04$, and knowledge elaboration, $\beta = .20$, $t = 2.06$, $p = .014$. However, contrary to predictions, curiosity positively predicted rehearsal, $\beta = .16$, $t = 1.61$, $p = .05$. Further, results unexpectedly revealed that surprise negatively predicted critical thinking, $\beta = -.18$, $t = -1.73$, $p = .05$. As expected, boredom negatively predicted rehearsal, $\beta = -.18$, $t = -1.94$, $p = .025$, and critical thinking, $\beta = -.15$, $t = -1.53$, $p = .05$. Lastly, for relations between learning strategies and learning achievement, critical thinking positively predicted learning achievement, $\beta = .21$, $t = 1.68$, $p = .046$. However, rehearsal unexpectedly predicted learning achievement, $\beta = .26$, $t = 2.33$, $p = .01$.

5.2.2.4. Mediation effects of learning strategies between epistemic emotions and learning achievement. As part of the second step of the path analysis, we tested for mediation between epistemic emotions and learning achievement via learning strategies. Consistent with Muis et al.'s (2015) framework, mediation analyses revealed that rehearsal mediated relations between boredom and learning achievement, with a standardized point estimate of -.04 and a 90% confidence interval of -.113 to -.009. Similarly, critical thinking mediated relations between boredom and learning achievement, with a standardized point estimate of -.03 and a 90%

confidence interval of -.087 to -.001. Both were full mediations. These results indicate that boredom predicted the use of less rehearsal and less critical thinking, both of which in turn predicted lower learning achievement. Consistent with predictions, critical thinking fully mediated relations between curiosity and learning achievement, with a standardized point estimate of .03 and a 90% confidence interval of .001 to .100. This indicates that curiosity predicted more critical thinking, which in turn, predicted greater learning achievement. No further significant results were identified. Table 12 presents a comparison of expected relations versus observed relations. We discuss and interpret these results next.

6. General Discussion

We sought to better understand the role that epistemic emotions play when learning about complex and controversial socio-scientific topics. Specifically, we sought to test and extend Muis and colleagues' (2015) theoretical framework, which proposes relations between epistemic beliefs, epistemic emotions, learning strategies, and learning achievement during complex learning. We employed two different methods of analysis and used self-reported data as well as trace data to explore the antecedents and consequences of epistemic emotions. We responded to calls to examine the sequential dynamics between emotions and cognition (D'Mello et al., 2014; Goetz et al., 2014; Muis et al., 2015) and considered a broad set of epistemic cognitive processes that may play an important role in contending with complex and controversial knowledge (Chinn & Rinehart, 2016; Greene et al., 2008). We operationalized learning as a deep understanding of text, as captured by an intra-text inference verification task.

Overall, our findings provide support for Muis et al.'s (2015) proposition that epistemic beliefs act as an antecedent to epistemic emotions via appraisals of epistemic congruity, but also found that other types of cognitive appraisals, including appraisals of novelty and complexity, and appraisals of the attainment of epistemic aims, also served as antecedents to epistemic emotions. Further, results supported the proposition that epistemic emotions have consequences for self-regulated learning via learning strategies and epistemic strategies employed. In the following sections, we discuss the extent to which findings aligned with Muis et al.'s (2015) framework and previous empirical work. Lastly, we consider theoretical implications for research on epistemic emotions and epistemic cognition, and discuss limitations and directions for future work.

6.1 Antecedents of Epistemic Emotions

The combined analysis of self-reported and real-time data provided empirical evidence for the arousal of epistemic emotions when learning from complex and contradictory learning material. The analysis of think-aloud protocols provided evidence for three antecedents to epistemic emotions: appraisals of epistemic (in)congruency, appraisals of information novelty and complexity, and appraisals of the attainment of epistemic aims. In response to our first research question, it appears that the majority of epistemic emotions were triggered by appraisals of information novelty and complexity. This result is consistent with Loewenstein's (1994) knowledge gap theory and Silvia's (2010) novelty-complexity theory which, taken together, stipulate that emotions such as curiosity, surprise, and confusion arise from the processing of novel or challenging information in contexts that can be more or less complex.

The fact that epistemic emotions related to epistemic (in)congruity were less frequent than epistemic emotions related to information novelty and complexity might be explained by the tacit nature of epistemic beliefs and the distinct role they play in learning. Drawing from Muis's (2007) model of epistemic beliefs and self-regulated learning, we suggest that epistemic emotions related to epistemic (in)congruity may be more prominent during the task definition phase of self-regulated learning. According to Muis (2007), the task definition phase of self-regulated learning involves the activation of learners' tacit epistemic beliefs and the perception of the task's characteristics – including its epistemic characteristics – which then feed into the creation of an idiosyncratic task definition. Task definition, like other self-regulated learning phases, is an ongoing process: As learners encounter new pieces of information, they may recycle or revise their task definition. As such, appraisals of epistemic congruity may only occur during the punctual event that is task definition or redefinition, making epistemic emotions related to epistemic (in)congruity less frequent than epistemic emotions related to appraisals of information novelty and complexity. As for epistemic emotions related to epistemic aims, their low frequency of occurrence may be due to the nature of the task presented: An ill-defined problem-solving situation, for instance, might have led to more emotions related to epistemic aims (see D'Mello et al., 2014). In sum, more research is needed to explore the arousal of epistemic emotions in authentic and varied contexts, such as problem-solving situations, or collaborative group work.

As for relations between epistemic emotions and epistemic cognition, while we did not have a specific hypothesis for the order of transitions between these variables, our observations are aligned with theoretical relations. We found that, in cases where epistemic emotions and epistemic cognition were sequentially related, epistemic cognition always occurred after epistemic emotions. Whereas epistemic beliefs are posited to be activated prior to appraisals of epistemic congruity, our observations suggest that epistemic cognition such as using epistemic strategies is likely to occur after the arousal of epistemic emotions, just like other learning strategies. For instance, epistemic emotions related to appraisals of information novelty and complexity might be followed by a justification strategy that focuses on the discrepant information (D'Mello et al., 2014). Similarly, epistemic emotions related to epistemic incongruity might be followed by a source evaluation strategy or an integration strategy, and epistemic emotions related to the obstruction of an epistemic aim might be followed by recycling that aim or setting a new one. In other words, our observations suggest that whether one measures epistemic beliefs or epistemic strategies or aims matters in terms of the sequential ordering of relations. Moving forward, researchers will need to clearly differentiate between epistemic beliefs and other, more dynamic epistemic cognitive processes, and to select measurement methods accordingly (Mason, 2016).

6.2 Evaluating Muis et al.'s (2015) Model

Overall, results obtained from state-transition analysis (Study 1) and path analysis (Study 2) were broadly aligned with Muis et al.'s (2015) model. In terms of relations between epistemic beliefs and epistemic emotions, out of 28 hypothesized relations, eight significant paths were observed, linking each dimension of epistemic beliefs to one of the epistemic emotions considered. Indeed, out of the eight significant paths obtained, six were aligned with hypothesis. Specifically, individuals who believed in the active construction of knowledge reported less anxiety during learning, and individuals who believed that knowledge claims are justified via inquiry reported more curiosity and enjoyment, as well as less frustration and boredom. Unexpectedly, those who believed in justification via inquiry reported more surprise, and those who believed that knowledge is uncertain reported more boredom. Boredom, which has been found to arise after prolonged confusion (D'Mello et al., 2014), was not expected to arise for learners who believed in the tentative character of climate change knowledge. The existence of conflicting claims about climate change might have seemed obvious to individuals who believe in the uncertainty of climate change knowledge, who may have been bored with the characterization of climate change knowledge in the experimental material. Of course, this relationship may also be a spurious one. As for surprise, whereas Muis et al. (2015) found that surprise was unrelated to epistemic beliefs, we obtained different results: Surprise was positively predicted by less constructivist epistemic beliefs about the complexity of knowledge (expected), but also by more constructivist beliefs about the justification for knowing (unexpected). Less constructivist epistemic beliefs may relate to the arousal of surprise in cases where the epistemic nature of the learning task is perplexing to learners, as suggested by Muis et al. (2015). On the other hand, the vast majority of instances of surprise in think-aloud protocols was found to relate to novel and/or challenging information, not to epistemic cognition.

In terms of relations between epistemic beliefs and learning strategies, four significant paths were observed, all in support of Muis et al.'s (2015) model, which comprised 16 hypothesized relations. Consistent with previous theoretical (Muis, 2007) and empirical (Chan, Ho, & Ku, 2011; Lin, Liang, & Tsai, 2012; Nielson, 2011; Pieschl, Stallman, & Bromme, 2014) work, more constructivist epistemic beliefs directly predicted deeper learning strategies. Indeed, a belief in the complexity of climate change knowledge positively related to greater use of critical thinking and elaboration strategies, as did a belief in justification via inquiry.

As for relations between epistemic emotions and learning strategies, path analysis and state-transition analysis generally supported the hypothesis that neutral and positive emotions such as curiosity and enjoyment support a deeper engagement with the learning tasks, whereas negative emotions such as anxiety and frustration relate to shallower engagement. Out of 14 hypothesized relations, we identified seven significant paths: three were consistent with hypotheses, one was counter to hypotheses, and three were not hypothesized per se. Additionally, state-transition analysis showed three meaningful relations between epistemic emotions and learning strategies, one which was in line with hypotheses, and two that were unexpected. Specifically, curiosity was related to all learning strategies, deep and shallow. This finding replicates results from Muis et al. (2015), who also found that curiosity was the most significant predictor of learning strategies among epistemic emotions. In Study 2, we found that curiosity related to greater learning achievement via critical thinking. Research by Bohn-Gettler and Rapp (2011) had similarly shown that individuals induced with a happy mood engaged in more coherence-building inferences and attained greater text comprehension than sad-induced individuals. As for enjoyment, unlike Muis et al. (2015), we found no significant relations to learning strategies in path analysis, but state-transition analysis revealed that learners tended to continue to read after having expressed enjoyment, which indicates that enjoyment has consequences for learners' motivation via continued engagement with the learning material.

For negative emotions, results suggest that they may hinder the use of deep learning strategies. Path analysis showed that anxiety negatively related to knowledge elaboration (although this trend did not reach significance), and boredom negatively related to critical thinking and rehearsal. As for surprise, considered a neutral emotion, its relationship with learning strategies was inconsistent across the two studies: Replicating findings by Muis et al. (2015), surprise negatively predicted critical thinking in path analysis; however, surprise was shown to positively predict critical thinking in state-transition analysis. Muis et al. (2018) suggest that when the experience of surprise is mild, learner's engagement with the task is not interrupted or perturbed. However, when the intensity of surprise is high and the information is perceived as comprehensible, Silvia (2010) suggests that curiosity ensues, which in turn enhances the likelihood of critical thinking, as demonstrated in our first study. Might it be the case that the arousal of curiosity between surprise and a subsequent state is so short that it fails to be verbalized by learners? More research is needed to empirically test how curiosity may moderate the relationship between surprise and critical thinking.

Finally, results provide support for the hypothesis that epistemic emotions relate to one's understanding of complex and controversial socio-scientific topics via learning strategies. We found full mediation between epistemic emotions, learning strategies and learning achievement. Contrary to Muis et al. (2015), who had unexpectedly found a negative effect of curiosity, enjoyment and confusion on learning via metacognitive self-regulation, our findings are consistent with the hypothesized model. Curiosity emerged as the most significant epistemic emotion, predicting greater learning via critical thinking (in path analysis) and metacognitive self-regulation (in state-transition analysis). For negative emotions, boredom emerged as the more consequential epistemic emotion, predicting lesser learning by decreasing the use of both deep and shallow learning strategies.

Overall, findings from this research suggest that to advance research on epistemic emotions, future work will have to consider various arousal antecedents to emotions, as emotions triggered by different appraisals may lead to different consequences for learning. Although results from our first study did not show differences in consequences as a function of epistemic emotions' antecedents, our investigation was limited by the small number of transitions on which we could conduct statistical analyses. As such, more research is needed before a definitive conclusion can be reached regarding the role of antecedents of epistemic emotions in predicting consequences for learning. Similarly, future research should consider subtypes of emotions, and how these may differentially predict self-regulated learning. For instance, how may interest-type curiosity and deprivation-type curiosity (Litman & Jimerson, 2004) be differently predicted by various informational or epistemic contexts? And how may these different types of curiosity predict different learning processes and outcomes? Similarly, how may various information or epistemic contexts trigger different intensities of surprise (Munnich & Ranney, 2018) or boredom (Goetz et al., 2011) and what type of strategies may learners put in place to regulate different intensities of epistemic emotions?

In sum, it appears that Muis et al.'s (2015) integrated model may require the inclusion of predictive variables such as epistemic aims, and moderating variables such as information novelty and complexity, and emotional intensity to fully explain how epistemic emotions relate to epistemic cognition and self-regulated learning. Consequently, this will require that future work uses specific measurement methods to uncover learners' epistemic aims, and to investigate learners' appraisals of information novelty and complexity as learning unfolds. To this end, facial video recording can be combined with retrospective affective-cognitive judgment protocols (see D'Mello & Graesser, 2012).

6.3 Limitations and Directions for Future Work

The work presented here included a number of limitations that should be considered and addressed in future work. A first limitation concerns the small sample that was used for this research relative to the large number of hypotheses tested. The resource demands of using think-aloud protocols to measure cognitive or affective processes often lead to relatively small sample sizes that can affect statistical power. Relatedly, the large number of statistical tests conducted herein may have led to alpha inflation. However, using a correction would be too restrictive as it would reduce power. A larger sample size would address this issue. As such, we recommend using caution when interpreting the current findings. A second limitation concerns the investigation of emotions using a think-aloud method. Specifically, the occurrence of emotions in this study was relatively low, and this may be because we did not specifically instruct learners to express their emotions out loud. Akin to individuals' threshold for experiencing an emotion (D'Mello et al., 2014), individuals' threshold for expressing an emotion out loud is likely to be highly idiosyncratic and sensitive to social and emotional regulation. No elements in the design of this study were put in place to minimize barriers to emotion verbalization. To counter this inherent limitation, researchers should consider emote-aloud protocols (e.g., Craig et al., 2008; D'Mello, Craig, Sullins, & Graesser, 2006) where participants are specifically encouraged and trained to verbalize their affective states. However, for this method to fully serve researchers, groundwork is needed where language is closely examined to decipher how learners spontaneously label their emotions. For instance, do expressions such as "I'm intrigued" and "I wonder" reflect curiosity, or might they as well reflect confusion or frustration? Do indicators such as "astonished" and "amazed" reflect similar or different emotions? Researchers may consider complementing emote-aloud methods with cognitive interviewing to answer such interrogations.

A third limitation pertains to the absence of measurement and control of individual verbosity. Researchers using think-aloud protocols can address verbosity by using time-stamped data combined with statistical transformations (see, for example, Azevedo, Johnson, Chauncey, & Burkett, 2011). However, such data were not available for the current work. More research is needed to understand how individual differences in emotion expression may be addressed or controlled. Lastly, future research should consider the characteristics of the content and of the task that trigger emotions, such as reading text versus problem solving, or group work versus solo work. To further understand the role of epistemic cognition and epistemic emotions in self-regulated learning, it will be important for future studies to examine these constructs in contexts and disciplines that embrace an epistemology that differ from the epistemology of science, such as history or economics.

To conclude, this research attests to the importance of considering multiple data sources to advance knowledge about emotions and cognition in learning. Here, we have operated a conceptual and empirical distinction between epistemic beliefs and broader epistemic cognition that we believe will be fruitful for future research. Further, we have responded to calls to examine the temporal dynamics of epistemic emotions with innovative analyses, and have brought meaningful insights about the nature of epistemic emotions, including their antecedents and consequences for learning. We also contributed to advancing and extending Muis et al.'s (2015) integrated framework of epistemic beliefs, epistemic emotions, and self-regulated learning, which proposes one promising mediational mechanism to explain how epistemic cognition relates to self-regulated learning. Lastly, we believe that this work also extends Pekrun's (2006) control-value theory of achievement emotions by proposing new types of cognitive appraisals that serve as antecedents to emotions in educational settings. Given the importance of epistemic emotions, epistemic cognition and self-regulated learning for deep learning (Muis et al., 2015) and higher-order thinking processes such as critical thinking (Chan et al., 2011; Greene & Yu, 2016) and digital literacy (Greene et al., 2014), this research also indicates that much work is still needed to develop learning environments that efficiently leverage epistemic emotions to the benefit of a greater understanding of the complex and controversial issues that define the world we live in today.

Footnotes

1 Epistemic congruity or incongruity may be viewed as a special case of cognitive congruity or incongruity. Muis et al.'s (2015) use the term "cognitive incongruity" in their work to refer to the same phenomenon.

2 The Flesch-Kincaid readability test was developed in 1975 by Kincaid and colleagues (Kincaid, Fishburne, Rogers & Chissom, 1975) to assess the reading difficulty of U.S. Navy technical manuals and are now extensively used in education. The Flesch-Kincaid Grade Level presents a score as a US grade level, which also indicates the number of years of education generally required to understand a text.

3 Learning strategies were also self-reported by participants using the Motivation Strategies for Learning Questionnaire (MSLQ; Pintrich et al., 1993). However, data were not used in the analyses, given the high frequency and decent spread of the distributions from the think-aloud protocols. Moreover, think-aloud data have been shown to be more reliable measures for learning strategies than self-reported data (Winne et al., 2002).

4 This analytic approach is not a model-fitting analysis and, as such, model fit indices are not reported. See Hayes (2013) for a complete discussion of this macro.

References

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology, 29*, 344-370.

Azevedo, R., Johnson, A., Chauncey, A., & Burkett, C. (2010). Self-regulated learning with MetaTutor: Advancing the science of learning with MetaCognitive tools. In M. Khine & I. Saleh (Eds.), *New science of learning: Computers, cognition, and collaboration in education* (pp. 225–247). Amsterdam, The Netherlands: Springer.

Azevedo, R., Moos, D., Johnson, A., & Chauncey, A. (2010). Measuring cognitive and metacognitive regulatory processes used during hypermedia learning: Issues and challenges. *Educational Psychologist, 45,* 210-223.

Barzilai, S., & Zohar, A. (2012). Epistemic thinking in action: Evaluating and integrating online sources. *Cognition and Instruction, 30*, 39-85.

Barzilai, S., & Zohar, A. (2014). Reconsidering personal epistemology as metacognition: A multifaceted approach to the analysis of epistemic thinking. *Educational Psychologist, 49*, 13-35.

Bendixen, L. (2002). A process model of epistemic belief change. In B. K. Hofer, & P. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing*. Mahwah, NJ: Lawrence Erlbaum Association, Inc.

Bendixen, L. D., & Rule, D. C. (2004). An integrative approach to personal epistemology: A guiding model. *Educational Psychologist, 39*, 69-80.

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology, 45*, 180-191.

Bieg, M., Goetz, T., & Hubbard, K. (2013). Can I master it and does it matter? An intraindividual analysis on control-value antecedents of trait and state academic emotions. *Learning and Individual Differences, 28,* 102-108.

Bohn-Gettler, C. M., & Rapp, D. N. (2011). Depending on my mood: Mood-driven influences on text comprehension. *Journal of Educational Psychology, 103*, 562-577.

Boykoff, M. T., & Boykoff, J. M. (2004). Balance as bias: global warming and the US prestige press. *Global Environmental Change*, *14*, 125-136.

Bråten, I., Britt, M. A., Strømsø, H. I., & Rouet, J. F. (2011). The role of epistemic beliefs in the comprehension of multiple expository texts: Toward an integrated model. *Educational Psychologist*, *46*, 48-70.

Bråten, I., Ferguson, L. E., Strømsø, H. I., & Anmarkrud, Ø. (2014). Student working with multiple conflicting documents on a science issue: Relations between epistemic cognition while reading and sourcing and argumentation in essays. *British Journal of Educational Psychology, 84*, 58–85.

Bråten, I., & Strømsø, H. I. (2009). Effects of task instruction and personal epistemology on the understanding of multiple texts about climate change. *Discourse Processes, 47*, 1-31.

Bråten, I., Strømsø, H. I., & Samuelstuen, M. S. (2008). Are sophisticated students always better? The role of topic-specific personal epistemology in the understanding of multiple expository texts. *Contemporary Educational Psychology*, *33*, 814-840.

Broughton, S. H., Pekrun, R., & Sinatra, G. M. (2012). *Climate change, genetically modified foods, airport body scanners: Investigating students' emotions related to science topics.* Paper presented at the annual meeting of the American Educational Researchers Association, National Conference, Vancouver, Canada.

Brun, G., & Kuenzle, D. (2008). A new role for emotions in epistemology? In G. Brun, U. Doğuoğlu, & D. Kuenzle, D. (Eds.), *Epistemology and emotions* (pp. 1-32). Aldershot, UK: Ashgate.

Byrne, B. M. (2005). Factor analytic models: Viewing the structure of an assessment instrument from three perspectives. *Journal of Personality Assessment, 85*, 17-32.

Byrne, B. M. (2012). *Structural equation modeling with Mplus: Basic concepts, applications, and programming*. New York, NY: Routledge.

Chan, N. M., Ho, I. T., & Ku, K. Y. (2011). Epistemic beliefs and critical thinking of Chinese students. *Learning and Individual Differences*, *21*, 67-77.

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. L. A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist*, *46*, 141-167.

Chinn, C.A., & Rinehart, R.W. (2016). Epistemic cognition and philosophy: Developing a new framework for epistemic cognition. In J.A. Greene, W.A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 460-478). New York, NY: Routledge.

Corbett, J. B., & Durfee, J. L. (2004). Testing public (un)certainty of science: Media representations of global warming. *Science Communication, 26*, 129-151.

D'Mello, S. K., Craig, S. D., Sullins, J., & Graesser, A. C. (2006). Predicting affective states expressed through an emote-aloud procedure from AutoTutor's mixed-initiative dialogue. *International Journal of Artificial Intelligence in Education*, *16*, 3-28.

D'Mello, S. K., & Graesser, A. C. (2012). Dynamics of affective states during complex learning. *Learning and Instruction, 22,* 145-157.

D'Mello, S. K., Lehman, B., Pekrun, R., & Graesser, A. C. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29*, 153-170.

DeBacker, T. K., Crowson, H. M., Beesley, A., & Hestevold, N. L. (2008) The challenge of measuring epistemic beliefs: Analysis of three self-report instruments. *Journal of Experimental Education, 76*, 281-312.

Dole, J. A., & Sinatra, G. M. (1998). Reconceptualizing change in the cognitive construction of knowledge. *Educational Psychologist*, *33*, 109-128.

Ekman, P. (1984). Expression and the nature of emotion. *Approaches to Emotion*, *3*, 19-344.

Ellsworth, P. C. (2003). Confusion, concentration, and other emotions of interest: Commentary on Rozin and Cohen. *Emotion, 3,* 81-85.

Ellsworth, P. C. (2013). Appraisal theory: Old and new questions. *Emotion Review, 5*, 125–131.

Ellsworth, P. C., Scherer, K. R. (2003). Appraisal processes in emotion. In R. J. Davidson, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 572–95). Oxford, UK: Oxford University Press.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data (rev. ed.)*. Cambridge, MA: MIT press.

Ferguson, L. E., Bråten, I., & Strømsø, H. I. (2012). Epistemic cognition when students read multiple documents containing conflicting scientific evidence: A think-aloud study. *Learning and Instruction, 22*, 103-120.

Foster, M. I., & Keane, M. T. (2015). Why some surprises are more surprising than others: Surprises as a metacognitive sense of explanatory difficulty. *Cognitive Psychology, 81*, 74-116.

Franco, G. M., Muis, K. R., Kendeou, P., Ranellucci, J., Sampasivam, L., & Wang, X. (2012). Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics. *Learning and Instruction, 22*, 62-77.

Funk, C., & Kennedy, B. (2016). *The new food fights: US public divides over food science*. Pew Research Center. Retrieved from http://www.pewinternet.org/2016/12/01/the-new-food-fights/

Goetz, T., Frenzel, A. C., Hall, N. C., Nett, U. E., Pekrun, R., & Lipnevich, A. A. (2014). Types of boredom: An experience sampling approach. *Motivation and Emotion, 38*, 401-419.

Gowda, M. V. R., Fox, J. C., & Magelky, R. D. (1997). Students' understanding of climate change: Insights for scientists and educators. *Bulletin of the American Meteorological Society, 78*, 2232–2240.

Greene, J. A., & Azevedo, R. A. (2009). A macro-level analysis of SRL processes and their relations to the acquisition of a sophisticated mental model of a complex system. *Contemporary Educational Psychology, 34*, 18-29.

Greene, J. A., Azevedo, R., & Torney-Purta, J. (2008). Modeling epistemic and ontological cognition: Philosophical perspectives and methodological directions. *Educational Psychologist, 43*, 142-160.

Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. *Journal of Educational Psychology, 110,* 1084-1111.

Greene, J. A., Muis, K. R., & Pieschl, S. (2010). The role of epistemic beliefs in students' self-regulated learning with computer-based learning environments: Conceptual and methodological issues. *Educational Psychologist, 45,* 245-257.

Greene, J. A., Sandoval, W. A., & Bråten, I. (Eds.) (2016). *International handbook of epistemic cognition*. New York, NY: Routledge.

Greene, J. A., & Yu, S. B. (2016). Educating critical thinkers: The role of epistemic cognition. *Policy Insights from the Behavioral and Brain Sciences, 3,* 45-53.

Greene, J. A., Yu, S. B., & Copeland, D. Z. (2014). Measuring critical components of digital literacy and their relationships with learning. *Computers and Education, 76*, 55-69.

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis*. New York, NY: Guilford.

Hayes, A. F., & Preacher, K. J. (2013). *Statistical mediation analysis with a multi-categorical independent variable*. Unpublished white paper.

Heddy, B. C., Danielson, R. W., Sinatra, G. M., & Graham, J. (2017). Modifying knowledge, emotions, and attitudes about genetically modified foods. *Journal of Experimental Education*, *85*, 513-533.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology, 25*, 378-405.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67,* 88-140.

Hookway, C. (2008). Epistemic immediacy, doubt and anxiety: On a role for affective states in epistemic evaluation. In G. Brun, U. Doguoglu, & D. Kuenzle (Eds.), *Epistemology and emotions* (pp. 51–65). Aldershot, UK: Ashgate.

Hubbard, K., Hall, N. C., & Sverdlik, A (2019, April). *Phenomenology of boredom coping: Understanding students' lived experiences of coping with boredom in college*. AERA Annual Convention, Toronto, ON.

Hulme, M. (2009). *Why we disagree about climate change: Understanding controversy, inaction and opportunity*. Cambridge, England: Cambridge University Press.

Jaber, L. Z., & Hammer, D. (2016). Engaging in science: A feeling for the discipline. *Journal of the Learning Sciences*, *25*, 156-202.

Jirout, J., & Klahr, D. (2012). Children's scientific curiosity: In search of an operational definition of an elusive concept. *Developmental Review, 32*, 125-160.

Kang, M. J., Hsu, M., Krajbich, I. M., Loewenstein, G., McClure, S. M., Wang, J. T. Y., & Camerer, C. F. (2009). The wick in the candle of learning: Epistemic curiosity activates reward circuitry and enhances memory. *Psychological Science, 20,* 963–973.

Kata, A. (2012). Anti-vaccine activists, Web 2.0, and the postmodern paradigm: An overview of tactics and tropes used online by the anti-vaccination movement. *Vaccine*, *30*, 3778-3789.

Kienhues, D., Stadtler, M., & Bromme, R. (2011). Dealing with conflicting or consistent medical information on the web: When expert information breeds laypersons' doubts about experts. *Learning and Instruction, 21*, 193-204.

Kincaid, J., Fishburne, R., Rogers, R., & Chissom, B. (1975). Derivation of new 268 learning word meanings from context readability formulas (Automated Readability Index, fog count, and Flesch Reading Ease Formula) for Navy enlisted personnel. *Navy Training Command Research Branch Report*, 8-75.

Kitchener, K. S. (1983). Cognition, metacognition, and epistemic cognition. *Human Development, 26*, 222-232.

Lauriola, M., Litman, J. A., Mussel, P., De Santis, R., Crowson, H. M., & Hoffman, R. R. (2015). Epistemic curiosity and self-regulation. *Personality and Individual Differences, 83*, 202-207.

Lazarus, R. S. (1991). *Emotion and adaptation*. New York, NY: Oxford University Press.

Lin, Y. C., Liang, J. C., & Tsai, C. C. (2012). The relationships between epistemic beliefs in biology and approaches to learning biology among biology-major university students in Taiwan. *Journal of Science Education and Technology*, *21*, 796-807.

Litman, J. (2005). Curiosity and the pleasures of learning: Wanting and liking new information. *Cognition and Emotion*, *19*, 793-814.

Litman, J. A. (2008). Interest and deprivation factors of epistemic curiosity. *Personality and Individual Differences, 44*, 1585-1595.

Litman, J., Hutchins, T., & Russon, R. (2005). Epistemic curiosity, feeling-of-knowing, and exploratory behaviour. *Cognition and Emotion, 19*, 559-582.

Loewenstein, G. (1994). The psychology of curiosity: A review and reinterpretation. *Psychological Bulletin, 116*, 75-98.

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological Bulletin*, *127*, 267.

Lombardi, D., & Sinatra, G. M. (2012). College students' perceptions about the plausibility of human-induced climate change. *Research in Science Education*, *42*, 201-217.

Lowry, N., & Johnson, D. W. (1981). Effects of controversy on epistemic curiosity, achievement, and attitudes. *The Journal of Social Psychology, 115*, 31-43.

Markey, A., & Loewenstein, G. (2014). Curiosity. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 228-245). New York, NY: Taylor & Francis.

Mason, L. (2016). Psychological perspectives on measuring epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 375-392). New York, NY: Routledge.

Mason, L., Ariasi, N., & Boldrin, A. (2011). Epistemic beliefs in action: Spontaneous reflections about knowledge and knowing during online information searching and their influence on learning. *Learning and Instruction, 21*, 137-151.

Mason, L., Boldrin, A., & Ariasi, N. (2010). Epistemic metacognition in context: Evaluating and learning online information. *Metacognition and Learning, 5*, 67-90.

Meyer, W. U., Reisenzein, R., & Schützwohl, A. (1997). Toward a process analysis of emotions: The case of surprise. *Motivation and Emotion, 21*, 251-274.

Moors, A., Ellsworth, P. C., Scherer, K. R., & Frijda, N. H. (2013). Appraisal theories of emotion: State of the art and future development. *Emotion Review, 5*, 119-124.

Muis, K. R. (2007). The role of epistemic beliefs in self-regulated learning. *Educational Psychologist, 42*, 173-190.

Muis, K. R., Chevrier, M., & Singh, C. A. (2018). The role of epistemic emotions in personal epistemology and self-regulated learning. *Educational Psychologist*, *53*, 165-184.

Muis, K. R., Pekrun, R., Sinatra, G. M., Azevedo, R., Trevors, G., Meier, E., & Heddy, B. C. (2015). The curious case of climate change: Testing a theoretical model of epistemic beliefs, epistemic emotions, and complex learning. *Learning and Instruction, 39*, 168-183.

Muis, K. R., & Singh, C. A. (2018). The three facets of epistemic thinking in self-regulated learning. In D. Schunk & J. Greene (Eds.), *Handbook of self-regulated of learning and performance* (pp. 434–456). New York, NY: Routledge.

Munnich, E., & Ranney, M. A. (2018). Learning from surprise: Harnessing a metacognitive surprise signal to build and adapt belief networks. *Topics in Cognitive Science*, *11*, 164-177.

Op't Eynde, P., De Corte, E., & Verschaffel, L. (2007). Students' emotions: A key component of self-regulated learning? In P. A. Schutz & R. Pekrun (Eds.), *Emotion in education* (pp. 185-204). San Diego, CA: Elsevier Academic Press.

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18*, 315-341.

Pekrun, R., Goetz, T., Daniels, L. M., Stupnisky, R. H., & Perry, R. P. (2010). Boredom in achievement settings: Control-value antecedents and performance outcomes of a neglected emotion. *Journal of Educational Psychology, 102,* 531-549.

Pekrun, R., Goetz, T., Frenzel, A. C., Barchfeld, P., & Perry, R. P. (2011). Measuring emotions in students' learning and performance: The Achievement Emotions Questionnaire (AEQ). *Contemporary Educational Psychology, 36*, 36-48.

Pekrun, R., Lichtenfeld, S., Marsh, H. W., Murayama, K., & Goetz, T. (2017). Achievement emotions and academic performance: Longitudinal models of reciprocal effects. *Child Development, 88,* 1653-1670.

Pekrun, R., & Linnenbrink-Garcia, L. (2012). Academic emotions and student engagement. In S. L. Christenson, A. L. Reschly & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 259-282). New-York, NY: Springer.

Pekrun, R., & Meier, E. (2011). *Epistemic emotion scales (EES)*. Munich, Germany: Department of Psychology, University of Munich. Unpublished manuscript.

Pekrun, R., & Perry, R. P. (2014). Control-value theory of achievement emotions. In R. Pekrun, & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 120-141). New York, NY: Taylor & Francis.

Pekrun, R., & Stephens, E. J. (2012). Academic emotions. In K. R. Harris, S. Graham & T. Urdan (Eds.), *APA Educational Psychology Handbook* (Vol. 2, pp. 3-31). Washington, DC: American Psychological Association.

Pekrun, R., Vogl, E., Muis, K. R., & Sinatra, G. M. (2017). Measuring emotions during epistemic activities: The Epistemically-Related Emotion Scales. *Cognition and Emotion*, *31*, 1268-1276.

Pierce, C. S., Houser, N., & Kloesel, C. (1992). The Essential Pierce. *Selected Philosophical Writings, 2*, 1893-1913.

Pieschl, S., Stallmann, F., & Bromme, R. (2014). High school students' adaptation of task definitions, goals and plans to task complexity: The impact of epistemic beliefs. *Psihologijske Teme, 23*, 31-52.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*, 167-199.

Pintrich, P. R., Smith, D. A. F., Garcia, T., & McKeachie, W. J. (1993). Reliability and predictive validity of the motivated strategies for learning questionnaire (MSLQ). *Educational and Psychological Measurement, 53*, 801-813.

Poitras, E., & Trevors, G. (2012). Deriving empirically-based design guidelines for advanced learning technologies that foster disciplinary comprehension/Définir des lignes directrices fondées sur des données empiriques pour les technologies d'apprentissage avancé qui favorisent la compr. *Canadian Journal of Learning and Technology/La revue canadienne de l'apprentissage et de la technologie*, *38*, 1-22.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*, 879-891.

Preacher, K. J., Zyphur, M. J., & Zhang, Z. (2010). A general multilevel SEM framework for assessing multilevel mediation. *Psychological Methods, 15*, 209-233.

Reisenzein, R., & Studtmann, M. (2007). On the expression and experience of surprise: no evidence for facial feedback, but evidence for a reverse self-inference effect. *Emotion, 7,* 612.

Richter, T., & Schmid, S. (2010). Epistemological beliefs and epistemic strategies in self-regulated learning. *Metacognition and Learning, 5*, 47-65.

Rosenberg, E. L. (1998). Levels of analysis and the organization of affect. *Review of General Psychology, 2*, 247-270.

Royer, J. M., Carlo, M. S., Dufresne, R., & Mestre, J. (1996). The assessment of levels of domain expertise while reading. *Cognition and Instruction, 14*, 373-408.

Scheffler, I. (1977). In praise of the cognitive emotions. In I. Scheffler (Ed.), *In praise of the* *cognitive emotions and other essays in the philosophy of education* (pp. 3-7). New York, NY: Routledge.

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*, 498-504.

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology, 84*, 435-443.

Silvia, P. J. (2010). Confusion and interest: The role of knowledge emotions in aesthetic experience. *Psychology of Aesthetics, Creativity, and the Arts, 4,* 75-80.

Sinatra, G. M. (2016). Thoughts on knowledge about thinking about knowledge. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 479-491). New York, NY: Routledge.

Slovic, P. (1987). Perception of risk. *Science, 236*, 280-285.

Stathopoulou, C., & Vosniadou, S. (2007). Exploring the relationship between physics-related epistemological beliefs and physics understanding. *Contemporary Educational Psychology*, *32*, 255-281.

Strømsø, H. I., Bråten, I., & Britt, M. A. (2010). Reading multiple texts about climate change: The relationship between memory for sources and text comprehension. *Learning and Instruction, 20*, 192-204.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Boston, MA: Allyn Bacon.

Tiedens, L. Z., & Linton, S. (2001). Judgment under emotional certainty and uncertainty: The effects of specific emotions on information processing. *Journal of Personality and Social Psychology, 81*, 973–988.

Weber, E. U., & Stern, P. C. (2011). Public understanding of climate change in the United States. *American Psychologist*, *66*, 315.

Winne, P. H. (2001). Self-regulated learning viewed from models of information processing. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (Vol. 2, pp. 153-189). Mahwah, NJ: Lawrence Erlbaum Associate.

Winne, P. H., & Hadwin, A. F. (1998). Studying as self-regulated learning. *Metacognition in Educational Theory and Practice*, *93*, 27-30.

Winne, P. H., & Jamieson-Noel, D. (2002). Exploring students' calibration of self reports about study tactics and achievement. *Contemporary Educational Psychology*, *27*, 551-572.

Winne, P. H., Jamieson-Noel, D. L., & Muis, K. R. (2002). Methodological issues and advances in researching tactics, strategies, and self-regulated learning. In M. L. Maehr & P. R. Pintrich (Eds.), *Advances in motivation and achievement* (Vol. 12, pp. 121-158). Greenwich, CT: JAI.

Zeidner, M. (1998). *Test anxiety: The state of the art.* New York, NY: Plenum Press.

Zimmerman, B. J. (1998). Academic studying and the development of personal skill: A self-regulatory perspective. *Educational Psychologist, 33*, 73-86.

Table 1

Coding scheme for epistemic emotions, learning strategies, and epistemic cognition in think-aloud protocols

Code	Description	Example
	Epistemic emotions	
Surprise	Astonished, amazed	*Epistemic*: [The ocean level will rise by 10 to 20 cm…] "Holy goodness!" "[We still do not have a basis for establishing that human pollution of the atmosphere is the main cause of climate change.] I find very surprising." "[This will have a dramatic effect on farming and forestry, while at the same time there will be a greater need for heating.] That really surprises me." "[... the concentration of methane has increased by around 151%] Wow, this is shocking."
Enjoyment	Excited, enthusiastic	*Epistemic*: "That's kind of cool to know!" "I think I like where this is going." *Achievement*: "Cool. I feel good about this. On to the next one."
Curiosity	Interested, intrigued	*Epistemic*: "It's interesting to think about how one comes into play with the other." "I wonder where it's increasing."
Confusion	Puzzled, muddled	*Epistemic*: "Hum, the article says that the greenhouse effect is naturally occurring while the other article said that the

		greenhouse effect is made by humankind. Did I read the other one wrong?" "Ok. I'm kind of confused."
Frustration	Irritated, dissatisfied	*Epistemic*: "[The oil and gas deposits that are concealed there are estimated to amount to 30% of the earth's deposits.] Ooh, this guy frustrates me." "I think it's kind of ridiculous to pretend that what people are doing somehow hasn't affected climate change." *Topic*: "[A warmer climate could result in better growing conditions and lower heating costs.] This is literally stupid." "…and then America can just annex us and then we can just create a fortress of North America and that'll be great, you know... I don't know, this is frustrating." *Achievement*: "[The sun's magnetic field will, to a varying degree, stem the quantity of particles that penetrate our atmosphere.] I don't get this. This is so annoying."
Anxiety	Worried, nervous	*Topic*: "[The Arctic ice is melting so quickly that a sea passage between the Atlantic Ocean and the Pacific Ocean may be accessible to ordinary ships during the summer by 2050.] That sounds really horrible and scary."
Boredom	Dull, monotonous	*Achievement*: "Manmade greenhouse... blah blah blah. Ugh." "Okay, this is not important, I won't take notes."
	Self-regulated learning strategies	
Prior knowledge activation	Searching memory for relevant prior knowledge; asserting that information	"[…water vapor, which is by far the most significant, by causing a lot of clouds in the atmosphere.] Also, the chlorophane gases are also important for global warming."

	from text was prior knowledge in memory	"That's what we see in the news."
Rereading	Rereading or revisiting a section of the text that had previously been read	"[…North Atlantic to such a degree that there is a genuine risk of serious and long-term cooling.] …genuine risk long-term cooling."
Reproduction strategies	Paraphrasing; rehearsal for memorization	"He also mentions enormous riches oil and gas deposits."
Critical thinking	Making judgments on the basis of a criterion; developing one's own opinion on the basis of what was read; qualifying or ascribing value to information; thinking about implications beyond the text	"Kind of a catch 22, almost, that oil which in turn fossil fuels are helping or making the ice caps melt, and by the ice caps melting we're getting more oil, that helps the ice caps melt more." "This text doesn't explain much about the blame that is assumed." "This is a huge range."
Knowledge elaboration	Coordinating informational sources; generative note-taking; producing summaries that include elements from more than three sentences apart; making inferences; hypothesizing; elaborating on what has been read with prior knowledge or other elements in the text or in previous texts; self-questioning	"This can have negative consequences such as, um, rising ocean levels which in turn create more evaporation which can lead to stronger weather patterns, I guess." "These manmade discharges, do they increase the concentration?" "Right, so even though quantitatively our discharges may not be significant, it is in effect disrupting the balance, which is the carbon dioxide cycle."
Metacognitive self-regulation	Making judgment of learning; emitting feeling of knowing; monitoring progress towards goals; monitoring use of strategies	"I didn't know that." "Wait, what? I'm going to have to read that again." "So far, I understand everything." "…and visualization helps me to remember things, hopefully it'll help."

	Epistemic cognition	
Epistemic beliefs	Stating that knowledge is simple or complex (*complexity*), certain or tentative (*certainty*), that the source of knowing is oneself via active construction or experts and other authoritative sources (*source*).	"…that's not something, well for right now, well we can never know for certain, but we don't exactly have the best idea now." "[Global warming may also weaken the Gulf Stream and result in serious cooling in Northern Europe.] The key word there is "may." There are too many things going on." "…all these factors contribute to a major change in climate. But it is unknown for now." "I would like to know who is doing the research for the UN climate panel, and then decide for myself whether the information is reliable, accurate."
Epistemic aims	Setting the aim to acquire facts, understand processes, or develop an integrated perspective	"I would like to hear other people's thoughts on this though, particularly indigenous folks."
Sourcing strategies	Evaluating the quality and relevancy of a source on the basis of trustworthiness of the author or the quality of the evidence provided	"I would like to know more about him, what else, what other research he has been doing, see if he is a reliable source for information." "So this author should like, show that the change in the orbit or the change in the sun activity is also increasing the temperature of the earth. People won't be able to evaluate whether this is true or not." "Okay Time Magazine, that is not science, that's like third-hand news."

Integration strategies	Evaluating, comparing and contrasting claims made across multiple sources; providing explanations to account for differences between the various perspectives	"I think they're both true, I can't pick one and say the other is not true I don't think. They're probably both related in some way." "Okay so while this article addresses facts about the climate in relation to the atmosphere these things are not mutually exclusive things." "But it just said a lot of the place, in the last article, a lot of the temperature gets colder. Now I don't know who to believe."
Justification strategies	Evaluating and justifying knowledge on the basis of personal experiences (i.e., the five senses), recall of information stored in memory, coherence with knowledge claims that are believed to be true, logic or scientific reasoning; or making a decision on the trustworthiness or veracity of a knowledge claim without further justification	"I don't know how hurricanes work at all so I am just going to take this guy on his word." "…that also makes sense and checks out to things I've learned to date." "[Time magazine reports that hurricanes have increased in both number and intensity since 1995.] That's a very short time to be measured. Maybe take a longer sample. "[Time magazine reports that hurricanes have increased in both number and intensity since 1995.] Yes, I can attest to that."

Table 2

Coding scheme for antecedents of epistemic emotions

Antecedent of epistemic emotion	**Description**	**Example**
Epistemic (in)congruity	Epistemic emotion is related to an appraisal of alignment of misalignment between the epistemic nature of the task and one's beliefs about the nature of knowledge, the source of knowing, or the justification for knowing.	*Surprise*: "Wow (surprise), they're at odds with each other!" *Curiosity*: "I mean it's interesting to learn about a different viewpoint." *Frustration*: "I think it's ridiculous to pretend that what people are doing somehow hasn't affected climate."
Information novelty and complexity	Epistemic emotion is related to an appraisal of alignment or misalignment between new or recently processed information and one's prior knowledge, based on information's novelty and complexity.	*Surprise*: "[…of carbon dioxide (CO2) has increased by around 31 per cent.] Wow! That's shocking." *Curiosity*: "[Time magazine reports that hurricanes have increased in both number and intensity since 1995.] I wonder what the number is exactly." *Confusion*: "Okay, kind of confused about the whole water vapor thing, the difference, or relation between that and our C02 discharges, but everything else seems to make sense."
Epistemic aims	Epistemic emotion is related to an appraisal of attainment or blockage of epistemic aim	*Enjoyment*: When particles that originate from previously exploded stars penetrate the atmosphere, they could affect the formation of low clouds. That's kind of cool to know!"

Table 3

Frequency of verbalized emotions by object focus

	Surprise	Curiosity	Enjoyment	Confusion	Frustration	Anxiety	Boredom	Total
Epistemic	86	92	7	16	6	0	0	207
Topic	0	0	1	0	34	17	0	52
Achieve	0	0	1	0	4	0	3	8
Total	86	92	9	16	44	17	3	267

Table 4

Frequency of verbalized epistemic emotions by antecedent

	Epistemic (in)congruity	Information novelty and comprehensibility	Epistemic aims	Total
Surprise	9	77	0	86
Curiosity	29	63	0	92
Enjoyment	0	5	2	7
Confusion	2	14	0	16
Frustration	6	0	0	6
Total	46	159	2	207

Table 5

Frequency of epistemic emotions, learning strategies, and epistemic cognition in think-aloud protocols

	Frequency
Epistemic emotions	
Surprise	86
Curiosity	92
Enjoyment	7
Confusion	16
Frustration	6
Total	207
Learning strategies	
Prior knowledge activation	182
Rereading	339
Rehearsal	709
Knowledge elaboration	626
Critical thinking	454
Metacognitive self-regulation	358
Total	2668
Epistemic cognition	
Epistemic beliefs	18
Epistemic aims	7
Sourcing strategies	105
Integration strategies	19
Justification strategies	217
Total	366

Table 6

Frequency of transition from epistemic emotion (left column) to another emotion, learning strategies, or epistemic cognition (top row)

	Other emotions	**PKA**	**Rereading**	**RE**	**KE**	**Critical thinking**	**MSR**	**Continues to read**	**Epistemic cognition**	**Total**
Surprise	6	4	0	6	14	18	5	30	3	86
Curiosity	2	4	3	8	11	11	11	32	10	92
Enjoyment	0	1	1	0	0	0	1	3	1	7
Confusion	0	1	1	3	0	1	2	8	0	16
Frustration	0	0	0	0	0	3	0	3	0	6
Total	8	10	5	17	25	33	19	76	14	207

PKA = Prior knowledge activation; RE = Rehearsal; KE = Knowledge elaboration; MSR = metacognitive self-regulation

	PKA	**RR**	**RE**	**KE**	**CT**	**MSR**	**Total**
Surprise	4	0	6	14	18	5	86
Curiosity	4	3	8	11	11	11	92
Enjoyment	1	1	0	0	0	1	7
Confusion	1	1	3	0	1	2	16
Frustration	0	0	0	0	3	0	6
Total	10	5	17	25	33	19	207
Sample total	182	339	709	626	454	358	2668

Table 7

Frequency of curiosity to metacognitive self-regulation transitions

	Following curiosity	**Total**
Metacognitive self-regulation	11 (22.92 %)	358 (13.42 %)
Other learning strategies	37 (77.08 %)	2310 (86.58 %)
Learning strategies	48 (100 %)	2668 (100 %)

Table 8

Frequency of surprise to rehearsal transitions

	Following surprise	**Total**
Rehearsal	6 (12.77 %)	709 (26.57 %)
Other learning strategies	41 (87.23 %)	1959 (63.43 %)
Learning strategies	47 (100 %)	2668 (100 %)

Table 9

Frequency of surprise to critical thinking transitions

	Followed surprise	**Total**
Critical thinking	18 (38.30 %)	454 (17.02 %)
Other learning strategies	29 (61.70 %)	2214 (82.98 %)
Learning strategies	47 (100 %)	2668 (100 %)

Table 10

Means and standard deviations for self-reported variables

	M	*SD*
Knowledge assessments		
Prior knowledge test	48.60	16.33
Inference verification task	65.41	12.38
Self-reported epistemic beliefs		
Uncertainty	5.65	1.62
Complexity	5.92	1.46
Justification: Inquiry	7.07	1.71
Source: Active construction	5.60	1.47
Self-reported epistemic emotions		
Surprise	2.46	.90
Curiosity	3.30	.83
Enjoyment	2.37	.77
Confusion	2.19	.76
Frustration	2.48	.89
Anxiety	2.08	.91
Boredom	2.15	.77

Table 11

Correlations between knowledge assessments, self-reported epistemic beliefs, self-reported epistemic emotions, and learning strategies

	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1. PK	.189	.112	-.162	.114	.134	-.209*	-.139	-.248*	-.037	-.021	-.021	-.038	-.076	.017	.193*	.030
2. Post-test	---	.368*	-.213*	.025	-.138	-.153	.003	-.110	-.137	.059	-.069	-.090	.217*	.267*	.279*	.125
3. Complexity		---	-.367*	.149	.035	-.144	.110	-.029	-.046	.025	.025	-.076	.105	.310*	.290*	.094
4. Uncertainty			---	-.067	.120	-.009	-.138	-.058	-.016	-.153	-.171	.213*	-.165	-.101	-.120	-.049
5. Justification				---	-.013	.146	.252*	.267*	-.064	-.152	.004	-.247*	.076	.243*	.197*	.128
6. Source					---	-.062	-.063	-.031	-.028	-.108	-.164	.079	-.050	-.083	.011	-.010
7. Surprise						---	.543*	.422*	.364*	.227*	.528*	-.219*	.157	.095	-.078	.008
8. Curiosity							---	.568*	.332*	.213*	.445*	-.295*	.138	.208*	.179	.074
9. Enjoyment								---	.208*	.043	.246*	-.269*	.100	.083	.093	-.072
10. Confusion									---	.503**	.552*	.122	.057	.064	.052	.061
11. Frustration										---	.714*	.173	-.050	.040	.074	.039
12. Anxiety											---	-.036	.002	.019	.012	-.023
13. Boredom												---	-.186	-.087	-.145	-.009
14. Rehearsal													---	.562*	.218*	.304*
15. Elaboration														---	.658*	.602*
16. CT															---	.556*
17. MSR																---

*$p < .05$; † = think-aloud data, PK = prior knowledge, CT = critical thinking, MSR = metacognitive self-regulation. Verbalized epistemic emotions were not included in the correlation table as frequencies were too low.

Table 12

Number of expected relations versus observed relations in path analysis and state-transition analysis

	Muis et al.'s (2015) model	Consistent with hypothesis	Contrary to hypothesis	Not hypothesized	Consistent with Muis et al.'s (2015) results
Epistemic beliefs to epistemic emotions	28	6	2	0	3
Epistemic beliefs to learning strategies	16	4	0	0	2
Epistemic emotions to learning strategies	14	4	1	5	4
Learning strategies to learning achievement	4	1	1	0	1
Total	62	15	4	5	10

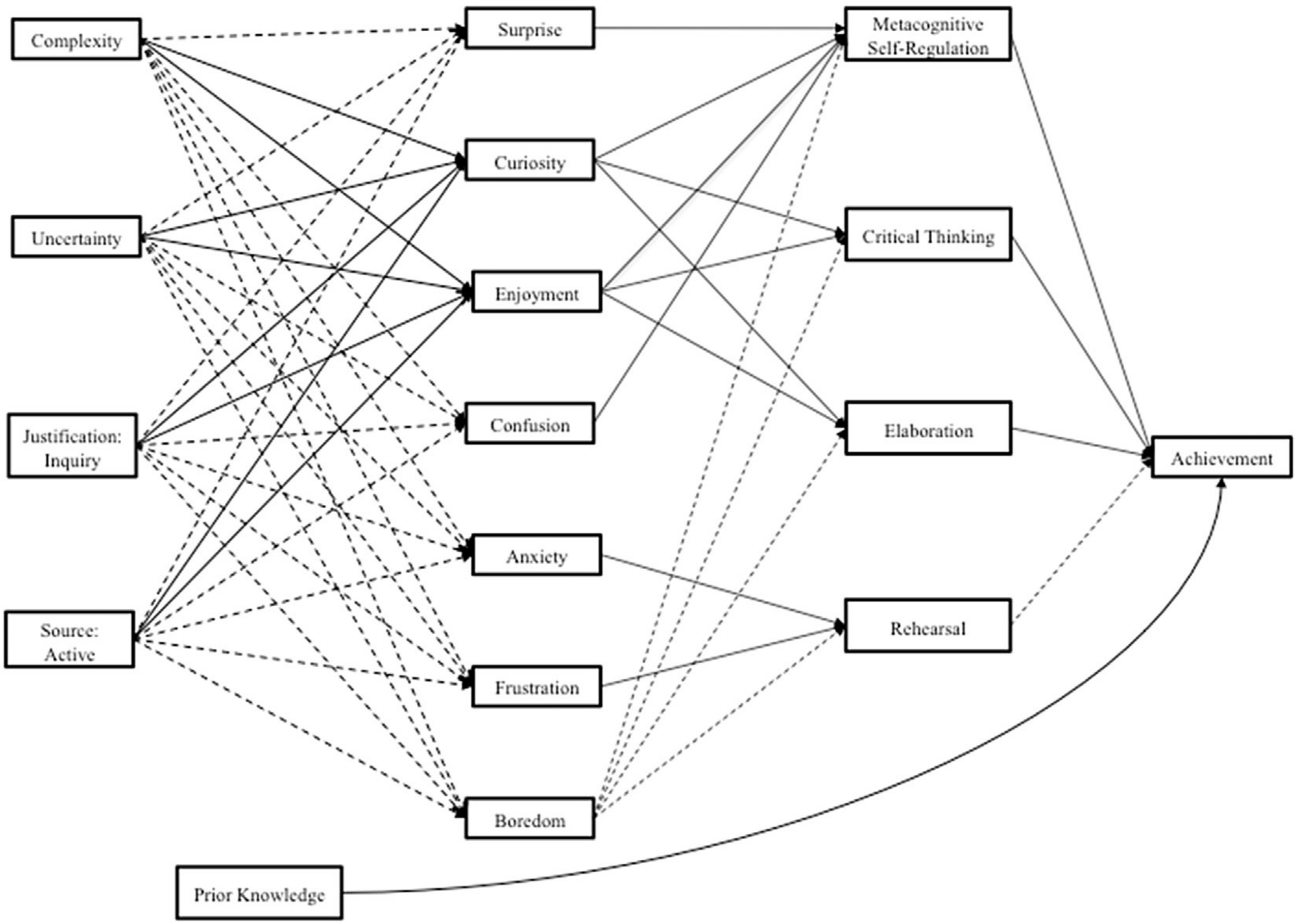

Figure 1. Muis et al.'s (2015) hypothesized model (reprinted with permission from *Learning and Instruction*)

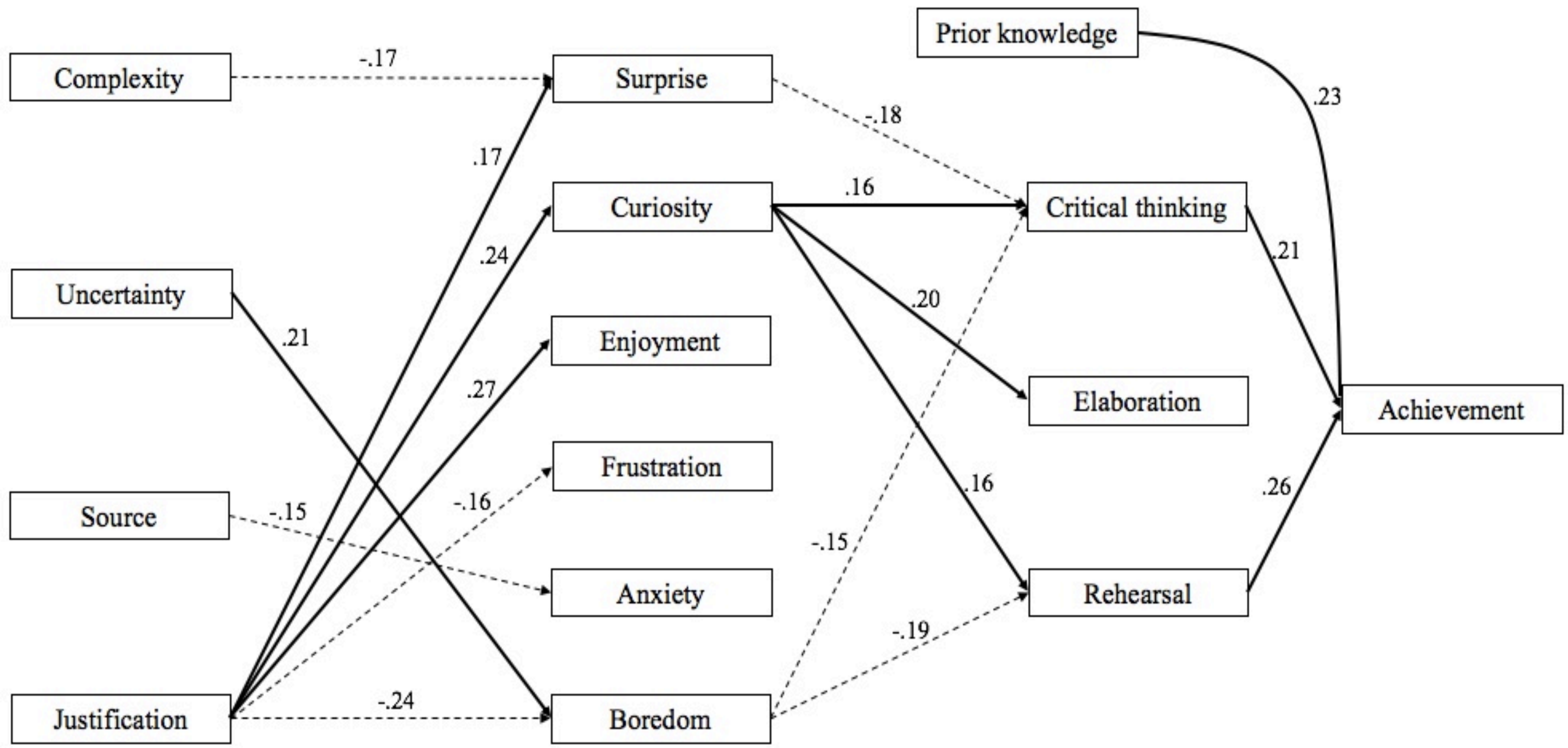

Figure 2. Final model with significant standardized beta coefficients at p < .05. Paths for insignificant coefficients are not included. Doted lines represent negative relations and solid lines represent positive relations.

Appendix A

Experimental Texts

1. Manmade Greenhouse Effect: Humans Cause Climate Change

Center for International Climate and Environmental Research - University of Oslo
http://www.cicero.uio.no/abc/klimaendringer.html

The UN's climate panel concludes in its third main report from 2001 that it is highly probable that manmade discharges of climate gases have contributed significantly to the climate changes observed in the last 30 to 50 years.

Manmade greenhouse effect
Since pre-industrial times (around 1750) the concentration of carbon dioxide (CO_2) has increased by around 31 per cent, the concentration of methane (CH_4) has increased by around 151 per cent and the concentration of nitrogen oxide (N_2O) has increased by around 17 per cent. These increases are due to manmade discharges and have resulted in a *stronger* greenhouse effect. Human activities have also introduced into the atmosphere smaller quantities of a number of climate gases that do not exist in the atmosphere naturally.

The increase in the concentration of CO_2 in the atmosphere forms the primary constituent (around 60%) of the strengthening of the greenhouse effect for which mankind is responsible. These manmade discharges of CO_2 are first and foremost due to the consumption of fossil fuels (coal, oil and gas) and the deforestation of tropical regions.

Mankind's discharges amount to only a small part of the quantity of climate gases released into the atmosphere and the effect is minor in relation to, for example, the effect of naturally occurring water vapour. The problem is that the climate system is very complex and sensitive, and even small changes in the system can trigger major consequences. Nature's own discharges of climate gases form part of a cycle in which, for example, rotting trees release CO_2 and living trees absorb CO_2 through photosynthesis. Our CO_2 discharges from, among other things, the burning of fossil fuels do not form part of this cycle and result in surplus CO_2 which remains in the atmosphere for a long time.

2. Climate Changes Are Due To Natural Causes.

APOLLON – University of Oslo research magazine
Professor Oddbjørn Engvold, Institute of Theoretical Astrophysics, University of Oslo
Climate has always varied over time and will continue to do so. This is a normal state of affairs. Changes to the earth's climate are to a large extent steered by astronomical conditions. For example, small changes in the earth's orbit around the sun and changes in the tilt with respect to the earth's rotational axis – which is responsible for us having seasons – are associated with significant climate changes. Changeovers between ice ages and warmer periods are demonstrably linked to these external astronomical conditions.

The sun affects the layer of clouds
Without the sun we would not have the greenhouse effect, which is a prerequisite for us having liveable conditions on our planet. Even small variations in the radiation from the sun will affect the climate. The sun is a magnetic star and areas of its surface have strong magnetic fields. These affect its radiation and can result in both weak increases and decreases, and these in turn affect the climate even in the case of changes at the per thousand level.

The sun's magnetic fields surround both the earth and the other planets. When particles that originate from previously exploded stars penetrate the atmosphere, they could affect the formation of low clouds. This in turn has an effect on the earth's weather. The sun's magnetic field will, to a varying degree, stem the quantity of particles that penetrate our atmosphere. This could function as an "on/off" switch for the layer of clouds around the earth.

There has been much debate about climate in recent years and the discussion has often been about the extent to which mankind's activities are affecting our climate in relation to the natural variations. We still do not have a basis for establishing that human pollution of the atmosphere is the main cause of climate change.

3. The Negative Consequences Of A Stronger Greenhouse Effect

Stronger storms, more hurricanes and increasingly tumultuous weather are just a few of the negative consequences we can expect in the next few years. Global warming may also weaken the Gulf Stream and result in serious cooling in Northern Europe.

JOURNALIST GUSTAV JENSEN
A number of oceanographers fear highly uncomfortable side effects due to global warming. It may weaken the ocean currents in the North Atlantic to such a degree that there is a genuine risk of serious and long-term cooling both in the Nordic Region and large parts of Europe and North America. The Nordic Region would be significantly colder without the Gulf Stream.

Oceanographers know all too well that the warnings will cause surprise because we are reminded almost daily of the opposite, namely that global warming will raise the earth's average temperature. However, paradoxically, both things could well occur at the same time. If the circulation of the Atlantic is disturbed, we could have a fall in the average temperature of 3-5 °C. This will have a dramatic effect on farming and forestry, while at the same time there will be a greater need for heating.

And there is much that indicates that the disturbances are well underway. More ice is melting due to global warming and more precipitation is falling over, among other places, Russia. This is resulting in greater outward flows of freshwater from the major Russian rivers into the Arctic Ocean. At the same time we risk losing the Western Arctic ice and Greenland ice.

When the ice surrounding the poles melts, this will not just result in an increased mass of water, it will also result in increased evaporation from the oceans. This will provide hurricanes with energy. *Time* magazine reports that hurricanes have increased in both number and intensity since 1995.

According to the UN's climate panel, an increased greenhouse effect resulted in water levels rising between 10 and 20 cm in the last century and by 2100 ocean levels will rise by between 9 and 88 cm. This will be catastrophic for many coastal communities – especially in developing countries.

4. Warmer Climate Presents New Opportunities

Regions that are now becoming accessible due to global warming conceal enormous riches. The melting of the ice permits the exploitation of resources in the northerly regions.

JOURNALIST JOHN HULTGREN

Temperatures around the North Pole are increasing at double the rate of other places around the globe according to UN experts. The Arctic ice is melting so quickly that a sea passage between the Atlantic Ocean and the Pacific Ocean may be accessible to ordinary ships during the summer by 2050. The route through the Northwest Passage to Asia will reduce the journey distance between London and Tokyo from 21,000 to 16,000 kilometres.

The northern regions that are becoming accessible also conceal enormous riches. The oil and gas deposits that are concealed there are estimated to amount to 30 per cent of the earth's deposits.

And there is more to be found in the northern regions than petroleum. There is also gold, diamonds, copper and zinc. There will be a lot of traffic due to such exploration says Frederic Lasserre, a geographer at Laval University in Quebec in Canada who is a specialist in Arctic regions.

The director of the Nansen Environmental and Remote Sensing Center, also points out positive consequences of global warming, which occurs in the Arctic in particular: - A warmer climate could result in better growing conditions and lower heating costs. The ice in the Barents Sea will be pushed northwards and eastwards due to increasing south-westerly winds and warmer weather. This will expand winter fishing grounds and make it easier for the gas and oil industry to operate during the winter season.

Appendix B

Prior Knowledge Test

Below are statements about central topics concerning natural and environmental issues. Please circle the option that you believe correctly completes each statement.

1. The Kyoto Protocol deals with
   a) trade agreements between rich and poor countries
   b) reduction in the discharge of climate gases
   c) the pollution of the Pacific Ocean
   d) protection of the ozone layer
   e) limitations on international whaling

2. The greenhouse effect is due to
   a) holes in the ozone layer
   b) increased use of nuclear energy
   c) increased occurrence of acidic precipitation
   d) heat trapped in the atmosphere
   e) the pollution of the oceans

3. Mankind's discharges of carbon dioxide (CO_2) are largely due to the use of
   a) propellants (chlorofluorocarbon) in spray cans
   b) fertilizers in farming
   c) phosphatic detergents
   d) fossil fuels
   e) atomic energy

4. Research indicates that the earth's average temperature
   a) has risen by more than 5 °C in the last 100 years
   b) has risen by more than 5 °C in the last 10 years
   c) has risen by less than 1 °C in the last 100 years
   d) has risen by more than 10 °C in the last 100 years
   e) is in the process of becoming stabilized

5. Some of the most important climate gases are
   a) chlorine and hydrogen
   b) oxygen and propane
   c) nitrogen oxides and butane
   d) propellants and aerosols
   e) water vapour and nitrous oxide

6. The earth's climate has changed
   a) due to astronomical conditions
   b) due to changes in the earth's circumference at the equator
   c) primarily due to increased discharges of ozone gas
   d) due to reduced discharges of ozone gas

e) because the ocean currents have increased in intensity

7. The concentration of carbon dioxide (CO_2) in the atmosphere
   a) varies between high and low degrees of longitude
   b) varies very little from place to place
   c) is greatest in industrialized parts of the world
   d) is greatest in the polar regions
   e) varies a lot from place to place

8. The greenhouse effect is
   a) primarily a natural process
   b) primarily manmade
   c) a relatively new phenomenon
   d) greatest in the stratosphere
   e) strongest in industrialized parts of the world

9. Global climate change can
   a) lead to a lowering of ocean levels
   b) lead to less extreme weather on the entire earth
   c) lead to an influence of ocean currents
   d) lead to increased volcanic activity
   e) lead to more solar energy escaping from the atmosphere

10. Climate gases
   a) do not occur naturally in the atmosphere
   b) are necessary for much of the life on the earth
   c) did not exist in pre-industrial times
   d) are exclusively synthetic combinations
   e) can cause legionaires' disease

11. Mankind's discharges of carbon dioxide (CO_2)
   a) can lead to an increase in the ozone layer
   b) are substantially reduced through international environmental initiatives
   c) are necessary for the life on the earth
   d) can change the heat balance of the earth
   e) introduce into the atmosphere the largest part of the climate gases

12. The Kyoto Protocol is
   a) a binding agreement between USA and EU
   b) a binding agreement managed by the World Trade Organization (WTO)
   c) a binding international agreement managed by the UN
   d) still not ratified by a sufficient number of countries
   e) an important agreement about the storing of radioactive waste

13. Human activities
   a) form the basis of the greenhouse effect

b) enhance the greenhouse effect
c) have increased the amount of ozone in the ozone layer
d) have made the earth resemble a greenhouse
e) can influence the radiation from the sun

14. The earth's average temperature increases
    a) because of a rise in temperature in the core of the earth
    b) because of changes in the moon's reflection of the sunlight
    c) because of less clouds in the atmosphere
    d) because of increased discharges of climate gases
    e) because the radiation of heat from the sun penetrates more easily down to the surface of the earth

15. The greenhouse effect is enhanced by
    a) increased use of fossil fuels
    b) radiation of heat from the sun
    c) holes in the ozone layer
    d) increased planting in tropical regions
    e) more growth of gene-modified plants

Appendix C

Topic-Specific Epistemic Beliefs Questionnaire (Adapted to Climate Change)

Issues concerning climate are highly topical and often mentioned in the media. We can read daily about issues such as climate change, pollution of the atmosphere, global warming, extreme weather, rise in ocean levels, and melting of ice in polar regions. This is material that we often encounter in newspapers and magazines, as well as on TV and radio. Most people who do research on climate have a background in natural science, for example in chemistry, biology, or meteorology. The following questions concern knowledge about climate and how one comes to know about climate. There are no right or wrong answers to these questions; it is your personal beliefs that interest us. Use the scale below to answer the questions. If you strongly agree with a statement, circle 10; if you strongly disagree, circle 1. If you more or less agree with a statement, circle the number between 1 and 10 that best expresses your belief.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Strongly disagree									Strongly agree

Uncertainty of knowledge about climate change

1. What is considered to be certain knowledge about climate today, may be considered to be false tomorrow
2. Certain knowledge about climate is rare
3. The results of climate research are preliminary
4. Theories about climate can be disproved at any time
5. The knowledge about issues concerning climate is constantly changing
6. Problems within climate research do not have any clear and unambiguous solution

Complexity of knowledge about climate change

7. *With respect to knowledge about climate, there are seldom connections among different issues
8. *Within climate research, accurate knowledge about details is the most important
9. *Within climate research, various theories about the same will make things unnecessarily complicated
10. *Knowledge about climate is primarily characterized by a large amount of detailed information
11. *The knowledge about climate problems is indisputable
12. *There is really no method I can use to decide whether claims in texts about issues concerning climate can be trusted

Source of knowledge about climate change

13. *I often feel that I just have to accept that what I read about climate problems can be trusted
14. *When I read about issues concerning climate, the author's opinion is more important than mine

15. *With respect to climate problems, I feel I am on safe ground if I only find an expert statement
16. *When I read about climate problems, I only stick to what the text expresses
17. *My personal judgments about climate problems have little value compared to what I can learn about them from books and articles

Justification for knowing about climate change

18. To check whether what I read about climate problems is reliable, I try to evaluate it in relation to other things I have learned about the topic
19. When I read about issues related to climate, I try to form my own understanding of the content
20. To gain real insight into issues related to climate, one has to form one's own personal opinion of what one reads
21. When I read about issues concerning climate, I evaluate whether the content seems logical
22. To be able to trust knowledge claims in texts about issues concerning climate, one has to check various knowledge sources
23. Within climate research, there are connections among many topics
24. I understand issues related to climate better when I think through them myself, and not only read about them

*Reverse coded

Appendix D

Epistemic Emotions Scale

We are interested in the emotions you experienced when learning about genetically modified foods from the text you just read. For each emotion, please indicate the strength of that emotion by clicking the number that best describes the intensity of your emotional response during learning.

	Not at all	**Very little**	**Moderate**	**Strong**	**Very strong**
	1	2	3	4	5
1. Curious					
2. Bored					
3. Confused					
4. Surprised					
5. Interested					
6. Anxious					
7. Frustrated					
8. Inquisitive					
9. Dull					
10. Amazed					
11. Worried					
12. Happy					
13. Muddled					
14. Irritated					
15. Monotonous					
16. Excited					
17. Astonished					
18. Dissatisfied					
19. Nervous					
20. Joyful					
21. Puzzled					
22. Others: ____________					

Appendix E

Post-Test Inference Verification Test

Each of the following sentences consists of a statement that can reasonably be inferred from one of the texts you have just now read, or of a statement that cannot reasonably be inferred from one of the four texts. If an inference can reasonably be drawn on the basis of one of the four texts, mark this statement as Yes. If it is not reasonable to draw an inference on the basis of one of the four texts, mark this statement as No.

		Yes	**No**
1.	Warmer climate in the Arctic can lead to some traditional trades being replaced with new industrial activity		
2.	Increased evaporation from the oceans can lead to more natural disasters in the future		
3.	Global warming can be due to the fact that the sun's magnetic fields draw the earth and the other planets closer to the sun		
4.	Global warming may result in both cooling in Northern Europe and higher average temperature on the earth		
5.	The UN's climate panel concludes that mankind's discharges of climate gases have resulted in a stronger greenhouse effect in the last decades		
6.	That the earth's climate changes is to a large extent steered by astronomical conditions, although these can only lead to temperature changes at the per thousand level		
7.	The melting of ice in the northerly regions may lead to territorial conflicts between countries such as Canada and the USA		
8.	Discharges of CO_2 due to the consumption of fossil fuels and the deforestation of tropical regions form part of a cycle in which, for example, rotting trees release CO_2 and living trees absorb CO_2 through photosynthesis		
9.	The natural greenhouse effect is much more important for the earth's average temperature than is the manmade greenhouse effect		
10.	Studies of the celestial bodies can give us knowledge about the causes of global climate changes		
11.	A weakening of the Gulf Stream can create better production conditions for farming and forestry in the Nordic Region		

12. Without human beings' discharges of CO_2 into the atmosphere, the warming of the surface of the earth and the air layer around the earth could not be compared to what takes place in a greenhouse

13. The consumption of fossil fuels and the deforestation of tropical regions are most responsible for the strengthening of the greenhouse effect

14. The rise in temperatures around the North Pole may lead to increased extraction of oil and gas

15. The manmade discharges of CO_2 contribute little to the strengthening of the greenhouse effect compared to the impact of naturally occurring water vapour

16. The global climate changes may be steered from space at least as much as from the earth

17. Because the circulation of the Atlantic is disturbed, we could have a catastrophic rise in water levels towards 2100—especially in developing countries

18. A weakening of the Gulf Stream could negatively affect farming and forestry in the Nordic Region.

19. Warmer climate in the Arctic could reduce the need for heating so much that there will be no use for the enormous oil and gas deposits that become accessible there.

20. Increased greenhouse effect can lead to significant losses of territory for countries such as the Netherlands, Bangladesh, and the Maldives

21. Enormous riches can become accessible in the northerly regions due to reduced journey distance through the Northwest Passage to Asia

Bridging Text

In Chapter 3, we empirically tested a model that situates epistemic emotions as mediators in the relation between epistemic cognition and self-regulated learning. Antecedents of epistemic emotions were examined using verbal data, and two analytical approaches were used to test the model at different levels of granularity: In Study 1, we examined the immediate consequences of epistemic emotions on self-regulated learning strategies; in Study 2, we assessed predictive relations between epistemic beliefs, epistemic emotions, learning strategies, and learning achievement over an entire learning session.

In Chapter 4, the generalizability of this model is tested by examining the mediational role of epistemic emotions in the relationship between epistemic cognition and another important outcome of education: critical thinking. When thinking about socio-scientific issues, one goal is to educate learners who can think critically in making decisions that have personal and societal consequences. Further, researchers have called for greater conceptual clarity between epistemic cognition and critical thinking, and emphasized the importance of empirical research to map the interrelationships between these two constructs (see Bråten, 2016). The study presented in Chapter 4 addresses this question by situating epistemic cognition as one important underpinning to critical thinking. Furthermore, it addresses limitations in epistemic cognition and critical thinking research by presenting an empirical study that measures critical thinking in a meaningful way in the context of an epistemically demanding task.

References

Bråten, I. (2016). Epistemic cognition interventions. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 360–371). New York, NY: Routledge.

Chapter 4

Manuscript 2

Thinking Critically About Socio-Scientific Issues: The Roles of Epistemic Cognition and Epistemic Emotions

Chevrier, M., Muis., K. R., Pekrun, R., Sinatra, G., & Denton, C. A. (under review). Thinking critically about socio-scientific issues: The roles of epistemic cognition and epistemic emotions. *Contemporary Educational Psychology*.

Abstract

When contending with socio-scientific issues, individuals' expectations about the nature of knowledge and knowing, as well as their emotions when these expectations are met or not, may play an important role in critical thinking. In this study, we examined the role of epistemic emotions in mediating the relationship between epistemic cognition and critical thinking when contending with conflicting knowledge about genetically modified foods. Two hundred four university students completed a prior knowledge test and reported epistemic beliefs about genetically modified foods and read a text that presented advantages and disadvantages of genetically modified foods. Participants then reported the epistemic emotions they experienced during reading, and then composed an argumentative essay about genetically modified foods. Essays were coded for critical thinking. Results from path analysis revealed that a belief in complex knowledge predicted less surprise, less enjoyment, less confusion, and less frustration, and a belief in the active constructive of knowledge predicted more frustration. In turn, confusion and anxiety positively predicted critical thinking, and frustration and boredom negatively predicted critical thinking. Lastly, confusion and frustration mediated relations between epistemic beliefs and critical thinking. Results suggest complex relations between epistemic cognition, epistemic emotions, and critical thinking that have implications for educational practice as well as for future research on epistemic cognition and epistemic emotions.

Keywords: epistemic cognition; epistemic beliefs; emotions; critical thinking.

Introduction

The information landscape in the 21st century is one of contrast. On the one hand, the Internet and social media provide an unprecedented wealth of diverse and accessible information from around the world. On the other hand, the structure of social networks and algorithmic filtering (e.g., news feeds, recommendations) have considerably narrowed the breadth of content that individuals consume, making it increasingly difficult to escape echo chambers and challenge one's views with new information (Garimella, De Francisci Morales, Gionis, & Mathioudakis, 2018; Marks, Copland, Loh, Sunstein, & Sharot, 2019; Sîrbu, Pedreschi, Giannotti, & Kertész, 2019). In this context, any topic is likely to become the object of controversy. Topics of personal and global relevance such as ways to combat climate change or the safety of infant vaccines appear to be controversial and unresolved matters, dividing the public's opinion and stifling political action. To make informed decisions individually and collectively, the challenge lies in overcoming personal biases, and weighing the pros and cons of conflicting perspectives to reconcile views. This is one aspect of the process known as critical thinking (Kuhn, 2018).

There is little debate over the idea that society benefits when individuals are able to think deeply and critically about important issues (e.g., Dewey, 1933; Halpern, 2014). Educating critical thinkers is of vital importance for the well-being of future generations. Accordingly, the Organisation for Economic Cooperation and Development (OECD; Tremblay, Lalancette & Roseveare, 2012) has made teaching critical thinking a priority for higher education. However, empirical research in the United States shows that teaching critical thinking skills is arduous and often unyielding (Abrami et al., 2008; Huber & Kuncel, 2015; Niu, Behar-Horenstein, & Garvan, 2013), with up to 45% of American students completing post-secondary degrees lacking these essential skills (Arum & Roksa, 2011). In light of these observations, many have pointed out that to improve critical thinking outcomes, empirical work is needed to achieve a greater understanding of the underlying cognitive, motivational, and affective mechanisms that enable critical thinking (Alexander, 2014; Bråten, 2016; Greene & Yu, 2016).

Controversial socio-scientific topics are characterized by the presence of opposing views that offer conflicting explanations to complex and multifaceted phenomena (Levinson, 2006). Deciding what to believe or what to do about these topics requires that individuals engage with the underlying issues of knowledge that characterizes these topics: What counts as knowledge? How certain are the facts? Who can be trusted to provide a clear perspective on the topic? In other words, thinking critically about socio-scientific topics requires thinking about the knowledge- and knowing-related aspects of these issues (Greene & Yu, 2016), a process termed *epistemic cognition* (Greene, Bråten, & Sandoval, 2016). However, when engaged with complex and conflicting issues, individuals' expectations about the nature of knowledge and knowing may be challenged, and in turn elicit emotions such as surprise, curiosity, confusion, frustration, or anxiety (Muis, Chevrier, & Singh, 2018; Muis et al., 2015).

Common understandings of critical thinking assume that emotions have no role to play in critical thinking, except perhaps to introduce unwarranted bias (Kahneman, 2004). However, knowing and feeling are closely related, and emotions may play a significant role in helping individuals disentangle the two (Brun & Kuenzle, 2008; Damasio, 2005). Indeed, evidence suggests that the way individuals feel about complex and conflicting knowledge plays a role in knowledge building and knowledge revision (Muis et al., 2015; Trevors & Kendeou, 2017). However, little is known about how cognitive and affective processes relate to critical thinking. As such, the aim of the current study is to shed light on the role that epistemic cognition and epistemic emotions play when thinking critically about socio-scientific issues. In the following sections, we define the concepts of critical thinking, epistemic cognition, and epistemic emotions, and review theoretical and empirical work that informed the hypotheses of the current study.

Thinking Critically About Controversial Topics

Critical thinking is regarded as one of the most important skills that individuals can develop and is a fundamental aim of education (Bailin and Siegel, 2003; Halpern, 2014). Though several definitions of critical thinking are offered in the literature (e.g., Ennis, 2018; Facione, 1990; Kurfiss, 1988; Lipman, 1991; Scriven & Paul, 1996; Siegel, 1988), Ennis (2018) argued that they do not significantly differ from each other. Drawing from these definitions, we define critical thinking as purposeful, reasonable and reflective thinking that enables individuals to decide what to believe or what to do when facing complex and conflicting issues (Ennis, 2018; Facione, 1990).

Definitions of critical thinking typically assume that critical thinking requires both *skills* and *dispositions* (e.g., Bailin & Siegel, 2003; Ennis, 2018; Facione, 1990; Paul, 1990). Here, skills are defined as the ability to coordinate multiple cognitive processes together to an end and include, for instance, verbal reasoning, problem-solving, and self-regulation (e.g., Halpern, 2014). On the other hand, dispositions refer to the relatively stable traits, attitudes, and habits of mind that characterize those who not only possess the skills to think critically, but who use those skills adequately (Siegel, 1988). These dispositions include inquisitiveness, open-mindedness, and willingness to engage in effortful thinking, among others. Identifying the skills and dispositions associated with critical thinking has been the object of an important task force put forth by the American Philosophical Association. A panel of 46 experts and leading scholars, The Delphi Committee, proposed six fundamental skills associated with critical thinking, as well as 16 subskills and 19 dispositions. The six fundamental skills of critical thinking included interpretation, analysis, evaluation, inference, explanation, and self-regulation.

Recent research has shown that specific critical thinking skills are different across academic disciplines (Gordon, 2000). For instance, in nursing, critical thinking is concerned with rigorous investigation and reflection on all aspects of a clinical situation to decide on an appropriate course of action (Simpson & Courtney, 2002). In engineering, critical thinking consists of considering assumptions in problem-solving, selecting appropriate methods for experiments, structuring open-ended design problems, and assessing social impacts (Claris & Riley, 2012). When it comes to taking a position on a socio-scientific issue such as genetically modified foods, the task of critical thinking rests on identifying opposing arguments, assumptions, and evidence, evaluating the credibility, reliability, and relevance of claims, producing valid explanations and arguments, and making decisions or drawing valid conclusions (Facione, 1990; Kuhn & Crowell, 2011).

Bailin and Siegel (2003), as well as other philosophical theorists of critical thinking (e.g., Paul, 1990), emphasized the importance of generalizable abilities such as assessing reasons, evaluating claims, identifying underlying assumptions, and recognizing and applying valid forms of justification. They argue that what is "critical" about critical thinking is the use of a criterion—an *epistemic* criterion—for evaluating reasons and making sound judgments. The generalizable reasoning abilities described by Bailin and Siegel (2003) have long been studied by educational and developmental psychologists in the field of epistemic cognition (e.g., Chinn, Sandoval, & Samarapungavan, 2011; Greene et al., 2016; Hofer & Bendixen, 2012; King & Kitchener, 1994; Muis, Bendixen, Haerle, 2006). Epistemic cognition concerns individuals' thoughts and beliefs about the nature of knowledge and the process of knowing (Hofer &

Pintrich, 1997). From the perspective of educational development, Kuhn (1991, 1999) identified the development of epistemic cognition as perhaps the most central underpinning of critical thinking. However, little research on critical thinking has considered individuals' beliefs and thoughts about knowledge and knowing (Alexander, 2014; Hofer, 2004; Greene & Yu, 2016). We next review literature that has explored relations between epistemic cognition and critical thinking.

The Role of Epistemic Cognition in Critical Thinking

Epistemic cognition. Epistemic cognition refers to how individuals vet, acquire, understand, justify, and use knowledge (Greene et al., 2016). Specifically, individuals engage in epistemic cognition when they activate personal beliefs about the nature of knowledge and knowing (i.e., epistemic beliefs), define epistemic aims and criteria for knowing, and use evaluation and justification strategies to address issues of knowledge and knowing (Barzilai & Zohar, 2014; Muis et al., 2018). The vast majority of research on epistemic cognition has focused on epistemic beliefs, which refer to individuals' personal beliefs about the nature of knowledge and the process of knowing (Hofer & Pintrich, 1997). Hofer and Pintrich (1997) proposed that epistemic beliefs comprise four dimensions: (1) the *complexity* of knowledge, ranging from the belief that knowledge consists of a simple accumulation of facts, to the belief that knowledge consists of a complex structure of interrelated propositions; (2) the *uncertainty* of knowledge, ranging from the belief that knowledge is certain and unchanging, to the belief that knowledge is tentative and evolving; (3) the *sources* of knowing, ranging from the view that knowledge resides in external authorities, to the view that individuals are knowers that actively construct knowledge; (4) the *justification* for knowing, which addresses how individuals evaluate knowledge claims, from an unquestioning reliance on authorities, to the evaluation and integration of evidence and arguments from various sources.

Numerous empirical studies have shown that individuals who adopt more constructivist epistemic cognition (e.g., who believe that knowledge is complex, tentative, actively constructed, and justified via evaluation) use better learning strategies (Schommer, 1990), show better self-regulation during problem solving (Muis, 2008; Muis & Franco, 2010), and attain greater academic performance (Schommer, Crouse, & Rhodes, 1992; Muis & Duffy, 2013) than those who adopt less constructivist epistemic cognition (i.e., who believe that knowledge is simple, certain, handed down from, and justified by authorities).

Relations between epistemic cognition and critical thinking. Across multiple studies, more constructivist epistemic cognition has been positively associated with critical thinking. Specifically, constructivists are better at identifying the elements of discourse (i.e., assumptions, evidence, arguments; Mason & Boscolo, 2004) and understanding authors' viewpoints (Barzilai & Eshet-Alkalai, 2015) when reading texts that comprise conflicting perspectives, compared to individuals with less constructivist epistemic cognition. Similarly, when contending with multiple sources of information, individuals with more constructivist epistemic cognition performed better at evaluating the trustworthiness and credibility of information using the features of the sources, distinguishing between types of sources, making associations between a source and its content, using criteria to evaluate the trustworthiness of sources, and using source integration strategies than those with absolutist, relativist, or less constructivist views (Barzilai & Zohar, 2012; Bråten, Anmarkrud, Brandmo, & Strømsø, 2014; McGinnis, 2016; Strømsø & Bråten, 2014).

More constructivist beliefs about the justification for knowing have been associated with the use of more competent criteria to evaluate the trustworthiness of sources (Strømsø et al., 2011). Moreover, learners with more constructivist epistemic cognition have been found to possess greater argumentative skills (Chan, Ho, & Ku, 2011; Mason & Boscolo, 2004; Yang & Tsai, 2010), which Kuhn (2018) situates as a key dimension of critical thinking. Constructivists are also better able to support their statements with acceptable, relevant, and multiple justifications (Mason & Scirica, 2006). In sum, individuals who possess more constructivist epistemic cognition are more likely to possess the cognitive skills necessary to think critically. In support of this, Muis and Duffy (2013) found that graduate students who received an intervention designed to develop more constructivist epistemic beliefs over the course of a semester also showed more critical thinking when learning statistics.

Despite much empirical work dedicated to exploring the link between epistemic cognition and the skills associated with critical thinking, much less work has explored how the dispositions to think critically may also relate to epistemic cognition. Namely, compared to less constructivist epistemic cognition, more constructivist epistemic cognition has been related to the will to take on multiple perspectives, reconsider one's own thinking when drawing conclusions about controversial issues (Schommer-Aikins & Hutter, 2002), engage in effortful thinking (Hyytinen, Holma, Toom, Shavelson & Lindblom-Ylänne; 2014), and display skepticism towards unreliable sources (McGinnis, 2016). Though motivational and affective dispositions have been proposed to support critical thinking (Chinn et al., 2011; Muis et al., 2015; 2018), researchers from both the critical thinking and epistemic cognition literature have generated limited research to understand how epistemic cognition relates to the affective states that dispose learners to think critically. We next review research that has explored the relation between emotions and critical thinking.

Epistemic Emotions and Critical Thinking

There is increasing evidence for the important role of emotions for learning processes and outcomes. Empirical research has related emotions to academic motivation, knowledge building and revision, as well as academic performance (Pekrun & Linnenbrink-Garcia, 2014). Broadly, emotions are defined by interrelated psychological processes that include affective (e.g., feeling nervous), cognitive (e.g., ruminating thoughts), motivational (e.g., a desire to escape), expressive (e.g., displaying a frown), and physiological (e.g., increased heart rate) components (Ellsworth, 2013; Shuman & Scherer, 2014). Emotions can generally be classified in terms of valence, where pleasant emotions are positive and unpleasant emotions are negative (e.g., enjoyment is positive, surprise is neutral, frustration is negative), and level of activation (e.g., anxiety is activating, boredom is deactivating; see Pekrun & Stephens, 2012).

In educational psychology, one important line of research has concerned achievement emotions, that is, emotions that are tied to achievement activities (e.g., studying) or achievement outcomes (success or failure), such as anxiety, pride, or shame. However, not all emotions triggered in educational settings are related to achievement. Notably, Pekrun and Stephens (2012) distinguished topic emotions, social emotions, as well as epistemic emotions. Topic emotions relate to the content of learning (e.g., pride when learning about the American space conquest), whereas social emotions focus on relations to others in the learning context (e.g., compassion, gratitude; Weiner, 2007). Of particular relevance to critical thinking, epistemic emotions relate to the perceived quality of knowledge and the processing of information (Pekrun & Stephens, 2012).

Muis et al. (2018) proposed that epistemic emotions arise as the result of appraisals of alignment or misalignment between the characteristics of incoming messages and individuals' cognitive characteristics, including prior knowledge, epistemic beliefs, and epistemic aims. In the context of contending with socio-scientific issues such as climate change, vaccination, or genetically modified foods, incoming messages are likely to be characterized by knowledge claims that are complex that also include a degree of uncertainty (Levinson, 2006). For individuals seeking simple and certain answers, engaging with such content may trigger a variety of epistemic emotions such as confusion, frustration, or anxiety. However, facing the same content, individuals who expect knowledge to be uncertain and tentative, and who see value in consulting multiple sources before coming to a conclusion, may experience curiosity and enjoyment (Chevrier et al., under review; Muis et al., 2015). When presented with tasks that engage individuals' beliefs about the nature of knowledge and knowing, frequently occurring epistemic emotions include surprise, curiosity, enjoyment, confusion, frustration, anxiety, and boredom (Muis et al., 2015; Pekrun et al., 2017).

Surprise is likely to occur when individuals appraise new information as unexpected (e.g., Meyer, Reisenzein, & Schützwohl, 1997) or when they are unable to generate an explanation for the new information (e.g., Foster & Keane, 2015). Mildly surprising information can lead to deep processing and integration of information, whereas information that is greatly surprising can be regarded as implausible and new information may fail to be integrated (Munnich & Ramney, 2018). When information is not overly complex or perceived as relatively comprehensible, curiosity may arise. Litman (2008) proposes that epistemic curiosity arises in one of two forms: as a pleasant desire for information (i.e., interest-type curiosity), or as an unpleasant urge to obtain information to close the gap between what one knows and what one wants to know (e.g., deprivation-type curiosity; see also Loewenstein, 1994; Markey & Lowenstein, 2012). If the course of curiosity is followed, enjoyment may ensue, for instance, when validation or verification of a hypothesis is achieved (Brun & Kuenzel, 2008), or when an epistemic aim is achieved (Chinn et al., 2011; Muis et al., 2018). Confusion, on the other hand, follows from a lack of understanding when novel and complex information is perceived as incomprehensible (Muis et al., 2018). Confusion can also arise in the face of severe discrepancies or contradictions, or from a disruption of goals or sequences of action (D'Mello & Graesser, 2012; Ellsworth, 2003). If an individual repeatedly fails to resolve the discrepancy causing confusion, frustration may arise (D'Mello & Graesser, 2012). Frustration can be described as a blend of anger and disappointment and, as such, can be an activating emotion when closer to anger, or deactivating if closer to disappointment (Pekrun et al., 2002).

Another negative emotion is anxiety, which arises when a message implicates knowledge that is core to one's identity. Individuals may begin to doubt or feel uncertain about their beliefs in a proposition, and feel that their identity is threatened (Hookway, 2008). Pekrun (2002, 2006) described anxiety as a "complex" emotion that can either benefit or hinder motivation to engage in effortful thinking. On the one hand, anxiety can reduce cognitive resources such as memory, leading to poor performance on complex or difficult tasks, as well as poor academic achievement (see Pekrun et al., 2002; Zeidner, 2014). However, for some individuals, anxiety can increase extrinsic motivation to invest effort in complex processes such as analytical and critical thinking to avoid goal-related failure. Lastly, boredom may arise when information is unchallenging (Chevrier et al., under review) or when an intense negative emotion like frustration or anxiety precipitates disengagement (D'Mello et al., 2014).

Consequences of epistemic emotions. Pekrun (Pekrun et al., 2002; Pekrun, 2006; Pekrun & Perry, 2014) proposed that individuals process information in emotion-congruent ways. Specifically, Pekrun and colleagues proposed that positive emotions (e.g., interest-type curiosity, enjoyment) signal that the object of judgment is valuable, leading to more positive evaluations, greater efforts to engage, more elaboration of content, and more purposeful thinking than negative emotions. On the other hand, negative emotions (e.g., frustration, anxiety, boredom) have been related to more negative evaluations, fewer efforts to engage (anxiety may be an exception), less elaboration of content, and more irrelevant thinking (see Pekrun et al., 2002 for a review). Further, positive emotions have been found to facilitate holistic, intuitive, and creative ways of thinking, whereas negative emotions have been associated to more focused, detail-oriented, analytical, and rigid modes of processing information (e.g., Bless et al., 1996).

Thus, critical thinking is theorized to be facilitated by optimal levels of surprise and positive emotions such as curiosity and enjoyment, and hindered by certain negative emotions such as frustration and boredom. On the other hand, other negative emotions such as anxiety and confusion may be beneficial for critical thinking: D'Mello and Graesser (2014) argued that confusion is central to complex learning activities such as problem-solving and generating cohesive arguments. As such, confusion is expected to be beneficial to critical thinking because it signals that there is something wrong with the current state of affairs, which can precipitate critical thinking. Similarly, anxiety in the face of complex and conflicting information may motivate critical thinking via effortful thinking to reduce the discomfort of anxiety.

Empirical evidence. To date, little theoretical and empirical work has explored how epistemic cognition relates to epistemic emotions experienced when contending with complex or conflicting information. To address this gap, Muis et al. (2015) examined relations between epistemic cognition, epistemic emotions, learning strategies—including critical thinking—and learning achievement in the context of learning about climate change. They hypothesized that individuals with more constructivist beliefs would experience more positive emotions given the consistency between the to-be-learned content and their epistemic beliefs, whereas individuals with less constructivist beliefs would experience more negative emotions given the conflicting perspectives presented to them on the causes and consequences of climate change. Results from path analyses revealed that individuals who espoused more constructivist epistemic beliefs about the justification for knowing used more critical thinking strategies, and that this relationship was mediated by curiosity: The more learners believed that knowledge is justified by systematic inquiry and integration of sources of information, the more they experienced curiosity and, in turn, the more they used critical thinking and attained greater learning achievement. They also found that surprise negatively predicted critical thinking, but surprise was not predicted by any epistemic belief dimension.

Advancing this line of research, Chevrier et al. (under review) used think-aloud protocol to capture online epistemic emotions and learning strategies, including critical thinking, in the context of learning about climate change. State-transition analyses were conducted to explore how epistemic emotions transitioned into learning strategies. They found that surprise significantly increased the likelihood of critical thinking. However, a path analysis testing for relations between self-reported epistemic beliefs, self-reported epistemic emotions, online learning strategies, and learning achievement showed that surprise negatively predicted critical thinking. Results also showed that more constructivist epistemic beliefs about the justification for knowing predicted critical thinking via more curiosity and less boredom.

In sum, significant relations between epistemic cognition, epistemic emotions, and critical thinking are suggested in the literature. However, the studies reviewed were predominately designed to assess relations between epistemic beliefs, epistemic emotions, and critical thinking during learning; they did not instruct participants to think critically. As Greene et al. (2014) argued, the study of epistemic cognition and critical thinking should involve the need to argue for, and justify, conclusions drawn across sources and perspectives. As such, to fully understand the role of epistemic cognition and epistemic emotions in critical thinking, more research is needed that assesses these constructs in appropriate settings. To address this gap in the literature, the current study sought to examine relations between epistemic beliefs, epistemic emotions, and critical thinking in the context of producing a critical argument about a socio-scientific topic.

The Current Study

On the basis of theoretical and empirical considerations from Muis, Pekrun, and colleagues (Chevrier et al., under review; Muis et al., 2015, 2018; Pekrun et al., 2002; Pekrun, 2006; Pekrun et al., 2017), as well as from the work of D'Mello and colleagues (D'Mello & Graesser, 2012; D'Mello et al., 2014), we propose the following hypotheses (see Figure 1):

Hypothesis 1: Epistemic beliefs will predict critical thinking. Specifically, more constructivist beliefs will positively predict critical thinking, and less constructivist epistemic beliefs will negatively predict critical thinking.

Hypothesis 2: Epistemic beliefs will predict epistemic emotions. Specifically, more constructivist epistemic beliefs will positively predict positive epistemic emotions, including interest-type curiosity and enjoyment, and negatively predict surprise and negative emotions, including confusion, frustration, anxiety and boredom. In contrast, less constructivist epistemic beliefs will predict surprise as well as less positive emotions and more negative emotions.

Hypothesis 3: Epistemic emotions will predict critical thinking. Specifically, surprise, curiosity, enjoyment, confusion, and anxiety will positively predict critical thinking, whereas frustration and boredom will negatively predict critical thinking.

Hypothesis 4: Epistemic emotions will mediate relations between epistemic beliefs and critical thinking.

To test these hypotheses, we designed a study that specifically embedded a task that challenged individuals to critically evaluate knowledge claims from opposing perspectives, and to take position on the topic in the form of an argumentative essay. The topic selected was genetically modified foods. Participants first took a knowledge assessment test to assess baseline knowledge about genetically modified foods and reported epistemic beliefs, then read a text on genetically modified foods that was comprised of two parts. The first part of the text was informative in nature and written in the style of a refutation text to ensure that all participants would engage in essay writing with good baseline knowledge about the nature of genetically modified foods. Refutation texts address commonly held misconceptions and directly refute them by presenting correct scientific explanations (Sinatra & Broughton, 2011). The effectiveness of refutation texts for facilitating the revision of misconceptions has been well documented (see Tippett, 2010). The second part of the text was argumentative in nature and presented a series of points in favor for and against genetically modified foods. These points were supported by evidence that varied in strength and degree of certainty, but all information provided was valid as of November 2015 (when the materials for this study were developed and data were collected).

After having read the experimental text, participants wrote an argumentative essay in favor for or against genetically modified foods.

Method

Participants

Two hundred four university students participated. Participants were recruited from three research-intensive universities from Eastern Canada (40.7%), Western Canada (26.5%), and the Southern United States (32.8%). No differences between groups were found on any of the variables of interest as a function of location. Of the combined sample, 66.2% reported as female, and 33.8% as male. The sample was ethnically diverse, with 54% of participants identifying as Asian, 25% as White, 9.5% as Latino or Hispanic, 3.6% as Black or African-American, and 1.2% as Native, Hawaiian, or Pacific Islander. Overall, 61.2% of participants learned English as a second of foreign language, with 71.2% of these participants reporting that they had learned to speak and write English before the age of 10. No effects of whether or not English was the first language spoken or written were found on any of the variables of interest. Participants studied a variety of domains (e.g., business administration, social sciences, natural sciences, computer sciences, psychology, linguistics, arts) and reported an average GPA of 3.24 out 4.0 (SD = .55). Participants from the Western Canadian institution reported significantly lower GPA (M = 2.97, SD = .67) than participants from the Eastern Canadian (M = 3.43, SD = .44) and Southern American institutions (M = 3.30, SD = .39; $F(2, 124) = 10.02$, $p < .001$). Overall, no significant differences were observed between Canadian (M = 3.23, SD = .60) versus American (M = 3.30, SD = .39) participants in terms of reported GPA. Participants were 21.46 years of age on average (SD = 4.28).

Materials

Experimental text. Participants were given a text that first presented factual information about genetically modified foods, followed by a portion that presented advantages and disadvantages of genetically modified foods (see Appendix F). The first half of the text was adapted from Heddy, Danielson, Sinatra, and Graham (2017) and focused on debunking four common misconceptions about genetically modified foods by presenting accurate scientific explanations. Erroneous conceptions included the notion that genetically modifying food is the same process as cloning, that it involves injecting hormones into a plant or animal, that it only occurs in laboratories by scientists, and that it is the product of contemporary scientific research.

The second part of the text presented four advantages of, and four criticisms against genetically modified foods. It was written by the second author and adapted from content published by the Canadian Standards Association (Whitman, 2000). To counterbalance a possible effect of text order with regard to the presentation of the advantages and disadvantages of genetically modified foods, two versions of the text were created: one version presented the advantages first, followed by the disadvantages, and the other version presented the disadvantages first, then the advantages. The text contained 1295 words in total, including the informative and argumentative sections, with a Flesch-Kincaid index of grade 12.7 and a Flesch Reading Ease index of 37.7.

Prior knowledge test. Participants' prior knowledge about genetically modified foods was measured with a 10-item multiple-choice test adapted from Heddy et al. (2017; see Appendix G). Each question presented four possible choices and participants were instructed to select the best answer. Correct answers were given a score of 1 and incorrect answers were given a score of 0. Scores were then added to create a total sum, then a percentage, which was used as an indicator of prior knowledge.

A confirmatory factor analysis (CFA) was conducted to examine the factor structure of the prior knowledge test using Mplus Version 7.11 (Muthén & Muthén, 2015). The initial model revealed a poor fit, $\chi^2 = 103.94$, $df = 35$, $p < .001$, RMSEA = .05, and CFI = .88. An analysis of item loadings revealed low loadings for two items; therefore, these items were deleted. The final model (with the remaining eight items) resulted in a good fit, $\chi^2 = 64.14$, $df = 20$, $p < .01$, CFI = .94 and RMSEA = .04. Cronbach's reliability coefficient was acceptable, $\alpha = .79$.

Epistemic beliefs. Epistemic beliefs about genetically modified foods were measured with a version of TSEBQ (Bråten & Strømsø, 2009) adapted to this topic (see Appendix H). The TSEBQ comprises 24 items that participants rate on a 7-point Likert scale ranging from "strongly disagree" to "strongly agree." Four dimensions of epistemic beliefs were measured: six items assessed beliefs about the complexity of knowledge (e.g., "Knowledge about genetic modification is primarily characterized by a large amount of detailed information"), six items assessed beliefs about the uncertainty of knowledge (e.g., "Certain knowledge about genetic modification is rare"), five items assessed beliefs about the source of knowing (e.g., "I often feel that I just have to accept that what I read about genetic modification problems can be trusted"), and seven items assessed beliefs about justification for knowing (e.g., "When I read about issues concerning genetic modification, I evaluate whether the content seems logical").

A CFA was conducted to examine the factorial validity of scores for the instrument using Mplus7. The initial model (with 24 items) showed poor fit, $\chi^2 = 419.25$, $df = 246$, $p < .001$, RMSEA = .06, and CFI = .78. Due to low loadings, 10 items were deleted: three items were removed from the uncertainty subscale, three from the complexity subscale, two from the source subscale, and three from the justification subscale. The final model (with 14 dimensions) resulted in good fit, $\chi^2 = 102.31$, $df = 71$, $p < .001$, RMSEA = .05, and CFI = .93. Cronbach's reliability coefficients were acceptable, α = .69 for the uncertainty subscale; α = .68 for the complexity subscale; α = .68 for the source subscale, and .76 for the justification subscale.

Epistemic emotions. Epistemic emotions experienced while reading the experimental text were measured with the EES (Pekrun et al., 2017; see Appendix D). This questionnaire comprises 21 items that measure seven epistemic emotions, including: surprise, curiosity, enjoyment, confusion, frustration, anxiety, and boredom. Each item consisted of a single word describing one emotion, with three descriptors per emotion (e.g., “anxious,” “nervous,” and “worried” measured anxiety). Participants rated the intensity of their emotional responses to the text using a 5-point Likert scale ranging from “Not at all” to “Very strong.” The scores for the descriptors of each emotion were averaged to represent each emotion.

A CFA was conducted to examine the factorial validity of scores for the instrument using Mplus7. The initial model (with 7 dimensions) revealed a poor fit, $\chi^2 = 419.18$, $df = 168$, $p < .001$, RMSEA = .09, and CFI = .89. Due to low loadings, six items were removed: one from the curiosity subscale, one from the enjoyment subscale, one from the confusion subscale, one from the frustration subscale, and one from the boredom subscale. The final model resulted in good fit, $\chi^2 = 134.60$, $df = 69$, $p < .001$, RMSEA = .07, and CFI = .95. Final Cronbach’s reliability coefficients were acceptable, α = .74 for surprise; α = .80 for curiosity; α = .83 for enjoyment; α = .76 for confusion; α = .84 for frustration; α = .84 for anxiety; α = .77 for boredom.

Essay. To assess critical thinking, participants were instructed to compose a brief essay in favor for or against genetically modified foods and to justify their position. Instructions were as follows: “Based on the content you just read, write a brief (2-3 paragraphs) argument for or against genetically modified foods. Explain how you came to form and justify your point of view. You can refer back to the text you read, and include your judgment of the arguments, evidence, and conclusions it presented." Critical thinking was assessed using a coding scheme developed for this purpose.

Coding critical thinking in essays. A coding scheme was developed by the first author to assess critical thinking in argumentative essays. The coding scheme was informed by the work of Facione and Facione (2014; see Table 13 for full descriptions and examples). Five elements were targeted via the coding scheme: taking a position, presenting supportive arguments in favor of a position, acknowledging an alternative perspective, evaluating the validity of claims on both sides of the issue, and integrating arguments from opposing viewpoints into a coherent perspective or conclusion. One point was attributed if participants took a position; no points were attributed if participants did not take a position. One point was attributed if participants supported their position with valid arguments, evidence, facts or reasons; no points were attributed if no arguments were presented in support of their position or if arguments were invalid. One point was attributed if participants acknowledged and presented an alternative perspective on genetically modified foods; no points were attributed if participants only presented arguments in favor of one perspective. One point was attributed if participants evaluated claims or arguments before accepting them as valid; no points were attributed if participants expediently accepted or dismissed claims or arguments without evaluation. Lastly, one point was attributed if participants reconciled or integrated perspectives; no points were attributed if the conclusion was one-sided, categorical, or failed to acknowledge the validity of any counter-argument. Points were summed to create a total score on five.

The coding scheme was tested by the first and last authors using 31 transcripts (15% of the sample), and inter-rater reliability for the first round was established at 75%. All disagreements were resolved through discussion and were used to update the coding scheme. A second round of coding was performed, and final inter-rater reliability was established at 88%. The first author then coded the remainder of the essays.

Procedure

Participants provided informed consent to participate in the study and then completed the prior knowledge test and the TSEBQ to assess epistemic beliefs. Participants were then randomly assigned to read a version of the text that presented the advantages of genetically modified foods first (n = 102), or the disadvantages of genetically modified foods first (n = 102). After reading, participants completed the EES to capture the epistemic emotions they experienced while reading. Lastly, participants composed an argumentative essay and then completed a demographics questionnaire to conclude the study[1]. Participants were compensated for their time with $15 cash, a $10 gift card, or course credit, depending on the location of the study.

Results

Preliminary Analyses

Prior to conducting full analyses, all variables were inspected for skewness and kurtosis. Based on Tabachnick and Fidell's (2013) recommendations, acceptable ranges of ±3 for skewness and ±8 for kurtosis were used to investigate the relative normality of the distributions for each variable. Analyses revealed that the distributions for confusion (4.45), frustration (7.28), anxiety (3.73), and boredom (6.10) were positively skewed; however, given the nature of

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[1] Other measures were included in the study for the purposes of the larger study. Additional measures taken before learning included dietary self-concept, task value and self-efficacy for learning about GMF, prior attitude towards GMF, and baseline emotions about GMF. Additional measures taken after learning included learning strategies used while reading and final attitude towards GMF. Participants also completed two knowledge tests and an argument identification task prior to writing the argumentative essay.

emotions, normal distributions for these variables are unlikely, so the variables were retained for subsequent analyses. Examination of text order (i.e., advantages of genetically modified foods first or disadvantages of genetically modified foods first) showed no effect on all variables. Descriptive statistics for all variables are presented in Table 14 and correlations between variables are presented in Table 15.

To check for univariate outliers, each variable was converted to a standardized z-score. Any z-scores exceeding critical cut-offs of ±3.3 was considered an outlier (Tabachnick & Fidell, 2013). Results revealed univariate outliers for justification (n = 2, z = -3.36 to -5.53) and frustration (n = 1, z = 3.51). Instead of deletion, all cases were retained given the values were not extreme and did not exceed more than 2% of cases for each variable (see Cohen, Cohen, West, & Aiken, 2003). To check for multivariate outliers, Mahalanobis distances were calculated based on a χ^2 distribution with 12 degrees of freedom and a critical cut-off point of 32.91 (α = .001; see Meyers, Gamest, & Guarino, 2017; Tabachnick & Fidell, 2013). Three participants were removed from the sample for a total of 201 participants included in subsequent analyses. Lastly, an inspection of a bivariate correlation matrix using a recommended critical cut-off point of .70 (see Meyers et al., 2017) revealed one instance of multicollinearity in the data between confusion and curiosity (r = .86, p < .01). Given this finding, curiosity was removed from subsequent analyses to mitigate any potential confounding effect.

Mediation Path Analysis

To test the hypothesized mediation model depicted in Figure 3, we conducted a mediation analysis using Hayes and Preachers' (2013) MEDIATE macro for SPSS, which is recommended for testing complex mediational models and maintaining high power while controlling for Type I error rates (see Hayes & Preacher, 2013). Bootstrap sampling was used (with 5000 bootstraps), which does not require assumptions of normality and which was appropriate given a few slightly skewed variables. To examine the direct and indirect predictive relations between epistemic beliefs, epistemic emotions and critical thinking, mediation analysis was conducted. This allows the estimation of all direct predictive effects of four epistemic beliefs and six epistemic emotions simultaneously on critical thinking. A power analysis using *G*Power* (Faul & Erdfelder, 1992; for a full description, see Erdfelder, Faul, & Buchner, 1996) with power ($1— \beta$) set at .80 and α set at .05 revealed a required sample size of 218 for the present analysis. Given a sample of 201, the analysis would be underpowered. As such, we adjusted the level of the confidence intervals to 90% for the bootstrap sampling, which required a sample size of 180. The final model is depicted in Figure 4 with standardized effects.

We first examined the total effects model, which expresses the sum of the direct and indirect effects of epistemic beliefs on critical thinking scores to determine the predictive relations between epistemic beliefs and critical thinking, independent of the effects of mediational variables. We next calculated the direct effects of epistemic beliefs on epistemic emotions, the direct effects of epistemic beliefs on critical thinking, and the indirect effects of epistemic beliefs on critical thinking via epistemic emotions. At each step, we controlled for the effects of prior knowledge.

The total effects model for epistemic beliefs and critical thinking was significant, $F(5, 195) = 3.16$, $p = .009$, $R^2 = .075$. Complexity beliefs ($\beta = .22$, $SE = .09$, $t = 2.36$, $p = .019$) and uncertainty beliefs ($\beta = .22$, $SE = .09$, $t = 2.34$, $p = .02$) were direct predictors of critical thinking. For direct effects of epistemic beliefs on epistemic emotions, complexity beliefs negatively predicted surprise ($\beta = -.22$, $SE = .07$, $t = -3.07$, $p = .003$), confusion ($\beta = -.18$, $SE = .05$, $t = -$

3.32, $p = .001$), and frustration, ($\beta = -.13$, $SE = .07$, $t = -1.87$, $p = .063$), and source beliefs positively predicted frustration, ($\beta = .17$, $SE = .07$, $t = 2.42$, $p = .017$).

The full mediational analysis of the direct and indirect effects of epistemic beliefs and epistemic emotions on critical thinking was significant, $F(11, 189) = 2.67$, $p = .003$, $R^2 = .134$, indicating that epistemic beliefs and epistemic emotions together accounted for 13.4% of the variance associated with critical thinking. With epistemic emotions entered in the model, complexity beliefs ($\beta = .23$, $SE = .09$, $t = 2.40$, $p = .017$) and uncertainty beliefs ($\beta = .20$, $SE = .09$, $t = 2.12$, $p = .036$) remained significant predictors of critical thinking. As for epistemic emotions, confusion ($\beta = .28$, $SE = .17$, $t = 1.68$, $p = .095$) and anxiety ($\beta = .25$, $SE = .14$, $t = 1.81$, $p = .072$) were significant positive predictors, and frustration ($\beta = -.26$, $SE = .13$, $t = -1.99$, $p = .048$) and boredom ($\beta = -.21$, $SE = .11$, $t = -1.98$, $p = .049$) were significant negative predictors of critical thinking.

For indirect effects of epistemic beliefs on critical thinking via epistemic emotions, two significant mediation paths were identified. Results showed that the effect of complexity beliefs on critical thinking was mediated by confusion, with a point estimate of -.05 and bias corrected bootstrapped confidence intervals (90%) of -.107 to -.003. Further, the effects of source beliefs on critical thinking were mediated by frustration, with a point estimate of -.043 and bias corrected bootstrapped confidence intervals (90%) of -.106 to -.002. Contrary to predictions, the direction of these mediation paths was negative. Namely, more constructivist uncertainty beliefs negatively related to critical thinking via less confusion, and more constructivist source beliefs negatively related to critical thinking via more frustration.

Two Illustrative Cases

The following cases reflect examples of how epistemic beliefs and epistemic emotions related to critical thinking for different individuals. These cases were chosen as they represent individuals with similar demographic profiles and levels of prior knowledge about genetically modified foods, but whose epistemic beliefs and emotions as well as critical thinking skills present an interesting contrast.

Case 1. Case 1 was a 24-year-old female in the 3rd year of an environmental sciences degree with a self-reported GPA representing an academic average between 80%-84% (or A-). Case 1's prior knowledge about genetically modified foods was below average (test score = 20.00%). She reported epistemic beliefs that were slightly less constructivist than average on the complexity subscale (score = 3.33/7.00), less constructivist than average by more than two standard deviations on the uncertainty subscale (score = 2.83/7.00), and less constructivist than average on the source subscale by one standard deviation (score = 2.60/7.00). For epistemic emotions, she reported slightly less confusion than average (score = 1.33/5.00), slightly more frustration than average (score = 2.00/5.00), more anxiety than average by more than one standard deviation (score = 3.33/5.00), and more boredom than average by more than a standard deviation (score = 3.00/5.00).

Our analysis of Case 1's essay indicated little critical thinking (score = 2/5) and reflected a one-sided view of genetically modified foods. Her essay included a well-positioned positive stance on genetically modified foods ("Genetically modified food is the way of the future") as well as a few arguments in its support ("For instance, rice can be GM to have more nutrients, thus preventing millions of people from starvation" and "Already there are many Third World nations that have hungry and malnourished populations. Genetically modified foods can help them by modifying their staple of food grown there.") However, Case 1 did not identify nor engage with arguments from the opposing position. No arguments against genetically modified foods were specifically identified. Only the fact that genetically modified foods could have detrimental health effects was alluded to in a sentence that quickly dismissed the counter-argument with a statement that was justified by means of not having directly observed any opposing evidence: “Every day, there are hundreds of foods being bought in grocery stores that are GM and so far there have been no significant real downside to eating it (detrimental). In fact, I'm sure you've even eaten something that's been GM this week!” Further, no conclusions were reached that hinted to integration or reconciliation of perspectives. A conclusive statement was offered that solidified a position in favor of genetically modified foods (“Our knowledge is meant to be passed on to others so they can benefit from the fortunes that we are so lucky to have.”). Overall, Case 1 is representative of individuals with overall less constructivist epistemic beliefs who did not present elaborate critical thinking. Further, though prior knowledge was low, Case 1 reported little confusion. She also reported high levels of anxiety and boredom. Given that high has been being linked to increased efforts for analytical thinking (see Pekrun et al., 2002), it might be the case that repression of anxiety played an important role in this case.

Case 2. Case 2 was a 24-year-old female in the 2nd year of a degree in psychology. She reported a GPA representing an academic average between 85%-89% (or A). Akin to Case 1, Case 2’s prior knowledge about genetically modified foods was below average (test score = 20%). She reported epistemic beliefs that were more constructivist than average by more than one standard deviation on the uncertainty subscale (score = 5.00/7.00), more constructivist beliefs than average by more than one standard deviation on the uncertainty subscale (score = 5.83/7.00), and slightly less constructivist beliefs than average on the source subscale (score = 4.00/7.00). For epistemic emotions, she reported more confusion than average by more than one standard deviation (score = 3.00/5.00), more frustration than average by more than one standard deviation (score = 2.67/5.00), slightly more anxiety than average (score = 3.00/5.00), and slightly less boredom than average (score = 1.67/5.00).

Case 2's essay reflected an integrated perspective on genetically modified foods. Case 2 first assumed a cautiously positive stance on genetically modified foods ("Though the use of genetically modified foods may present possible solutions to certain of the world's problems, there is insufficient research on the matter and, more specifically, evidence supporting its proposed benefits.") She then presented some of benefits of genetically modified foods ("Genetically modified foods have been proposed to aid in addressing the many problems tied to the ever-growing population of the world, including malnutrition and land usage") and then exposed some criticism, pointing to a lack of supportive evidence ("However, these are mere propositions based on hypothetical scenarios [i.e., there is no evidence to show that certain foods can be genetically modified to provide additional vitamins and minerals - what has been proposed is a hypothetical solution.]"). The same pattern was repeated with the opposing perspective: Case 2 first presented arguments against genetically modified foods ("Meanwhile, a growing body of research is pointing to evidence supporting its harmful side effects. For instance, a causal link was found between the presence of the modified B.t. corn and death of monarch butterfly caterpillars. Research has also shown that GM fed rats had digestive tracts that differed to rats fed unmodified foods"), then identified limitations ("While research on the effects of GM foods in humans is still rather limited, such animal studies are an important start."). A full reconciliation of perspectives was not reached, but a conclusion was drawn that followed the aforementioned evaluations and identified a lack of evidence as a halt to fully embracing the benefits of genetically modified foods ("Overall, the research on genetically modified foods remains inconsistent and limited. There is insufficient evidence to show that the benefits of genetically modified foods could outweigh its costs."). It may be the case that an optimal level of anxiety and confusion, combined with low boredom, motivated Case 2 to exert efforts to analyze each perspective on genetically modified foods, in order to better understand their characteristics and nuances, resulting in observable critical thoughts.

Discussion

Socio-scientific issues such as genetically modified foods are often depicted as controversial by influencers who are either in favor or against the propositions of scientific expertise. In the face of such issues, successful critical thinking occurs when individuals purposefully decide what to believe or what to do by evaluating knowledge claims and reconciling opposing views, taking relevant evidence and context into account (Ennis, 1987; Facione, 1990). Prior theoretical and empirical work suggests that individuals' thoughts and beliefs about the nature of knowledge and knowing play an important role in supporting critical thinking. However, little is known about the role that knowledge- and knowing-related emotions may play in epistemic cognition and critical thinking. We hypothesized that epistemic cognition supports critical thinking via availing epistemic emotions.

This research contributes to the literature on epistemic cognition and epistemic emotions by empirically testing Muis et al.'s (2015, 2018) model of epistemic cognition and epistemic emotions, and by providing new findings concerning relations between epistemic cognition, epistemic emotions, and critical thinking. Further, this study is the first to explore these relations in the context of an elaborate critical thinking task where participants were asked to decide what to believe about a socio-scientific issue on the basis of conflicting evidence. Specifically, results showed that a belief in complex and uncertain knowledge directly predicted critical thinking

(Hypothesis 1). Complexity and source beliefs also predicted epistemic emotions, including surprise, confusion, and frustration (Hypothesis 2), and several epistemic emotions (i.e., confusion, frustration, anxiety, and boredom) in turn predicted critical thinking (Hypothesis 3). Lastly, confusion and frustration mediated relations between epistemic beliefs and critical thinking (Hypothesis 4). Next, we interpret each of the results described above and conclude with a discussion of limitations and directions for future research.

Effects of Epistemic Beliefs When Facing Socio-Scientific Issues

In support of our hypothesis, more constructivist epistemic beliefs about the nature of knowledge (complexity and uncertainty dimensions) significantly predicted critical thinking, indicating that the more individuals believed in complex and tentative knowledge, the more they presented support for arguments, acknowledged alternatives, evaluated claims, and drew balanced conclusions. However, epistemic beliefs about the nature of knowing (beliefs about the sources of, and justification for knowing) were not significantly related to critical thinking. It should be mentioned that it is frequent in epistemic belief research that not all belief dimensions are salient in a given situation, depending on the nature of the task (Greene et al., 2010; Hammer & Elby, 2002; Muis et al., 2006). Similar to this study, Strømsø, Bråten and Britt (2011) examined relations between epistemic beliefs and undergraduate students' evaluations of documents' trustworthiness and found that source beliefs significantly predicted evaluation of conflicting claims, but justification beliefs did not contribute significantly to trustworthiness scores.

Two dimensions of epistemic beliefs were found to have direct effects on three epistemic emotions, though the direction of these relations were variable. In particular, in line with hypotheses, the more individuals believed that knowledge about genetically modified foods is complex, the less likely there were to experience surprise, confusion, and frustration. This supports the notion that epistemic beliefs shape individuals' assumptions about the nature of knowledge (Muis, 2007), such that those who expected knowledge about genetically modified foods to be simple may have experienced dissonance related to the complex nature of information presented in the text, and thus reported higher levels of surprise, confusion, and frustration. However, contrary to hypothesis, an unexpected relation was found between source beliefs and frustration: The more individuals viewed personal interpretations and judgments as the main sources of knowledge about genetically modified foods, the more they experienced frustration when reading contradictory perspectives about the value and usefulness of genetically modified foods. This result is consistent with findings from Strømsø et al. (2011) who found that the more students viewed the self as a meaning maker, the less they trusted texts written by climate change experts. Similarly, Kardash and Scholes (1996) found that the less students believed in external authority as a source of knowledge, the stronger their opinions about the HIV-AIDS relationship.

It could be the case that individuals who believe that knowledge resides within the self (and who have low prior knowledge) also prefer to fall back on their own opinions and find it frustrating to have to consider the point of view of others. Traditionally, the belief that knowledge originates from external authorities has been viewed as "naïve," whereas the conception of self as a knower has been viewed as "sophisticated" (Hofer & Pintrich, 1997). However, researchers have called into question the assumption that more constructivist beliefs are better to espouse in all situations (see Bromme, Kienhues, & Stalh, 2008; Greene et al., 2010; Greene & Yu, 2014). Indeed, when novices face a complex topic such as genetically modified foods, it may be adaptive to assume that experts are trustworthy and to balance one's own judgments with reliance on external expert sources.

Lastly, it should be noted that contrary to hypothesis, more constructivist complexity beliefs did not significantly predict more enjoyment when reading about advantages and disadvantages of genetically modified foods. Following Muis et al.'s (2018) model of epistemic cognition and epistemic emotions, we hypothesized that enjoyment would stem from an alignment between epistemic beliefs that are congruent with the nature of science (i.e., more constructivist epistemic beliefs) and the epistemic nature of the material presented. Similarly, Franco et al. (2011) found that when individuals' epistemic beliefs are consistent with the knowledge representations in complex learning material, they perform better on various measures, including deep processing of information, text recall, and changes in misconceptions. However, Muis et al. (2018) suggested that epistemic emotions have more antecedents than were measured here, including perceptions of control and task value, as well as information novelty and complexity. They argued that if an individual with more constructivist epistemic beliefs has low perceived control or assigns little value to the task at hand, then he or she may experience lower levels of enjoyment. This suggests that epistemic beliefs alone cannot fully predict the type of epistemic emotions that are likely to arise in a given situation. As such, to fully understand the relationship between epistemic cognition and epistemic emotions more broadly, future work should include other epistemic emotion antecedents and take further contextual elements into account.

The Mediating Role of Epistemic Emotions in Critical Thinking

One important contribution of the current study is evidence that epistemic emotions play a role in mediating the relationship between epistemic cognition and critical thinking, thus providing support to Muis et al.'s (2015, 2018) model of epistemic emotions. Specifically, confusion mediated relations between complexity beliefs and critical thinking, and frustration mediated relations between source beliefs and critical thinking. However, the mediating role of epistemic emotions in the relationship between epistemic cognition and critical thinking was found to be more complex than first anticipated.

Consistent with the contention that confusion can be beneficial for complex cognitive tasks, confusion was found to be a positive predictor of critical thinking. Also consistent with hypotheses, confusion was negatively predicted by complexity beliefs and, as such, fully mediated relations between complexity beliefs and critical thinking. Although the full mediation effect seems to suggest that more constructivist complexity beliefs are detrimental to critical thinking via decreased levels of confusion, we suggest that the relations revealed here are more complex than they appear. It might be the case that compared to individuals with less constructivist epistemic beliefs, those who espouse more constructivist complexity beliefs experience less confusion related to the complex nature of genetically modified foods knowledge, but nevertheless perceive discrepancies between perspectives that can trigger levels of confusion that are beneficial for critical thinking. Indeed, philosophers such as Morton (2010) and Elgin (2008) have argued that epistemic emotions such as surprise and confusion can draw attention to the object of the emotion, which can lead to deep processing of information as well as metacognitive self-regulation (Muis et al., 2015). However, confusion can increase one's cognitive load, leaving few attentional resources to resolve the complex situation at hand (D'Mello & Graesser, 2014; Meinhardt & Pekrun, 2003), which can be detrimental for complex cognitive processes. To clarify how epistemic beliefs and confusion relate to critical thinking, future work is needed to shed light on what distinguishes beneficial forms from detrimental forms of confusion. To this end, qualitative work may be a fruitful avenue.

Further, the relationship between source belief and critical thinking was fully mediated by frustration. Frustration was found to be a negative predictor of critical thinking; however, frustration was positively related to the belief of the self as a knower, which raises questions about the conceptualization of source beliefs, as discussed above. Taken together, the mediation path indicated that espousing the belief that knowledge originates within oneself may be detrimental to critical thinking about complex and conflicting socio-scientific issues, via high levels of frustration. Indeed, frustration is an intense negative emotion that can overtake the cognitive system (Rosenberg, 1998), and is linked to a reduction of effortful thinking and an increase of rigid and shallow processing of information (see Pekrun, Goetz, Frenzel, Barchfeld, & Perry, 2011; Pekrun & Stephens, 2012). Indeed, D'Mello and Graesser (2012) proposed that frustration can lead to boredom and ultimately, disengagement from task. This is consistent with findings from this study, where we observed a negative relationship between boredom and critical thinking.

Moreover, we observed a significant positive relationship between anxiety and critical thinking, suggesting that anxiety may be beneficial for critical thinking. This result was expected and is consistent with Muis et al.'s (2015) results, who also noted a significant positive path from anxiety to critical thinking. In the present study, anxiety was unrelated to epistemic beliefs but may have been related to epistemic aims such as to understand the content or find the truth about genetically modified foods. Measuring epistemic aims as antecedents of epistemic emotions will be an important avenue to understand the conditions under which anxiety can benefit critical thinking, and those under which it does not.

In terms of positive emotions, in this study, we did not find significant predictive relationships between enjoyment and critical thinking, and curiosity was not included in mediational analyses due to issues of collinearity with confusion. Therefore, the current results do not replicate prior work by Muis et al. (2015) and Chevrier et al. (under review), who found curiosity to predict critical thinking in path analysis. Muis et al. (2018) proposed that curiosity and confusion are similar in that they both result from surprise triggered by dissonance, incongruity, or uncertainty. They proposed that the complexity of information or of a task predicts whether curiosity or confusion follows surprise. Specifically, they argued that when complexity is high, surprise may turn into confusion, whereas curiosity is more likely to ensue in cases where discrepancies can be easily revolved. In the current study, it appears that curiosity and confusion highly co-occurred. More research is needed to better understand how individuals experience curiosity and confusion when trying to determine what is true or what to believe about a complex and controversial topic.

Recent qualitative work by Danvers (2015) may help understand why, in this study, critical thinking was predicted by negative emotions and not by positive ones: Danvers asked 15 social science undergraduate students about what critical thinking *feels like*. Students' responses revealed the experience of critical thinking as moments of affective intensity that does not always feel good. Students reported reactive bodily responses to critical thinking, rather than a purely cognitive experience. Participants mentioned that critical thinking felt troubling and could be troublesome, using words such as "fiery" and "abrupt." Danvers' (2015) findings may also shed light on the fact that boredom negatively predicted critical thinking. Indeed, boredom is predominantly characterized by low arousal that is described by those who experience it as lacking meaning and significance in what one is doing (Hubbard, 2019; Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010), and is unlikely to be compatible with what has been described as the fiery and abrupt affective nature of critical thinking.

Overall, the current study provided support for many of the predictions posited in the epistemic cognition and emotion literature, yet also provided new insights into the epistemic and affective nature of critical thinking. Specifically, the notion that more constructivist epistemic cognition promotes critical thinking was generally supported, as was the contention that epistemic emotions mediate relations between epistemic cognition and cognitive processes. Further, results supported the idea that milder forms of negative emotions such as anxiety and confusion can be beneficial for critical thinking, whereas intense activating negative emotions (i.e., activating forms of frustration) or deactivating emotions (i.e., boredom) are detrimental for critical thinking. However, results also challenged the assumptions that positive emotions are required for critical thinking to occur. Lastly, our results challenge dominant conceptions about beliefs in the self as the primary source of knowledge as being beneficial for critical thinking. Our counter-hypothetical results provide additional support for the idea that there is a need to reconsider and reinvestigate how individuals productively conceive of and justify knowledge (see Chinn et al., 2011; Greene et al., 2008; Greene & Yu, 2014). Overall, findings from the current study support the notion that critical thinking is not necessarily something that feels good (Danvers, 2015), yet suggest that espousing more constructivist beliefs about the nature of knowledge may benefit critical thinking by tampering certain difficult emotions and supporting the use of critical thinking.

Educational Implications

The results obtained in the present study have several implications for educational interventions aimed at increasing critical thinking about socio-scientific issues. First, findings support the notion that knowledge- and knowing-related issues should be highlighted and discussed in educational settings, with the aim of developing more constructivist forms of epistemic cognition. Notably, discussions surrounding the complex and tentative nature of scientific knowledge may be beneficial to shaping individuals' expectations about the issues they will be called upon to reflect and act on during their lifetime. Ronald Barnett (2004), a prominent philosopher of higher education, has described the mission of university education as preparing students for a complex and uncertain future: For individuals to prosper, make decisions, and come to a position of security amid multiple interpretations, individuals must come not only to learn *for* uncertainty, but to learn to *live with* uncertainty. Barnett contends that no risk-free curricular approach can achieve this; instead, he calls for a curriculum that aims at educational transformation through exposure to dilemmas and uncertainties. This may include, for instance, confronting students with the limits of knowing in a field and with the limitations of the field as such. In addition to uncertainty- and complexity-focused curricula, Muis, Trevors, and Chevrier (2016) proposed that to achieve epistemic change, epistemic climates are needed that involve constructivist pedagogical approaches (e.g. inquiry-based learning, apprenticeship, collaborative learning, knowledge building, communities of practice), decentralized authority structures, open-ended assessment practices, and appropriate levels of teacher support, as students experience the sometimes difficult process of belief change.

Second, findings from the present study suggest that to develop critical thinking about socio-scientific issues, learning environments should be supportive of students' emotional responses. In particular, for students with less constructivist epistemic cognition, being exposed to complex and conflicting information may trigger surprise, confusion, and frustration. We argue that such emotions should be welcomed without judgment by teachers and peers, and that these emotional experiences should be normalized. Further, teachers should discuss their own epistemic emotions and model appropriate emotion regulation strategies (Gross, 2014). Related to confusion, students may have a tendency to want to avoid confusion by seeking out tasks with minimal intellectual challenges (situation selection), seeking help when challenged (situation modification), or intentionally ignoring or misattributing the cause of discrepant events to avoid confusion (reappraisal; D'Mello & Graesser, 2014; Gross, 2014; Harley, Pekrun, Taxer, & Gross, in press). However, teachers can discuss the drawback of these strategies, and further suggest and model a different set of emotion regulation strategies, including choosing to engage in tasks that are intellectually challenging (situation selection), open up to perspectives that do not at first flatter their preferred position (situation modification), and help students build competencies for critical reflection (competence enhancement). By reinforcing the latter strategies, students may become what Clifford (1988) describes as "academic risk takers," who are more tolerant to uncertainty and failure.

Third and relatedly, given observed relations between complexity beliefs, confusion and critical thinking, as well as between source beliefs, frustration and critical thinking, we suggest that students with less constructivist epistemic beliefs on these two dimensions may benefit from learning materials that trigger mild confusion, but without giving way to frustration. To this end, D'Mello and Graesser (2012) suggest pedagogical practices where misconceptions are exposed, where complexity is embraced, and where less cohesive texts and lectures replace the polished deliveries of textbooks and formal lectures. However, to avoid confusion turning into frustration or disengagement (D'Mello & Graesser, 2012), teachers should support the development of students' critical thinking skills and resolution strategies by scaffolding and modelling these abilities (Muis & Dufy, 2013), so that students become able to productively engage with confusion-inducing materials, to the benefit of deep and critical thinking.

Limitations and Future Directions

Several concerns may limit the results presented herein. First, the analysis used correlational associations of the study variables over time but did not experimentally manipulate the predictor variables. As such, future research should complement the approach used here with experimental studies. However, this may be easier to do with emotions, which can to some extent be manipulated experimentally, than with more stable epistemic beliefs. A second limitation concerns the rubric employed to capture critical thinking in essays. Specifically, we opted for a quantitative approach to coding critical thinking by attributing one point for the presence of each component of critical thinking. However, a weighted coding scheme or a holistic rubric are two other modes of critical thinking assessment that include qualitative elements of analysis that could have yielded different results. Therefore, future research is needed to replicate the findings presented here.

The current findings have important implications for future research on epistemic cognition and epistemic emotions. Specifically, to fully understand how epistemic cognition supports critical thinking, future research should explore the role that other facets of epistemic cognition play in mediating this relationship. For instance, how do individuals' knowledge of epistemic strategies shape critical thinking, and do these abilities predict the arousal of epistemic emotions in the face of complex and conflicting information? And how might epistemic aims moderate these relations? Prior work has shown that these other epistemic facets play a significant role in epistemic emotion arousal (see Chevrier et al., under review) and researchers have called for more research on epistemic cognition that conceptualize and operationalize the construct beyond the sole notion of epistemic beliefs (Greene et al., 2016; Muis et al., 2018).

Lastly, in light of the findings revealed herein, we contend that one important avenue for future work will be to investigate how different intensities of positive, neutral, and negative epistemic emotions relate to information processing and critical thinking. To this end, we believe that the self-report measurement of emotions can be complemented by and triangulated with trace data collected by think-aloud or emote-aloud protocols (e.g., Chevrier et al., under review; Craig, D'Mello, Witherspoon, & Graesser, 2006), physiological measures of emotions such as analysis of facial expression, electrocardiograms, and galvanic skin responses (Azevedo et al., 2013; D'Mello et al., 2014), and qualitative work. In sum, by broadening conceptual horizons and employing advanced methodologies, we believe that future research will provide a rich portrait of the ways in which epistemic cognition and epistemic emotions support critical thinking.

References

Abrami, P. C., Bernard, R. M., Borokhovski, E., Wade, A., Surkes, M. A., Tamim, R., & Zhang, D. (2008). Instructional interventions affecting critical thinking skills and dispositions: A stage 1 meta-analysis. *Review of Educational Research, 78*, 1102-1134.

Alexander, P. A. (2014). Thinking critically and analytically about critical-analytic thinking: An introduction. *Educational Psychology Review, 26*, 469-476.

Arum, R., & Roksa, J. (2011). *Academically adrift: Limited learning on college campuses*. Chicago, IL: University of Chicago Press.

Azevedo, R., Harley, J., Trevors, G., Duffy, M., Feyzi-Behnagh, R., Bouchet, F., & Landis, R. (2013). Using trace data to examine the complex roles of cognitive, metacognitive, and emotional self-regulatory processes during learning with multi-agent systems. In *International handbook of metacognition and learning technologies* (pp. 427-449). Springer, New York, NY.

Azevedo, R., Moos, D. C., Johnson, A. M., & Chauncey, A. D. (2010). Measuring cognitive and metacognitive regulatory processes during hypermedia learning: Issues and challenges. *Educational Psychologist, 45*, 210-223.

Bailin, S., & Siegel, H. (2003). Critical thinking. In N. Blake, P. Smeyers, R. Smith, & P. Standish (Eds.), *The Blackwell guide to the philosophy of education* (pp. 181-193). Oxford, UK: Blackwell Publishing.

Barnett, R. (2004). Learning for an unknown future. *Higher Education Research and Development, 23*, 247-260.

Barzilai, S., & Eshet-Alkalai, Y. (2015). The role of epistemic perspectives in comprehension of multiple author viewpoints. *Learning and Instruction, 36*, 86-103.

Barzilai, S., Tzadok, E., & Eshet-Alkalai, Y. (2015). Sourcing while reading divergent expert accounts: Pathways from views of knowing to written argumentation. *Instructional Science, 43*, 737-766.

Barzilai, S., & Zohar, A. (2012). Epistemic thinking in action: Evaluating and integrating online sources. *Cognition and Instruction, 30*, 39-85.

Barzilai, S., & Zohar, A. (2014). Reconsidering personal epistemology as metacognition: A multifaceted approach to the analysis of epistemic thinking. *Educational Psychologist, 49,* 13-35.

Bless, H., Clore, G. L., Schwarz, N., Golisano, V., Rabe, C., & Wölk, M. (1996). Mood and the use of scripts: Does a happy mood really lead to mindlessness*? Journal of Personality and Social Psychology, 71*, 665–679.

Bråten, I. (2016). Epistemic cognition interventions. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 360–371). New York, NY: Routledge.

Bråten, I., Anmarkrud, Ø., Brandmo, C., & Strømsø, H. I. (2014). Developing and testing a model of direct and indirect relationships between individual differences, processing, and multiple-text comprehension. *Learning and Instruction, 30,* 9-24.

Bråten, I., Britt, M. A., Strømsø, H. I., & Rouet, J.-F. (2011). The role of epistemic beliefs in the comprehension of multiple expository texts: Toward an integrated model. *Educational Psychologist, 46,* 48-70.

Bråten, I., & Strømsø, H. I. (2009). Effects of task instruction and personal epistemology on the understanding of multiple texts about climate change. *Discourse Processes, 47,* 1-31.

Bromme, R., Kienhues, D., & Stahl, E. (2008). Knowledge and epistemological beliefs: An intimate but complicate relationship. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs: Epistemological studies across diverse cultures* (pp. 423–441). New York, NY: Springer.

Brun, G., & Kuenzle, D. (2008). A new role for emotions in epistemology? In G. Brun, U. Doğuoğlu, & D. Kuenzle, D. (Eds.), *Epistemology and emotions* (pp. 1-32). Aldershot, UK: Ashgate.

Chan, N. M., Ho, I. T., & Ku, K. Y. (2011). Epistemic beliefs and critical thinking of Chinese students. *Learning and Individual Differences, 21*, 67-77.

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. L. A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist, 46*, 141-167.

Claris, L., & Riley, D. (2012). Situation critical: critical theory and critical thinking in engineering education. *Engineering Studies, 4,* 101-120.

Clifford, M. M. (1988). Failure tolerance and academic risk-taking in ten-to twelve-year-old students. *British Journal of Educational Psychology, 58,* 15-27.

Clore, G. L., Wyer, R. S., Dienes, B., Gasper, K., Gohm, C., & Isbell, L. (2001). Affective feelings as feedback: Some cognitive consequences. In L. L. Martin & G. L. Clore (Eds.), *Theories of mood and cognition: A user's handbook* (pp. 27-62). Mahwah, NJ: Lawrence Erlbaum.

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Craig, S. D., D'Mello, S., Witherspoon, A., & Graesser, A. (2008). Emote aloud during learning with AutoTutor: Applying the facial action coding system to cognitive–affective states during learning. *Cognition and Emotion, 22*, 777-788.

Danvers, E. C. (2016). Criticality's affective entanglements: rethinking emotion and critical thinking in higher education. *Gender and Education, 28,* 282-297.

DeBacker, T. K., Crowson, H. M., Beesley, A. D., Thoma, S. J., & Hestevold, N. L. (2008). The challenge of measuring epistemic beliefs: An analysis of three self-report instruments. *The Journal of Experimental Education, 76*, 281–312.

Dewey, J. (1933). *Philosophy and civilization*. Boston, MA: Heath & Co.

D'Mello, S. K., & Graesser, A. C. (2012). Dynamics of affective states during complex learning. *Learning and Instruction, 22,* 145–157.

D'Mello, S. K., & Graesser, A. C. (2014). Confusion. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), Handbook of emotions in education (pp. 289–310). New York: Routledge.

D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29*, 153–170.

Elgin, C. Z. (2008). Emotion and understanding. In G. Brun, U. Doguoglu, & D. Kuenzle (Eds.), *Epistemology and emotions* (pp. 33–50). Aldershot, UK: Ashgate.

Ellsworth, P. C. (2013). Appraisal theory: Old and new questions. *Emotion Review, 5*, 125–131.

Ennis, R. H. (1987). A taxonomy of critical thinking dispositions and abilities. In J. Baron a& R. Sternberg (Eds.), *Teaching thinking skills: Theory and practice* (pp. 9-26). New York, NY: Freeman.

Ennis, R. H. (2018). Critical thinking across the curriculum: A vision. *Topoi, 37*, 165-184.

Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behavior Research Methods, Instruments, and Computers, 28*, 1-11.

Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction (Research findings and recommendations)*. Newark, DE: American Philosophical Association.

Facione, P. A., Facione, N. C. (2014). *The holistic critical thinking scoring rubric: A tool for developing and evaluating critical thinking*. Available online: http://www.insightassessment.com/pdf_files/Rubric%20HCTSR.pdf

Faul, F., & Erdfelder, E. (1992). *GPOWER: A priori, post-hoc, and compromise power analyses for MS-DOS.* Bonn University, Department of Psychology: Bonn, Germany.

Ferguson, L. E., Bråten, I., & Strømsø, H. I. (2012). Epistemic cognition when students read multiple documents containing conflicting scientific evidence: A think-aloud study. *Learning and Instruction, 22*, 103-120.

Fisher, A. (2011). *Critical thinking: An introduction* (2nd ed). Cambridge, MA: Cambridge University Press.

Foster, M. I., & Keane, M. T. (2015). Why some surprises are more surprising than others: Surprises as a metacognitive sense of explanatory difficulty. *Cognitive Psychology, 81,* 74-116.

Franco, G. M., Muis, K. R., Kendeou, P., Ranellucci, J., Sampasivam, L., & Wang, X. (2012). Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics. *Learning and Instruction, 22*, 62-77.

Garimella, K., De Francisci Morales, G., Gionis, A., & Mathioudakis, M. (2018, April). Political discourse on social media: Echo chambers, gatekeepers, and the price of bipartisanship. In *Proceedings of the 2018 World Wide Web Conference* (pp. 913-922). International World Wide Web Conferences Steering Committee.

Gordon, J. (2000). Congruency in defining critical thinking by nurse educators and non-nurse scholars. *Journal of Nursing Education, 39*, 340–351.

Greene, J. A., & Azevedo, R. (2009). A macro-level analysis of SRL processes and their relations to the acquisition of a sophisticated mental model of a complex system. *Contemporary Educational Psychology, 34*, 18-29.

Greene, J. A., Azevedo, R., & Torney-Purta, J. (2008). Modeling epistemic and ontological cognition: Philosophical perspectives and methodological directions. *Educational Psychologist, 43*, 142-160.

Greene, J. A., Muis, K. R., & Pieschl, S. (2010). The role of epistemic beliefs in students' self-regulated learning with computer-based learning environments: Conceptual and methodological issues. *Educational Psychologist, 45,* 245-257.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016). *Handbook of epistemic cognition*. New York, NY: Routledge.

Greene, J. A., Torney-Purta, J., & Azevedo, R. (2010). Empirical evidence regarding relations among a model of epistemic and ontological cognition, academic performance, and educational level. *Journal of Educational Psychology, 102*, 234.

Greene, J. A., & Yu, S. B. (2014). Modeling and measuring epistemic cognition: A qualitative re-investigation. *Contemporary Educational Psychology, 39,* 12-28.

Greene, J. A., & Yu, S. B. (2016). *Educating critical thinkers: The role of epistemic cognition. Policy Insights from the Behavioral and Brain Sciences*. Advanced online publication.

Greene, J. A., Yu, S. B., & Copeland, D. Z. (2014). Measuring critical components of digital literacy and their relationships with learning. *Computers and Education, 76,* 55-69.

Gregoire, M. (2003). Is it a challenge or a threat? A dual-process model of teachers' cognition and appraisal processes during conceptual change. *Educational Psychology Review, 15,* 147-179.

Gross, J. J. (2014). Emotion regulation: Conceptual and empirical foundations. In J. J. Gross (Ed.), *Handbook of emotion regulation* (2nd ed.) (pp. 3-20). New York, NY: Guilford.

Halpern, D. F. (2014) *Thought and knowledge* (5th ed.). NY: Psychology Press.

Hammer, D., & Elby, A. (2002). On the form of personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 169-190). Mahwah, NJ: Lawrence Erlbaum Associates.

Harley, J. M., Pekrun, R., Taxer, J. L., & Gross, J. J. (in press). Emotion regulation in achievement situations: An integrated model. *Educational Psychologist*.

Hayes, A. F., & Preacher, K. J. (2013). *Statistical mediation analysis with a multicategorical independent variable.* Unpublished white paper.

Heddy, B. C., Danielson, R. W., Sinatra, G. M., & Graham, J. (2017). Modifying knowledge, emotions, and attitudes regarding genetically modified foods. *The Journal of Experimental Education, 85*, 513-533.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology, 25,* 378-405.

Hofer, B. K. (2004). Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology, 29,* 129-163.

Hofer, B. K., & Bendixen, L. D. (2012). Personal epistemology: Theory, research, and future directions. In K. R. Harris, S. Graham, & T. Urdan (Eds.), *APA Educational Psychology Handbook*, Vol. 1 (pp. 227–256). Washington, DC: American Psychological Association.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 6*, 88-140.

Hookway, C. (2008). Epistemic immediacy, doubt and anxiety: On a role for affective states in epistemic evaluation. In G. Brun, U. Doguoglu, & D. Kuenzle (Eds.), *Epistemology and emotions* (pp. 51–65). Aldershot, UK: Ashgate.

Hubbard, K., Hall, N. C., & Sverdlik, A. (2019, April). *Phenomenology of boredom coping: Understanding students' lived experiences of coping with boredom in college*. American Educational Research Association Annual Convention, Toronto, ON.

Huber, C. R., & Kuncel, N. R. (2015). *Does college teach critical thinking? A meta-analysis. Review of Educational Research*. Advance online publication.

Hyytinen, H., Holma, K., Toom, A., Shavelson, R. J., & Lindblom-Ylänne, S. (2014). The complex relationship between students' critical thinking and epistemological beliefs in the context of problem solving. *Frontline Learning Research, 2*, 1-25.

Kahneman, D., (2011). *Thinking, fast and slow*. New York, NY: Farrar, Straus and Giroux.

Kardash, C. M., & Scholes, R. J. (1996). Effects of preexisiting beliefs, epistemological beliefs, and need for cognition on interpretation of controversial issues. *Journal of Educational Psychology, 88*, 260.

Kincaid, J. P., Fishburne, R., Rogers, R. L, & Chissom, B. S. (1975). *Derivation of new readability formulas (Automated Readability Index, Fog Count, and Flesch Reading Ease formula) for Navy enlisted personnel*. Millington, TN: Chief of Naval Training.

King, P. M., & Kitchener, K. S. (2002). The reflective judgment model: Twenty years of research on epistemic cognition. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology. The psychology of beliefs about knowledge and knowing* (pp. 37–62). Mahwah, NJ: Erlbaum.

King, P. M., & Kitchener, K. S. (2004). Reflective judgment: Theory and research on the development of epistemic assumptions. *Educational Psychologist, 39*, 5-18.

Kuhn, D. (1991). *The skills of argument*. Cambridge, England: Cambridge University Press.

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28*, 16-46.

Kuhn, D. (2018). A role for reasoning in a dialogic approach to critical thinking. *Topoi, 37,* 121-128.

Kuhn, D., Cheney, R., & Weinstock, M. (2000). The development of epistemological understanding. *Cognitive Development, 15,* 309-328.

Kuhn, D., & Crowell, A. (2011). Dialogic argumentation as a vehicle for developing young adolescents' thinking. *Psychological Science, 22*, 545-552.

Kuhn, D., & Park, S. H. (2005). Epistemological understanding and the development of intellectual values. International *Journal of Educational Research, 43*, 111-124.

Kuhn, D., & Weinstock, M. (2002). What is epistemological thinking and why does it matter? In B. K. Hofer, & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 121–144). Mahwah, NJ: Erlbaum.

Kurfiss, J. G. (1988). *Critical thinking: Theory, research, practice, and possibilities* (Ashe-Eric Higher Education Report No. 2). Washington, DC: Association for the Study of Higher Education. (ERIC Document Reproduction Service No. ED304041)

Levinson, R. (2006). Towards a theoretical framework for teaching controversial socio-scientific issues. International *Journal of Science Education, 28*, 1201-1224.

Lipman, M. (1991). Thinking in education. Cambridge, UK: Cambridge University Press.

Loewenstein, G. (1994). The psychology of curiosity: A review and reinterpretation. *Psychological Bulletin, 116,* 75–98.

Markey, A., & Loewenstein, G. (2014). Curiosity. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotion in education* (pp. 228-245). New York, NY: Routledge.

Marks, J., Copland, E., Loh, E., Sunstein, C. R., & Sharot, T. (2019). Epistemic spillovers: Learning others' political views reduces the ability to assess and use their expertise in nonpolitical domains. *Cognition*, *188*, 74-84.

Mason, L., & Boscolo, P. (2004). Role of epistemological understanding and interest in interpreting a controversy and in topic-specific belief change. *Contemporary Educational Psychology, 29*, 103-128.

Mason, L., & Scirica, F. (2006). Prediction of students' argumentation skills about controversial topics by epistemological understanding. *Learning and Instruction,16*, 492-509.

McGinnis, D. (2016). Epistemological orientations and evidence evaluation in undergraduates. *Thinking Skills and Creativity, 19*, 279-289.

McPeck, J. (1981). *Critical thinking and education.* Toronto, Ontario, Canada: Oxford University Press.

Meinhardt, J., & Pekrun, R. (2003). Attentional resource allocation to emotional events: An ERP study. *Cognition and Emotion, 17,* 477-500.

Meyer, W. U., Reisenzein, R., & Schützwohl, A. (1997). Toward a process analysis of emotions: The case of surprise. *Motivation and Emotion, 21*, 251-274.

Meyers, L. S., Gamest, G., Guarino, A.J. (2017). Applied multivariate research: Design and interpretation (3rd ed.). Thousand Oaks, CA: SAGE Publications.

Morton, A. (2010). Epistemic emotions. In P. Goldie (Ed.), *The Oxford handbook of philosophy of emotion* (pp. 385-399). Oxford: Oxford University Press.

Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Educational Research, 74*, 317–377.

Muis, K. R. (2007). The role of epistemic beliefs in self-regulated learning. *Educational Psychologist, 42,* 173-190.

Muis, K. R. (2008). Epistemic profiles and self-regulated learning: Examining relations in the context of mathematics problem solving. *Contemporary Educational Psychology, 33*, 177–208.

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review, 18*, 3-54.

Muis, K. R., Chevrier, M., & Singh, C. A. (2018). The role of epistemic emotions in personal epistemology and self-regulated learning. *Educational Psychologist, 53,* 165-184.

Muis, K. R., & Duffy, M. C. (2013). Epistemic climate and epistemic change: Instruction designed to change students' beliefs and learning strategies and improve achievement. *Journal of Educational Psychology, 105*, 213-225.

Muis, K. R., & Franco, G. (2010). Epistemic profiles and metacognition: Support for the consistency hypothesis. *Metacognition and Learning, 5*, 27–45.

Muis, K. R., Pekrun, R., Sinatra, G. M., Azevedo, R., Trevors, G., Meier, E., & Heddy, B. C. (2015). The curious case of climate change: Testing a theoretical model of epistemic beliefs, epistemic emotions, and complex learning. *Learning and Instruction, 39*, 168-183.

Muis, K. R., & Singh, C. A. (2018). The three facets of epistemic thinking in self-regulated learning. In D. Schunk & J. Greene (Eds.), *Handbook of self-regulated of learning and performance* (pp. 434–456). New York, NY: Routledge.

Muis, K. R., Trevors, G., & Chevrier, M. (2016). Epistemic climate for epistemic change. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 331-359). New York, NY: Routledge.

Munnich, E., & Ranney, M. A. (2018). Learning from surprise: Harnessing a metacognitive surprise signal to build and adapt belief networks. *Topics in Cognitive Science, 11*, 164-177.

Muthén, L. K., & Muthén, B. O. (2015). *Mplus user's guide.* Los Angeles, CA: Muthén & Muthén.

Niu, L., Behar-Horenstein, L. S., & Garvan, C. W. (2013). Do instructional interventions influence college students' critical thinking skills? A meta-analysis. *Educational Research Review, 9*, 114-128.

Paul, R. W. (1990). *Critical thinking: What every person needs to survive in a rapidly changing world*. Santa Rosa, CA: Foundation for Critical Thinking.

Pekrun, R. (1992). The impact of emotions on learning and achievement: Towards a theory of cognitive/motivational mediators. *Applied Psychology, 41*, 359-376.

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18,* 315-341.

Pekrun, R., Goetz, T., Daniels, L. M., Stupnisky, R. H., & Perry, R. P. (2010). Boredom in achievement settings: Control-value antecedents and performance outcomes of a neglected emotion. *Journal of Educational Psychology, 102*, 531-549.

Pekrun, R., Goetz, T., Frenzel, A. C., Barchfeld, P., & Perry, R. P. (2011). Measuring emotions in students' learning and performance: The Achievement Emotions Questionnaire (AEQ). *Contemporary Educational Psychology, 36,* 36-48.

Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educational Psychologist, 37,* 91-105.

Pekrun, R., & Linnenbrink-Garcia, L. (2014). *International handbook of emotions in education*. New York, NY: Routledge.

Pekrun, R., & Perry, R. P. (2014). Control-value theory of achievement emotions. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 120-141). New York: Taylor & Francis.

Pekrun, R., & Stephens, E. J. (2012). Academic emotions. In K. R. Harris, S. Graham, T. Urdan, S. Graham, J. M. Royer, & M. Zeidner (Eds.), *APA educational psychology handbook* (Vol. 2, pp. 3-31). Washington, DC: American Psychological Association.

Pekrun, R., Vogl, E., Muis, K. R., & Sinatra, G. M. (2017). Measuring emotions during epistemic activities: The Epistemically-Related Emotion Scales. *Cognition and Emotion, 31,* 1268-1276.

Perry, W. G. Jr. (1970). *Forms of intellectual and ethical development in the college years: A scheme.* New York, NY: Holt, Rinehart and Winston.

Pham, M. T., Cohen, J. B., Pracejus, J. W., & Hughes, G. D. (2001). Affect monitoring and the primacy of feelings in judgment. *Journal of Consumer Research, 28,* 167-188.

Pintrich, P. R., Smith, D. A., Garcia, T., & McKeachie, W. J. (1991). *A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ)*. Ann Arbor, MI: University of Michigan.

Richter, T., & Schmid, S. (2010). Epistemological beliefs and epistemic strategies in self-regulated learning. *Metacognition and Learning, 5*, 47-65.

Rosenberg, E. (1998). Levels of analysis and the organization of affect. *Review of General Psychology, 2,* 247–270.

Sá, W. C., Stanovich, K. E., & West, R. F. (1999). The domain specificity and generality of belief bias: Searching for generalizable critical thinking skill. *Journal of Educational Psychology, 91,* 497–510.

Schommer, M. (1990). Effect of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*, 498–504.

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology, 84,* 435.

Schommer-Aikins, M., & Hutter, R. (2002). Epistemological beliefs and thinking about everyday controversial issues. *The Journal of Psychology, 136*, 5-20.

Schraw, G. (2010). Measuring self-regulation in computer-based learning environments. *Educational Psychologist, 45*, 258-266.

Schwarz, N., & Clore, G. L. (1983). Mood, misattribution, and judgments of well-being: Informative and directive functions of affective states. *Journal of Personality and Social Psychology, 45*, 513.

Schwarz, N., & Clore, G. L. (2007). Feelings and phenomenal experiences. In E. T. Higgins & A. W. Kruglanski (Eds.), *Social psychology: Handbook of basic principles* (2nd ed.) (pp. 385-407). New York, NY: Guilford Press.

Scriven, M., & Paul, R. (1996). *Defining critical thinking: A draft statement for the National Council for Excellence in Critical Thinking*. Available HTTP: http://www. criticalthinking. org/University/univlibrary/library. nclk p-01.

Shuman, V., & Scherer, K. R. (2014). Concepts and structure of emotions. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 13–35). New York: Routledge.

Siegel, H. (1988). *Educating reason: Rationality, critical thinking, and education*. New York, NY: Routledge.

Simpson, E., & Courtney, M. D. (2002). Critical thinking in nursing education: Literature review. *International Journal of Nursing Practice, 8,* 89-98.

Sinatra, G. M., & Broughton, S. H. (2011). Bridging reading comprehension and conceptual change in science education: The promise of refutation text. *Reading Research Quarterly, 46*, 374-393.

Sîrbu, A., Pedreschi, D., Giannotti, F., & Kertész, J. (2019). Algorithmic bias amplifies opinion fragmentation and polarization: A bounded confidence model. *PloS one, 14*, e0213246.

Strømsø, H. I., & Bråten, I. (2014). Students' sourcing while reading and writing from multiple web documents. *Nordic Journal of Digital Literacy, 2,* 92-111.

Strømsø, H. I., Bråten, I., & Britt, M. A. (2010). Reading multiple texts about climate change: The relationship between memory for sources and text comprehension. *Learning and Instruction, 20*, 192-204.

Strømsø, H. I., Bråten, I., & Britt, M. A. (2011). Do students' beliefs about knowledge and knowing predict their judgement of texts' trustworthiness?. *Educational Psychology, 31*, 177-206.

Tabachnick, B. G., and Fidell, L. S. (2013). *Using multivariate statistics*, 6th ed. Boston: Pearson.

Tippett, C. D. (2010). Refutation text in science education: A review of two decades of research. *International Journal of Science and Mathematics Education, 8,* 951-970.

Tremblay, K., Lalancette, D., Roseveare, D. (2012) *AHELO Feasibility Study Report. Volume 1 Design and Implementation*. Organization for Economic Co-operation and development (OECD). Retrieved from http://www.oecd.org/edu/skills-beyond-school/AHELOFSReportVolume1.pdf

Trevors, G. J., & Kendeou, P. (2018). *The effects of positive and negative emotions on knowledge revision*. Available at SSRN 3274111.

Weiner, B. (2007). Examining emotional diversity on the classroom: An attribution theorist considers the moral emotions. In P. A. Schutz & R. Pekrun (Eds.), *Emotions in education* (pp. 73–88). San Diego, CA: Academic Press.

Whitman, D. B. (2000). *Genetically modified foods: Harmful or helpful?* Canadian Standards Association: Discover Guides. Government of Canada, Ottawa, ON.

Winne, P. H., & Perry, N. E. (2000). Measuring self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 531–566). San Diego, CA: Academic Press.

Yang, F., & Tsai, C. (2010). Reasoning about science-related uncertain issues and epistemological perspectives among children. *Instructional Science: An International Journal of the Learning Sciences, 38*, 325-354.

Zeidner, M. (2014). Anxiety in education. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 265–288). New York: Routledge.

Table 13

Coding scheme for critical thinking in argumentative essays.

	1 point		0 points	
	Description	Example	Description	Example
Taking a stance	The writer takes a stance or identifies a position.	*I would say that I am for the development of genetically modified plants to help increase food production or nutrition.*	The writer does not take a stance. The text is informative, not argumentative.	*There are certain problems in the discourse on genetically modified foods that are preventing the two sides from productively engaging one another. Those arguing in favor of GM foods assume that the other side doesn't understand what they are talking about, because modifications to genes occur in nature and in farming practices such as cross-pollination. However, opponents of GM foods are generally talking only about a certain subset of genetic modification practices. This is a problem in defining the terms of the debate.*

Presenting supportive arguments	The writer supports his/her position with valid arguments, evidence, or reasons.	*Genetically modifying food is a necessary practice but it comes at a cost. Worldwide starvation can be combatted using GMFs. Rice which is the main staple of starving countries can be re-engineered to have the necessary nutrients to prevent malnutrition. More crops can also be genetically modified to survive in rough climates. Herbicide tolerance is another reason GMFs in necessary.*	No arguments or evidence are presented to support their position, or the arguments are invalid.	*I often hear about news on the dangers of GM and how it might be increasing cancer rates or how it is slowly taking over the food market and poisoning us. However, I just realized how little knowledge I have about GM and that it is not entirely a bad thing. I think the reaction to GM food is mostly coming from lack of information.*
Acknowledging an alternative perspective	The writer acknowledges an alternative perspective and engages with that perspective by identifying valid arguments in support of that perspective.	*GM crops are more resistant to pests, tolerant of herbicides (reducing environmental damage), tolerant of drought-ridden and high-salinity environments, and beneficial to the nutrition of impoverished populations who rely on a single crop for sustenance. That*	The write only presents arguments in favor of one perspective. The writer may acknowledge another point of view, but without identifying valid arguments in support of that perspective.	*[…] Furthermore, as GM plants become more tolerant to harsher environments (such as heightened tolerance to low water levels and high salinity in soil). Finally, by genetically modifying foods to have higher nutritional content, increasing the benefits per unit of*

		being said, there are many downsides to GM foods. GM foods have received great criticism due to agribusiness ruthlessly pursuing profit via GMOs without considering the potential hazards, while governments face criticism for not enforcing enough oversight.		*food, the overall demand for food can be met with a proportionally lower level of output. So cumulatively, GM foods provide a means of producing more food that is more effective, thereby offering a solution to the predicted increase in the world's total demand for food.*
Evaluating claims	The writer explains why a claim may be credible or not credible, reliable or unreliable, limited or generalizable, convincing or not convincing, etc.	*The study on the intestines on rats fed with GM potatoes could mean that there might be negative effects on humans. However, based on the text, it is inconclusive. The differences in intestines could even be helpful for humans.*	The writer expediently accepts or dismisses a claim without evaluating it – without providing a reason or explanation as to why it should be accepted or rejected.	*[…] The anti GM seem to rely on fear, paranoia and overall unsound arguments to argue their cause, and do not accept the undeniable positives of GM crops. Of the 4 arguments listed by the anti-GM side, all of them seem to be unfounded fears, or studies seem to be cherry-picked to fit their point of view.*
Reconciling or integrating perspectives	The conclusion acknowledges valid arguments on both sides. The conclusion should be	*[…] The ideal situation would be to fine-tune the process of genetic modification to eliminate the potential harm. The potential benefits of food*	The conclusion is one-sided, categorical, or fails to incorporate or acknowledge that there might be valid	*[…] In order to get rid of the problem of malnutrition on Earth, with its limited land availability and ever-increasing population, GMF is a gift that lets us*

	consistent with the evaluation.	*that is resistant to pests, droughts, and herbicides, are invaluable. We could create more efficient food production, in order to more effectively use our limited resources on earth. Naturally, producing a lot of food that has a negative effect on human health and nutrition is useless. Thus, we must thoroughly research the true effects of GM foods on human health before making a decision. Only with a great deal of knowledge on this topic can we proceed in making a decision on GM foods.*	arguments on the other side.	*increase the quality and quantity of yield, using the limited resources. Thus, I feel the GMF is the future of food.*

Table 14

Descriptive statistics for variables

	M	*SD*
Prior knowledge[a]	55.04	25.35
Uncertainty[b]	5.03	.96
Complexity[b]	4.40	1.02
Source[b]	3.97	1.00
Justification[b]	5.47	.74
Surprise[c]	2.46	.98
Curiosity[c]	1.82	.81
Enjoyment[c]	2.06	.93
Confusion[c]	1.74	.72
Frustration[c]	1.76	.93
Anxiety[c]	2.13	.95
Boredom[c]	1.74	.84
Critical thinking[c]	2.67	1.25

Note. [a] Percentage correct; [b]1-7 Likert scale; [c]1-5 Likert scale; [d]0-5 summed scores.

Table 15

Correlations between variables.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Prior knowledge	--											
2. Uncertainty	.06	--										
3. Complexity	.26**	-.11	--									
4. Source	.15*	.02	.33**	--								
5. Justification	.23**	.26**	.17*	.12	--							
6. Surprise	-.16*	.01	-.29**	-.16*	-.16*	--						
7. Curiosity	-.14	.01	-.30**	-.09	-.03	.39**	--					
8. Enjoyment	.05	.02	-.16*	-.15*	-.06	.45**	.21**	--				
9. Confusion	-.14*	-.02	-.26**	-.04	-.13	.39**	.86**	.19**	--			
10. Frustration	-.03	-.02	-.08	.14	.04	.23**	.50**	-.02	.54**	--		
11. Anxiety	-.02	.07	-.09	.02	.02	.37**	.62**	.08	.62**	.68**	--	
12. Boredom	-.09	-.05	-.05	-.01	-.12	.00	.28**	.01	.31**	.21**	.17*	--
13. Critical thinking	.15*	.16*	.18**	.06	.12	-.08	.05	.03	.03	-.06	.09	-.13

*$p < .05$; **$p < .01$

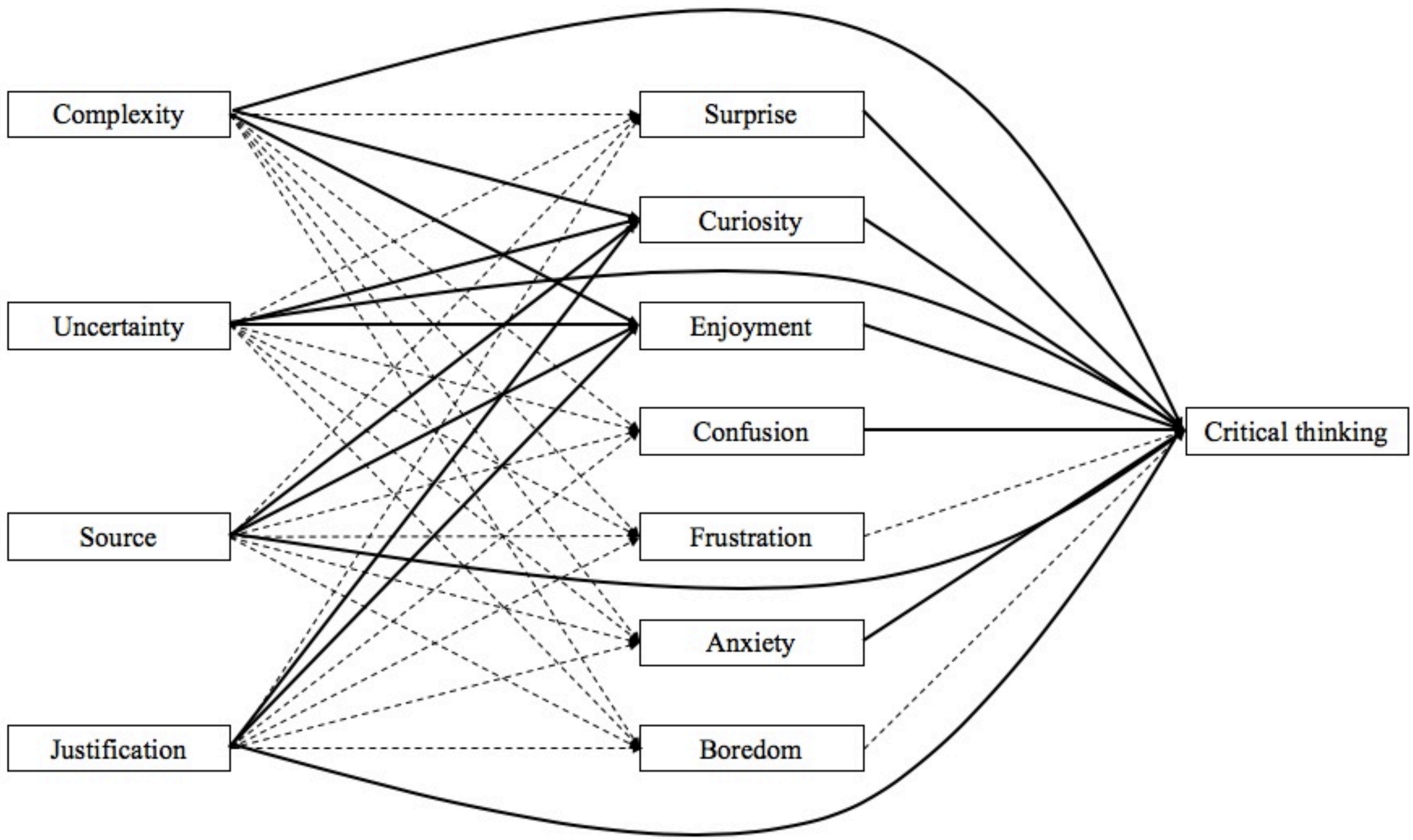

Figure 3. *Hypothesized model. Solid lines represent positive relationships; dotted lines represent negative relationships.*

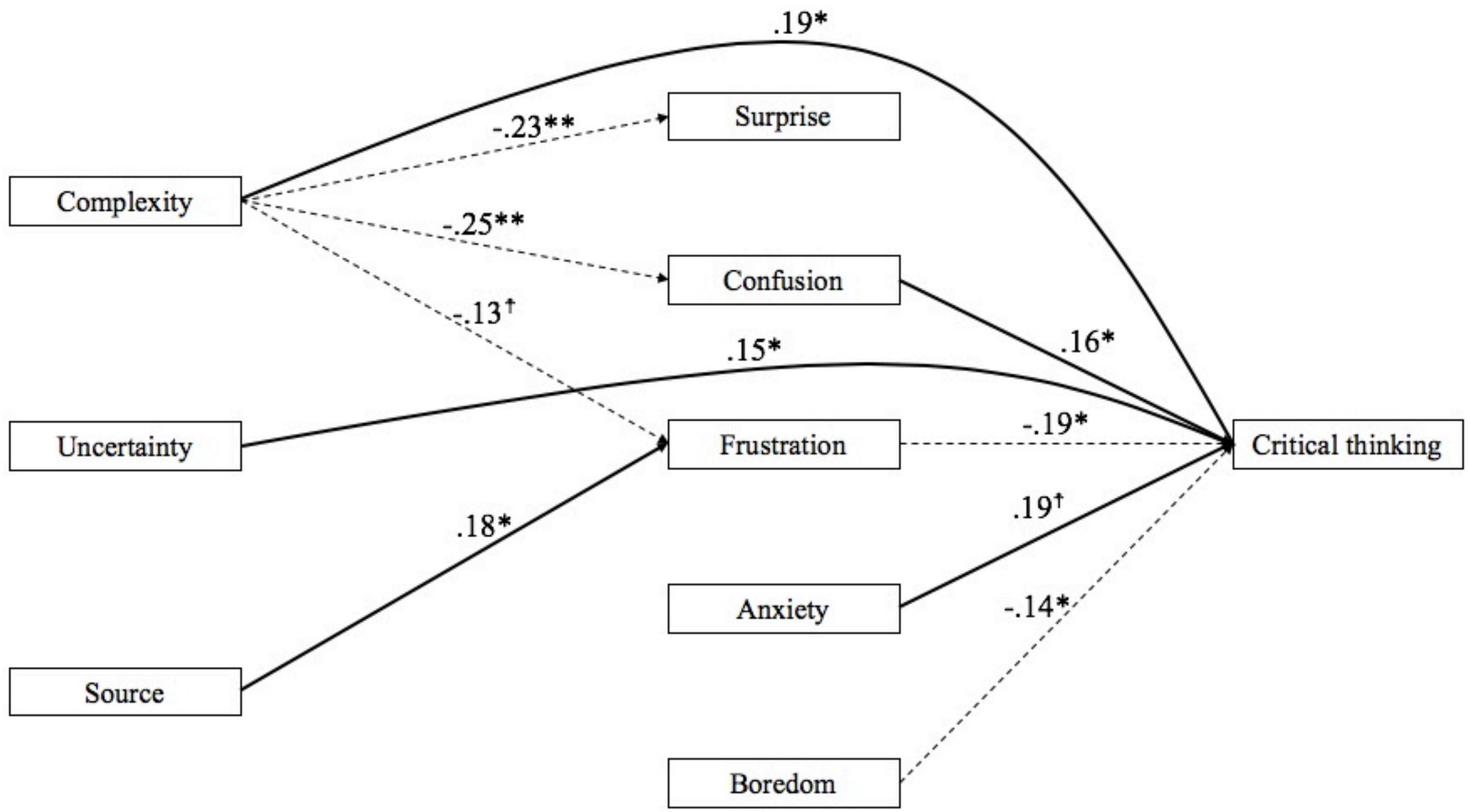

Figure 4. Final model with standardized coefficients. Only significant paths are represented. †p < .075; *p < .05; **p < .01.

Appendix F

Experimental Text

Version A (Pro-Con):
What Are Genetically Modified Foods?

Have you ever wondered what it means when you hear the term "genetically modified foods?" Have you ever thought about how genetically modified foods are developed? Each of those questions are quite interesting to think about given that some of the foods we eat may have been genetically modified. In answer to the first question, genetically modified foods are those that have been modified via genetic engineering or other more traditional methods in order to produce heritable improvements in plants or animals for specific uses (US Department of Agriculture, 2011). In other words, they are foods that have been modified at the gene level to produce a desired trait that would most likely not occur through natural processes. So, just what processes are involved in genetically modifying foods?

You may think that genetically modifying foods is the same process as cloning. This belief is not correct. Cloning involves making an exact genetic copy of an organism. All of the genetic information is identical between those two organisms. In contrast, the process of genetically modifying food can be done using gene cloning methods; however, the protein in the genetically modified organism has been modified somewhat so that the host (modified) organism will express the desired trait. Thus, the genetically modified organism is not usually an exact replica of the donor organism.

You may think that injecting hormones into a plant or animal is involved in the production of genetically modified foods. This belief is also incorrect. Injecting hormones into a plant or animal can increase its growth rate or its size. However, injecting hormones *does not modify* the genetic makeup of the plant or animal. In contrast, genetically modified foods have had some of their characteristics changed at the gene level.

Now you know that genetically modified foods are those foods that have had some of their genetic information changed. You may think that the development of genetically modified foods occurs only in laboratories by scientists. This is also not correct! Genetic modifications may happen through natural processes. For example, one type of a natural process for genetic modification of plants is cross-pollination. Cross-pollination occurs when the pollen from one plant is crossed with the pollen of a second plant. Corn plants are often cross-pollinated when wind carries pollen from one corn crop to a separate corn crop in nearby fields. When corn plants of different varieties are cross-pollinated, the seeds they produce will be genetically different than the original corn plants. The corn produced by these cross-pollinated plants is a combination of the two varieties of corn. The corn seeds from the new cross-pollinated plant will carry the new genetic information. That new genetic information will continue to be a part of that plant's offspring.

Since it is the case that genetically modified foods can occur through natural processes you may wonder just how long genetic modification of foods has been taking place. You may hold the belief that genetically modified foods are only a product of contemporary scientific research. This belief is not correct! Indeed, for many centuries farmers and gardeners have used cross-pollination of plants in an attempt to produce plants or flowers that would have particular qualities. For example, farmers have used selective pollination of plants in hopes of producing sweeter fruits or more colorful flowers. Even today, farmers and gardeners use cross-pollination in hopes of producing plants with more desirable traits.

In summary, genetically modified foods are those foods that have had some of their genetic information changed. Some foods can be genetically modified through natural processes such as cross-pollination. Farmers have used the process of genetically modifying foods for centuries as they attempt to develop plants with desired characteristics.

What are some of the advantages of GM foods?[2]

The world population has topped 7 billion people and is predicted to double in the next 50 years. Ensuring an adequate food supply for this booming population is going to be a major challenge in the years to come. GM foods promise to meet this need in a number of ways:

1) **Pest resistance** Crop losses from insect pests can be staggering, resulting in devastating financial loss for farmers and starvation in developing countries. Farmers typically use many tons of chemical pesticides annually. Consumers do not wish to eat food that has been treated with pesticides because of potential health hazards, and run-off of agricultural wastes from excessive use of pesticides and fertilizers can poison the water supply and cause harm to the environment. Growing GM foods such as B.t. corn can help eliminate the application of chemical pesticides and reduce the cost of bringing a crop to market.

2) **Herbicide tolerance** For some crops, it is not cost-effective to remove weeds by physical means such as tilling, so farmers will often spray large quantities of different herbicides (weed-killer) to destroy weeds, a time-consuming and expensive process, that requires care so that the herbicide doesn't harm the crop plant or the environment. Crop plants genetically-engineered to be resistant to one very powerful herbicide could help prevent environmental damage by reducing the amount of herbicides needed.

3) **Drought tolerance/salinity tolerance** As the world population grows and more land is utilized for housing instead of food production, farmers will need to grow crops in locations previously unsuited for plant cultivation. Creating plants that can withstand long periods of drought or high salt content in soil and groundwater will help people to grow crops in formerly inhospitable places.

4) **Nutrition** Malnutrition is common in Third World countries where impoverished peoples rely on a single crop such as rice for the main staple of their diet. However, rice does not contain adequate amounts of all necessary nutrients to prevent malnutrition. If rice could be genetically engineered to contain additional vitamins and minerals, nutrient deficiencies could be alleviated.

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[2] (Canadian Standards Association, 2000)

What are some of the criticisms against GM foods?

Environmental activists, religious organizations, public interest groups, professional associations and other scientists and government officials have all raised concerns about GM foods, and criticized agribusiness for pursuing profit without concern for potential hazards, and the government for failing to exercise adequate regulatory oversight. Here are some concerns:

1) **Unintended harm to other organisms** In 2013, a laboratory study was published in *Nature* showing that pollen from B.t. corn caused high mortality rates in monarch butterfly caterpillars. Monarch caterpillars consume milkweed plants, not corn, but the fear is that if pollen from B.t. corn is blown by the wind onto milkweed plants in neighboring fields, the caterpillars could eat the pollen and perish. Unfortunately, B.t. toxins kill many species of insect larvae indiscriminately; it is not possible to design a B.t. toxin that would only kill crop-damaging pests and remain harmless to all other insects.

2) **Reduced effectiveness of pesticides** Just as some populations of mosquitoes developed resistance to the now-banned pesticide DDT7uy, many people are concerned that insects will become resistant to B.t. or other crops that have been genetically modified to produce their own pesticides.

3) **Gene transfer to non-target species** Another concern is that crop plants engineered for herbicide tolerance and weeds will cross-breed, resulting in the transfer of the herbicide resistance genes from the crops into the weeds. These "superweeds" would then be herbicide tolerant as well. Other introduced genes may cross over into non-modified crops planted next to GM crops.

4) **Unknown effects on human health** There is a growing concern that introducing foreign genes into food plants may have an unexpected and negative impact on human health. A recent article published in Lancet examined the effects of GM potatoes on the digestive tract in rats. This study claimed that there were appreciable differences in the intestines of rats fed GM potatoes and rats fed unmodified potatoes.

Version B (Con-Pro):
What Are Genetically Modified Foods?

Have you ever wondered what it means when you hear the term "genetically modified foods?" Have you ever thought about how genetically modified foods are developed? Each of those questions are quite interesting to think about given that some of the foods we eat may have been genetically modified. In answer to the first question, genetically modified foods are those that have been modified via genetic engineering or other more traditional methods in order to produce heritable improvements in plants or animals for specific uses (US Department of Agriculture, 2011). In other words, they are foods that have been modified at the gene level to produce a desired trait that would most likely not occur through natural processes. So, just what processes are involved in genetically modifying foods?

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1) **Unintended harm to other organisms** In 2013, a laboratory study was published in *Nature* showing that pollen from B.t. corn caused high mortality rates in monarch butterfly caterpillars. Monarch caterpillars consume milkweed plants, not corn, but the fear is that if pollen from B.t. corn is blown by the wind onto milkweed plants in neighboring fields, the caterpillars could eat the pollen and perish. Unfortunately, B.t. toxins kill many species of insect larvae indiscriminately; it is not possible to design a B.t. toxin that would only kill crop-damaging pests and remain harmless to all other insects.

2) **Reduced effectiveness of pesticides** Just as some populations of mosquitoes developed resistance to the now-banned pesticide DDT7uy, many people are concerned that insects will become resistant to B.t. or other crops that have been genetically modified to produce their own pesticides.

3) **Gene transfer to non-target species** Another concern is that crop plants engineered for herbicide tolerance and weeds will cross-breed, resulting in the transfer of the herbicide resistance genes from the crops into the weeds. These "superweeds" would then be herbicide tolerant as well. Other introduced genes may cross over into non-modified crops planted next to GM crops.

4) **Unknown effects on human health** There is a growing concern that introducing foreign genes into food plants may have an unexpected and negative impact on human health. A recent article published in Lancet examined the effects of GM potatoes on the digestive tract in rats. This study claimed that there were appreciable differences in the intestines of rats fed GM potatoes and rats fed unmodified potatoes.

What are some of the advantages of GM foods? (CSA, 2000)

The world population has topped 7 billion people and is predicted to double in the next 50 years. Ensuring an adequate food supply for this booming population is going to be a major challenge in the years to come. GM foods promise to meet this need in a number of ways:

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[3] (Canadian Standards Association, 2000)

1) **Pest resistance** Crop losses from insect pests can be staggering, resulting in devastating financial loss for farmers and starvation in developing countries. Farmers typically use many tons of chemical pesticides annually. Consumers do not wish to eat food that has been treated with pesticides because of potential health hazards, and run-off of agricultural wastes from excessive use of pesticides and fertilizers can poison the water supply and cause harm to the environment. Growing GM foods such as B.t. corn can help eliminate the application of chemical pesticides and reduce the cost of bringing a crop to market.

2) **Herbicide tolerance** For some crops, it is not cost-effective to remove weeds by physical means such as tilling, so farmers will often spray large quantities of different herbicides (weed-killer) to destroy weeds, a time-consuming and expensive process, that requires care so that the herbicide doesn't harm the crop plant or the environment. Crop plants genetically-engineered to be resistant to one very powerful herbicide could help prevent environmental damage by reducing the amount of herbicides needed.

3) **Drought tolerance/salinity tolerance** As the world population grows and more land is utilized for housing instead of food production, farmers will need to grow crops in locations previously unsuited for plant cultivation. Creating plants that can withstand long periods of drought or high salt content in soil and groundwater will help people to grow crops in formerly inhospitable places.

4) **Nutrition** Malnutrition is common in Third World countries where impoverished peoples rely on a single crop such as rice for the main staple of their diet. However, rice does not contain adequate amounts of all necessary nutrients to prevent malnutrition. If rice could be genetically engineered to contain additional vitamins and minerals, nutrient deficiencies could be alleviated.

Appendix G

Prior Knowledge Test

We are interested in what you know about genetically modified foods. Please read the following questions carefully and select the most correct response to the best of your knowledge.

1. Beneficial genetic modification of foods only occurs through…
   a. natural processes.
   b. artificial processes.
   c. radiation processes.
   d. Both A and B

2. Processes used by scientists to modify the genetic makeup of plants and animals include which of the following?
   a. Cloning
   b. Hormone injection
   c. Cross Pollination
   d. Herbicides

3. When using gene cloning methods, a genetically modified organism is...
   a. an exact replica of the donor organism.
   b. a bit different than the donor organism.
   c. in no way similar to the donor organism.
   d. gene cloning methods cannot be used to genetically modify organisms.

4. Cross-pollination is considered to be a process through which plants can be...
   a. genetically modified.
   b. cloned.
   c. hormone injected.
   d. exactly replicated.

5. Which of the following can genetically modify plants or animals?
   a. Farmers
   b. Scientists and Farmers
   c. Animals and Farmers
   d. Scientists, Animals, and Farmers

6. What will happen to the genetic offspring of plants and animals that have been genetically modified?
   a. The genes will be passed to the new offspring.
   b. The offspring's genetic makeup will revert back to its original state.
   c. A radical genetic mutation will occur.
   d. They will be physically or mentally disabled.

7. Applying hormones to a plant or animal may change what about that organism?
   a. The size of the plant or animal

b. The genetic makeup of that plant or animal
c. The DNA of that plant or animal
d. The size of successive generations of that plant or animal

8. Adding or inhibiting a plant's or animal's DNA occurs only in...
a. nature
b. laboratories and farms
c. laboratories and nature
d. laboratories, farms, and nature

9. When were processes used to modify a plant's or animal's DNA developed?
a. In the past 10 years
b. In the past 50 years
c. In the past 100 years
d. Longer than 100 years

10. Methods that are NOT used in producing genetically modified foods include which of the following?
a. Gene cloning methods
b. Hormone injection
c. Cross Pollination
d. Selective Pollination

Appendix H

Topic-Specific Epistemic Beliefs Questionnaire (Adapted to Genetically Modified Foods)

Issues concerning genetic modification are highly topical and often mentioned in the media. We can read about issues such as genetically modified foods, diets, hunger, health and wellness. This is material that we often encounter in newspapers and magazines, as well as on TV and radio. Most people who do research on genetic modification have a background in natural science, for example in chemistry, biology, or medicine. The following questions concern knowledge about genetic modification and how one comes to know about genetic modification. There are no right or wrong answers to these questions; it is your personal beliefs that interest us. Use the scale below to answer the questions. Click the response that best expresses your personal belief.

1	**2**	**3**	**4**	**5**	**6**	**7**
Strongly Disagree						Strongly Agree

Certainty of knowledge about genetically modified foods

1. What is considered to be certain knowledge about genetic modification today, may be considered to be false tomorrow
2. Certain knowledge about genetic modification is rare
3. The results of genetic modification research are preliminary
4. Theories about genetic modification can be disproved at any time
5. The knowledge about issues concerning genetic modification is constantly changing
6. Problems within genetic modification research do not have any clear and unambiguous solutions

Simplicity of knowledge about genetically modified foods

7. *With respect to knowledge about genetic modification, there are seldom connections among different issues
8. *Within genetic modification research, accurate knowledge about details is the most important
9. *Within genetic modification research, various theories about the same topic will make things unnecessarily complicated
10. *Knowledge about genetic modification is primarily characterized by a large amount of detailed information
11. *The knowledge about problems with genetic modification is indisputable
12. *There is really no method I can use to decide whether claims in texts about issues concerning genetic modification can be trusted

Source of knowledge about genetically modified foods

13. *I often feel that I just have to accept that what I read about genetic modification problems can be trusted
14. *When I read about issues concerning genetic modification, the author's opinion is more important than mine

15. *With respect to genetic modification problems, I feel I am on safe ground if I only find an expert statement
16. *When I read about genetic modification problems, I only stick to what the text expresses
17. *My personal judgments about genetic modification problems have little value compared to what I can learn about them from books and articles

Justification for knowing about genetically modified foods

18. To check whether what I read about genetic modification problems is reliable, I try to evaluate it in relation to other things I have learned about the topic
19. When I read about issues related to genetic modification, I try to form my own understanding of the content
20. To gain real insight into issues related to genetic modification, one has to form one's own personal opinion of what one reads
21. When I read about issues concerning genetic modification, I evaluate whether the content seems logical
22. To be able to trust knowledge claims in texts about issues concerning genetic modification, one has to check various knowledge sources
23. Within genetic modification research, there are connections among many topics
24. I understand issues related to genetic modification better when I think through them myself, and not only read about them

*Reverse coded

Chapter 5

Final Discussion

Epistemic cognition, defined as the ways in which individuals acquire, justify, and use knowledge, is necessary to successfully navigate complex informational landscapes in the 21st century. A growing body of research demonstrates that differences in epistemic cognition predict a variety of academic processes and outcomes, including academic achievement (Barzilai & Zohar, 2014; Buehl & Alexander, 2005; Greene, Muis, & Pieschl, 2010; Hofer, 2000; Schommer, Crouse & Rhodes, 1992), self-regulated learning (Muis, 2007, 2008), digital literacy (Kammerer, Amann, & Gerjets, 2015), and motivation (Muis, 2004). Recent research on epistemic cognition has shed light on the multiple epistemic structures through which individuals perceive and apprehend knowledge (Bromme, Pieschl, & Stahl, 2010; Chinn, Buckland, & Samarapungavan, 2011; Greene, Azevedo, & Torney-Purta, 2008; Muis, Bendixen, & Haerle, 2006; Muis, 2007), and has generated novel and integrated frameworks (Barzilai & Zohar, 2014; Bråten, Britt, Strømsø & Rouet, 2011; Chinn, Rinehart & Buckland, 2014; Muis, Chevrier, & Singh, 2018).

However, despite evidence that epistemic cognition "matters" (Kuhn, 1999), a recent meta-analysis has shown that the relationship between epistemic cognition and academic achievement is surprisingly small (r = .162, p < .001; Greene, Cartiff, & Duke, 2018). A few reasons may explain this. As discussed in Chapter 2, a narrow focus on epistemic beliefs, as opposed to other structures such as epistemic aims or epistemic strategies, may have limited researchers' perceptions of the epistemic processes actually at play in learning contexts. Additionally, concerns about the psychometric adequacy of frequently used measures of epistemic cognition (i.e., self-report instruments) may have prevented researchers from reliably measuring what they believed to be measuring, making relations between epistemic cognition and outcome variables disputable. Further, as argued by Bråten and colleagues (2011), much more research is needed to understand the mediational mechanisms by which epistemic cognition predicts learning. Lastly, it may be the case that epistemic cognition has a greater effect on educational outcomes such as digital literacy or critical thinking than on achievement per se.

The purpose of this dissertation was to address these gaps by proposing a multi-study investigation into the role of epistemic emotions as a promising mediator in the relation between epistemic cognition and important educational outcomes, namely self-regulated learning and critical thinking. By adopting new conceptualizations and using advanced methodological and analytical approaches to match these conceptualizations, I have addressed several of the issues that have limited previous research in epistemic cognition. Therefore, the conclusions drawn in this dissertation add new insights into the nature and role of epistemic emotions in epistemic cognition, specifically as it concerns the antecedents and consequences of epistemic emotions.

Contributions of the Present Dissertation

This dissertation makes several contributions of theoretical importance. First, on the basis of a comprehensive literature review, I identified key facets of epistemic cognition and articulated integrated definitions that establish clear conceptual distinctions, notably between epistemic beliefs and epistemic cognition, as well as between epistemic cognition and critical thinking. In both cases, definitions and distinctions have been unclear or inconsistent, resulting in calls from leading scholars for increased conceptual clarity in empirical research (see Bråten, 2016; Greene, Sandoval & Bråten, 2016). Further, we have empirically examined these relations, thereby providing support for the notion that the degree to which epistemic beliefs are considered constructivist relates to the extent to which individuals perceive and address issues of knowledge (Chapter 3, Study 1), as well as for the notion that epistemic cognition is an important underpinning to critical thinking (Chapter 4).

Second and importantly, in this dissertation, we have provided evidence for the mediating role of epistemic emotions in the relation between epistemic cognition and important educational outcomes. We have extended and bolstered Muis and colleagues' (Muis et al., 2015; Muis, Chevrier, & Singh, 2018) integrated framework of epistemic cognition and epistemic emotions by testing the model in three ways: In Chapter 3, we tested how epistemic emotions relate to learning strategies in a short time span (Study 1), as well as over the course of an entire learning session (Study 2). Further, we have tested the generalizability of the model by testing the role of epistemic emotions as a mediator in the relationship between epistemic cognition and two important educational outcomes: learning achievement (Chapter 3, Study 2) and critical thinking (Chapter 4). In doing so, the research presented in Chapter 4 attests to the importance of studying how epistemic cognition relates to other epistemically-related processes such as problem-solving, and decision-making, in a variety of contexts, including non-academic ones.

Third, the research presented in this dissertation contributes to extending Pekrun's control-value theory of academic emotions (Pekrun, 2006; Pekrun & Perry, 2014) by advancing knowledge on one type of academic emotion, i.e., epistemic emotions. Specifically, we empirically tested three new types of cognitive appraisals that serve as antecedents to emotions in educational settings (i.e., appraisals of epistemic congruence, appraisals of information novelty and complexity, appraisals of epistemic aim achievement).

This dissertation also makes contributions of methodological importance. First, the data collection methods employed in Chapter 3 presented one way to operationalize distinctions between epistemic beliefs and online epistemic cognition. Second, in Chapter 3, we presented a novel analytical approach to examine the immediate consequences of emotions on learning processes (see also D'Mello & Graesser, 2012). Lastly, in Chapter 4, we developed a coding scheme to capture critical thinking about socio-scientific issues that can be used to inform future empirical work as well as instructional interventions to increase critical thinking of controversial socio-scientific issues.

Similarly, from the perspective of improving learning and critical thinking around socio-scientific issues of personal and global relevance, the conclusions reached in this dissertation indicate several paths for the design of effective interventions around epistemic cognition and epistemic emotions. These include teaching students to embrace uncertainty and complexity, and to accept and learn to regulate the unpleasant but beneficial emotions that may accompany this endeavor. In the following section, I address the potential limitations of this dissertation and then discuss directions for future work in this area.

Limitations of the Present Dissertation

The conclusions drawn from this dissertation may be limited in several ways. First, the experimental conditions used in the studies presented here differ in many ways from the naturalistic conditions in which individuals typically engage in learning and thinking about socio-scientific issues, which include, for instance, web searching and open-ended discussions with people of similar or opposing perspectives. Instead, in the studies presented in Chapter 3 and Chapter 4, participants had access only to a fixed number of written documents on an imposed topic and had to complete tasks they may have lacked personal significance. Given that epistemic cognition and critical thinking are two higher-order processes that require motivated and effortful thinking, one could question the extent to which participants were motivated to deploy their best epistemic cognition and critical thinking. Indeed, Hyytinen, Holma, Toom, Shavelson, and Lindblom-Ylänne (2014) found that under experimental conditions, students' motivation to think critically did not match their actual critical thinking skills. Similarly, knowing that participants did not have access to further sources of information other than the documents provided to them during the experiment might have prevented some individuals from questioning the trustworthiness of the sources provided or conversely, cause them to accept claims at face value. This may have decreased the quantity and quality of epistemic cognition and critical thinking observed in these studies. Similarly, given that task value and perceived control are important antecedents to emotions in academic settings (Pekrun, 2006), it may be the case that low task value could have impacted the arousal of epistemic emotions in these experimental settings, thereby limiting the generalizability of the findings. As such, future work examining relations between epistemic cognition, emotions and also critical thinking should consider more naturalistic settings, such as open-ended Internet searches or group discussions.

Other limitations concern the measurement of constructs and analytical approaches employed in this dissertation. Specifically, only quantitative measurements of epistemic cognition, epistemic emotions, self-regulated learning, and critical thinking were taken. For epistemic emotions, prior theoretical and empirical work, as well as several findings from this dissertation, indicate that several epistemic emotions, whether positive or negative in valence (e.g., surprise, confusion, anxiety), can be beneficial or detrimental to learning and thinking, depending on their level of intensity, and possibly also on their chronometry (i.e., how long an emotion lasts before it fades away). Indeed, by nature, emotions are highly fluid and ephemeral, and can last only a passing moment or linger for several minutes or hours, and this is a variable that matters. Indeed, lasting emotions may morph into different emotional states that can have important consequences for learning and thinking, such as when lasting confusion turns into frustration or disengagement (D'Mello & Graesser, 2012). In the work presented here, we did not take measurement of emotions' chronometry, but this will be crucial for future work to advance theories of academic emotions in general, and of epistemic emotions in particular. To this end, advanced methods such as physiological measures of facial expression, physical activation, heart rate or skin conductivity may be considered.

Lastly, the analyses presented in this dissertation used correlational associations of variables, and we did not manipulate predictor variables. To this end, mood induction protocols (for a review, see Quigley, Lindquist, & Barrett, 2014) can be used to elicit and assess emotions. However, this may be more difficult to achieve for more stable epistemic beliefs.

Future Directions

Several avenues for future work have already been delineated in the discussion of the limitations presented above. However, there are two additional areas in need of future research that warrant a fuller discussion. The first pertains to underexplored contexts and the second concerns the study of relations between epistemic cognition and epistemic emotions across the lifespan.

Underexplored contexts. There are several ways in which individuals engage in learning and thinking about socio-scientific issues: one way is by consulting documentation, such as in this dissertation; other ways include dyadic or group discussions, or participation in relevant communities of practice where knowledge is generated and shared. To date, little is known about how epistemic cognition and epistemic emotions may arise and relate to learning in thinking in these alternative contexts. Specifically, which additional psychological or social processes may act as antecedents to epistemic emotions in these contexts? And how might group dynamics mediate or moderate the consequences of epistemic emotions on relevant outcomes?

Looking beyond the context of socio-scientific issues, underexplored contexts relevant to this line of research include disciplines or topics that are based on an epistemology that is different from the epistemology of science, such as history, economics, literature, or creative or artistic work, inside and outside of educational settings. What epistemic emotions arise when learning or thinking about the conflicting issues that populate these contexts? How are these emotions related to facets of epistemic cognition? And what role do epistemic emotions play in these contexts? Relatedly, how are epistemic emotions experienced and expressed across socio-cultural contexts? In educational settings, socio-cultural elements such as the nature of feedback, the meaning of assessment outcomes, peer support structures, or task complexity, can significantly affect perceived control and task value (Pekrun, 2006), and may modulate the arousal, intensity, and chronometry of epistemic emotions. In turn, these variations may potentially affect the consequences of epistemic emotions for learning and thinking.

Relations between epistemic cognition and epistemic emotions across the lifespan. To fully understand the role of epistemic emotions in epistemic cognition, future research will be necessary to assess how current understandings generalize to different populations across the lifespan, from children to adolescents to experts. Prior work has shown that the way in which negative emotions relate to learning processes and outcomes is different for children than for adults, possibly because children have not yet developed emotion regulation to the same extent as adults (e.g., Muis, Psaradellis, Di Leo, Lajoie, & Chevrier, 2015). Further, among the adult population, differences have been established with regard to the ways in which novice and experts perceive, use, and justify knowledge (Greene & Yu, 2014) that may impact the arousal and consequences of epistemic emotions in various learning contexts. Further, differences in epistemic cognition development and emotional experiences may affect several educational processes and outcomes in ways unknown to date. Muis et al. (2006) proposed that the development of epistemic cognition is shaped by experiences in the family and social environments, then later in educational settings. However, little is known about how epistemic emotions (for instance, confusion, curiosity, or joy of learning), whether experienced or modelled, shape the development of epistemic cognition. Reciprocally, might the development of epistemic cognition shape epistemic emotional experiences in educational settings later in life?

At later points in life, what role may epistemic emotions play in educational perseverance, the attainment of higher education degrees, or professional success? With specific concern for doctoral education and academic careers, what role may epistemic emotions play in degree completion, academic success, and well-being, as opposed to burnout or attrition? Indeed, the study of epistemic emotions as one facet of epistemic cognition is rife with research questions that remain to be explored and that could reveal new perspectives on instructional interventions designed to increase learning and thinking about complex issues and beyond.

Concluding Comments

In an increasingly complex and uncertain world, it is becoming more important than ever for individuals to be proficient in how to vet, acquire, use, and justify knowledge in the face of complex and conflicting issues. Understanding how individuals think and feel when contending with socio-scientific issues of personal and global importance is an important line of research that requires integrated conceptualizations and sophisticated methodologies. My objectives for the present dissertation were to review theoretical assumptions about the structures of epistemic cognition, identify methodological approaches that are aligned with these conceptualizations, and use contextualized data to investigate the emotional facet of epistemic cognition, its antecedents and consequences for important educational outcomes, including self-regulated learning and critical thinking. In addressing these issues, I hope to have contributed to a more complete understanding of epistemic cognition and its relations to learning and thinking about socio-scientific issues, and also to have broadened the horizons of future research by including epistemic emotions in the conversation.

References

Barzilai, S., & Zohar, A. (2014). Reconsidering personal epistemology as metacognition: A multifaceted approach to the analysis of epistemic thinking. *Educational Psychologist, 49*, 13-35.

Bråten, I. (2016). Epistemic cognition interventions: Issues, challenges, and directions. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 360–372). New York, NY: Routledge.

Bråten, I., Britt, M. A., Strømsø, H. I., & Rouet, J.-F. (2011). The role of epistemic beliefs in the comprehension of multiple expository texts: Toward an integrated model. *Educational Psychologist, 46*, 48-70.

Bromme, R., Pieschl, S., & Stahl, E. (2010). Epistemological beliefs are standards for adaptive learning: A functional theory about epistemological beliefs and metacognition. *Metacognition and Learning, 5*, 7-26.

Buehl, M. M., & Alexander, P. A. (2005). Motivation and performance differences in students' domain-specific epistemological belief profiles. *American Educational Research Journal, 42*, 697-726.

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. L. A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist, 46*, 141-167.

Chinn, C. A., Rinehart, R. W., & Buckland, L. A. (2014). Epistemic cognition and evaluating information: Applying the AIR model of epistemic cognition. In D. Rapp and J. Braasch (Eds.), *Processing inaccurate information: Theoretical and applied perspectives from* *cognitive science and the educational sciences* (pp. 425-453). Cambridge, MA: MIT Press.

D'Mello, S. K., & Graesser, A. C. (2012). Dynamics of affective states during complex learning. *Learning and Instruction, 22*, 145–157.

Danielson, R. W., Sinatra, G. M., & Kendeou, P. (2016). Augmenting the refutation text effect with analogies and graphics. *Discourse Processes, 53*, 392-414.

Greene, J. A., Azevedo, R., & Torney-Purta, J. (2008). Modeling epistemic and ontological cognition: Philosophical perspectives and methodological directions. *Educational Psychologist, 43*, 142-160.

Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. *Journal of Educational Psychology*. Advanced online publication.

Greene, J. A., Muis, K. R., & Pieschl, S. (2010). The role of epistemic beliefs in students' self-regulated learning with computer-based learning environments: *Conceptual and methodological issues. Educational Psychologist, 45*, 245-257.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016c). Reflections and future directions for epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 495– 510). New York, NY: Routledge.

Greene, J. A., & Yu, S. B. (2014). Modeling and measuring epistemic cognition: A qualitative re-investigation. *Contemporary Educational Psychology, 39,* 12-28.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology, 25*, 378-405.

Hyytinen, H., Holma, K., Toom, A., Shavelson, R. J., & Lindblom-Ylänne, S. (2014). The complex relationship between students' critical thinking and epistemological beliefs in the context of problem solving. *Frontline Learning Research, 2,* 1-25.

Kammerer, Y., Amann, D. G., & Gerjets, P. (2015). When adults without university education search the Internet for health information: The roles of Internet-specific epistemic beliefs and a source evaluation intervention. *Computers in Human Behavior, 48*, 297-309.

Kuhn, D. (1999). A developmental model of critical thinking. Educational researcher, 28, 16-46.

Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Educational Research, 74*, 317–377.

Muis, K. R. (2007). The role of epistemic beliefs in self-regulated learning. *Educational Psychologist, 42*, 173-190.

Muis, K. R. (2008). Epistemic profiles and self-regulated learning: Examining relations in the context of mathematics problem solving. *Contemporary Educational Psychology, 33*, 177-208.

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review, 18,* 3-54.

Muis, K. R., Chevrier, M., & Singh, C. A. (2018). The role of epistemic emotions in personal epistemology and self-regulated learning. *Educational Psychologist, 53,* 165-184.

Muis, K. R., Pekrun, R., Sinatra, G. M., Azevedo, R., Trevors, G., Meier, E., & Heddy, B. C. (2015). The curious case of climate change: Testing a theoretical model of epistemic beliefs, epistemic emotions, and complex learning. *Learning and Instruction, 39*, 168–183.

Muis, K. R., Psaradellis, C., Lajoie, S. P., Di Leo, I., & Chevrier, M. (2015). The role of epistemic emotions in mathematics problem solving. *Contemporary Educational Psychology, 42*, 172–185.

Muis, K. R., & Singh, C. A. (2018). The three facets of epistemic thinking in self-regulated learning. In D. Schunk & J. Greene (Eds.), *Handbook of self-regulated of learning and performance* (pp. 434–456). New York, NY: Routledge.

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18*, 315–341.

Pekrun, R., & Perry, R. P. (2014). Control-value theory of achievement emotions. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 120–141). New York, NY: Taylor & Francis.

Quigley, K. S., Lindquist, K. A., & Barrett, L. F. (2013). Inducing and measuring emotion: Tips, tricks, and secrets. Chapter in H. T. Reis & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp. 220– 250). New York, NY: Cambridge University Press.

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology, 84*, 435.

Bibliography

Abrami, P. C., Bernard, R. M., Borokhovski, E., Wade, A., Surkes, M. A., Tamim, R., & Zhang, D. (2008). Instructional interventions affecting critical thinking skills and dispositions: A stage 1 meta-analysis. *Review of Educational Research, 78*, 1102-1134.

Alexander, P. A. (2014). Thinking critically and analytically about critical-analytic thinking: An introduction. *Educational Psychology Review, 26*, 469-476.

Alexander, P. A. (2016). The arguments for and the reasoning about epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 100-110). New York, NY: Routledge.

Alexander, P. A., Winters, F. I., Loughlin, S. M., & Grossnickle, E. M. (2012). Students' conceptions of knowledge, information, and truth. *Learning and Instruction, 22*, 1-15.

Arum, R., & Roksa, J. (2011). *Academically adrift: Limited learning on college campuses*. Chicago, IL: University of Chicago Press.

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology, 29*, 344-370.

Azevedo, R., Harley, J., Trevors, G., Duffy, M., Feyzi-Behnagh, R., Bouchet, F., & Landis, R. (2013). Using trace data to examine the complex roles of cognitive, metacognitive, and emotional self-regulatory processes during learning with multi-agent systems. In *International handbook of metacognition and learning technologies* (pp. 427-449). Springer, New York, NY.

Azevedo, R., Johnson, A., Chauncey, A., & Burkett, C. (2010). Self-regulated learning with MetaTutor: Advancing the science of learning with MetaCognitive tools. In M. Khine &

I. Saleh (Eds.), *New science of learning: Computers, cognition, and collaboration in education* (pp. 225–247). Amsterdam, The Netherlands: Springer.

Azevedo, R., Moos, D., Johnson, A., & Chauncey, A. (2010). Measuring cognitive and metacognitive regulatory processes used during hypermedia learning: Issues and challenges. *Educational Psychologist, 45,* 210-223.

Bailin, S., & Siegel, H. (2003). Critical thinking. In N. Blake, P. Smeyers, R. Smith, & P. Standish (Eds.), *The Blackwell guide to the philosophy of education* (pp. 181-193). Oxford, UK: Blackwell Publishing.

Barnett, R. (2004). Learning for an unknown future. *Higher Education Research & Development*, *23*, 247-260.

Barzilai, S., & Eshet-Alkalai, Y. (2015). The role of epistemic perspectives in comprehension of multiple author viewpoints. *Learning and Instruction, 36*, 86-103.

Barzilai, S., Tzadok, E., & Eshet-Alkalai, Y. (2015). Sourcing while reading divergent expert accounts: Pathways from views of knowing to written argumentation. *Instructional Science, 43*, 737-766.

Barzilai, S., & Weinstock, M. (2015). Measuring epistemic thinking within and across topics: A scenario-based approach. *Contemporary Educational Psychology, 42,* 141-158.

Barzilai, S., & Zohar, A. (2012). Epistemic thinking in action: Evaluating and integrating online sources. *Cognition and Instruction, 30,* 39-85.

Barzilai, S., & Zohar, A. (2014). Reconsidering personal epistemology as metacognition: A multifaceted approach to the analysis of epistemic thinking. *Educational Psychologist, 49,* 13-35.

Baxter Magolda, M. B. (1992). *Knowing and reasoning in college: Gender-related patterns in students' intellectual development*. San Francisco, CA: Jossey-Bass.

Baxter Magolda, M. B. (2004). A constructivist conceptualization of epistemological reflection. *Educational Psychologist*, *39*, 31-42.

Belenky, M., Clinchy, B., Goldberger, N., & Tarule, J. (1986). Women's ways of knowing: The development of self, voice, and mind. New York, NY: Basic Books.

Bendixen, L. (2002). A process model of epistemic belief change. In B. K. Hofer, & P. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing*. Mahwah, NJ: Lawrence Erlbaum Association, Inc.

Bendixen, L. D., & Rule, D. C. (2004). An integrative approach to personal epistemology: A guiding model. *Educational Psychologist, 39*, 69-80.

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology, 45*, 180-191.

Bieg, M., Goetz, T., & Hubbard, K. (2013). Can I master it and does it matter? An intraindividual analysis on control-value antecedents of trait and state academic emotions. *Learning and Individual Differences, 28,* 102-108.

Bless, H., Clore, G. L., Schwarz, N., Golisano, V., Rabe, C., & Wölk, M. (1996). Mood and the use of scripts: Does a happy mood really lead to mindlessness? *Journal of Personality and Social Psychology, 71,* 665–679.

Bohn-Gettler, C. M., & Rapp, D. N. (2011). Depending on my mood: Mood-driven influences on text comprehension. *Journal of Educational Psychology, 103*, 562-577.

Boykoff, M. T., & Boykoff, J. M. (2004). Balance as bias: Global warming and the US prestige press. *Global Environmental Change*, *14*, 125-136.

Bråten, I. (2016). Epistemic cognition interventions. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 360–371). New York, NY: Routledge.

Bråten, I., Anmarkrud, Ø., Brandmo, C., & Strømsø, H. I. (2014). Developing and testing a model of direct and indirect relationships between individual differences, processing, and multiple-text comprehension. *Learning and Instruction*, *30*, 9-24.

Bråten, I., Britt, M. A., Strømsø, H. I., & Rouet, J.-F. (2011). The role of epistemic beliefs in the comprehension of multiple expository texts: Toward an integrated model. *Educational Psychologist, 46,* 48-70.

Bråten, I., Ferguson, L. E., Strømsø, H. I., & Anmarkrud, Ø. (2014). Student working with multiple conflicting documents on a science issue: Relations between epistemic cognition while reading and sourcing and argumentation in essays. *British Journal of Educational Psychology, 84*, 58–85.

Bråten, I., Gil, L., Strømsø, H. I., & Vidal-Abarca, E. (2009). Personal epistemology across cultures: Exploring Norwegian and Spanish university students' epistemic beliefs about climate change. *Social Psychology of Education, 12*, 529-560.

Bråten, I., & Strømsø, H. I. (2009). Effects of task instruction and personal epistemology on the understanding of multiple texts about climate change. *Discourse Processes, 47*, 1-31.

Bråten, I., Strømsø, H. I., & Samuelstuen, M. S. (2008). Are sophisticated students always better? The role of topic-specific personal epistemology in the understanding of multiple expository texts. *Contemporary Educational Psychology*, *33*, 814-840.

Bromme, R., Kienhues, D., & Stahl, E. (2008). Knowledge and epistemological beliefs: An intimate but complicate relationship. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs* (pp. 423-441). New York, NY: Springer.

Bromme, R., Pieschl, S., & Stahl, E. (2010). Epistemological beliefs are standards for adaptive learning: A functional theory about epistemological beliefs and metacognition. *Metacognition and Learning, 5*, 7-26.

Broughton, S. H., Pekrun, R., & Sinatra, G. M. (2012). *Climate change, genetically modified foods, airport body scanners: Investigating students' emotions related to science topics.* Paper presented at the annual meeting of the American Educational Researchers Association, National Conference, Vancouver, Canada.

Brun, G., & Kuenzle, D. (2008). A new role for emotions in epistemology? In G. Brun, U. Doğuoğlu, & D. Kuenzle, D. (Eds.), *Epistemology and emotions* (pp. 1-32). Aldershot, UK: Ashgate.

Buehl, M. M., & Alexander, P. A. (2005). Motivation and performance differences in students' domain-specific epistemological belief profiles. *American Educational Research Journal*, *42*, 697-726.

Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002). Beliefs about schooled knowledge: Domain specific or domain general? *Contemporary Educational Psychology, 27*, 415-449.

Byrne, B. M. (2005). Factor analytic models: Viewing the structure of an assessment instrument from three perspectives. *Journal of Personality Assessment, 85*, 17-32.

Byrne, B. M. (2012). *Structural equation modeling with Mplus: Basic concepts, applications, and programming*. New York, NY: Routledge.

Chan, N. M., Ho, I. T., & Ku, K. Y. (2011). Epistemic beliefs and critical thinking of Chinese students. *Learning and Individual Differences*, *21*, 67-77.

Chandler, M. J., Hallett, D., & Sokol, B. W. (2002). Competing claims about competing knowledge claims. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 145-168). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Chevrier, M., Muis, K. R., Trevors, G., Psaradellis, C., Di Leo I., & Singh, C. (2016, August). *Epistemic emotions mediate relations between epistemic beliefs and learning strategies*. Poster presented at the annual convention of the American Psychological Association, Denver, CO.

Chevrier, M., Trevors, G. J., Muis, K. R., Psaradellis, C., & Di Leo, I., (2015, August). *Relations between epistemic beliefs and emotions when reading contradictory information.* Paper presented at the biennial conference of the European Association for Research on Learning and Instruction, Limassol, Cyprus.

Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*, 1-49.

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. L. A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist, 46,* 141-167.

Chinn, C. A., & Rinehart, R. W. (2016). Epistemic cognition and philosophy: Developing a new framework for epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 460-478). New York, NY: Routledge.

Clarebout, G., Elen, J., Luyten, L., & Bamps, H. (2001). Assessing epistemological beliefs: Schommer's questionnaire revisited. *Educational Research and Evaluation, 7*, 53-77.

Claris, L., & Riley, D. (2012). Situation critical: critical theory and critical thinking in engineering education. *Engineering Studies*, *4*, 101-120.

Clifford, M. M. (1988). Failure tolerance and academic risk-taking in ten-to twelve-year-old students. *British Journal of Educational Psychology*, *58*, 15-27.

Clore, G. L., Wyer, R. S., Dienes, B., Gasper, K., Gohm, C., & Isbell, L. (2001). Affective feelings as feedback: Some cognitive consequences. In L. L. Martin & G. L. Clore (Eds.), *Theories of mood and cognition: A user's handbook* (pp. 27-62). Mahwah, NJ: Lawrence Erlbaum.

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Corbett, J. B., & Durfee, J. L. (2004). Testing public (un)certainty of science: Media representations of global warming. *Science Communication, 26*, 129-151.

Craig, S. D., D'Mello, S., Witherspoon, A., & Graesser, A. (2008). Emote aloud during learning with AutoTutor: Applying the Facial Action Coding System to cognitive–affective states during learning. *Cognition and Emotion*, *22*, 777-788.

D'Mello, S. K., Craig, S. D., Sullins, J., & Graesser, A. C. (2006). Predicting affective states expressed through an emote-aloud procedure from AutoTutor's mixed-initiative dialogue. *International Journal of Artificial Intelligence in Education*, *16*, 3-28.

D'Mello, S. K., & Graesser, A. C. (2012). Dynamics of affective states during complex learning. *Learning and Instruction, 22,* 145-157.

D'Mello, S. K., & Graesser, A. C. (2014). Confusion. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *Handbook of emotions in education* (pp. 289–310). New York: Routledge.

D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29*, 153-170.

Danielson, R. W., Sinatra, G. M., & Kendeou, P. (2016). Augmenting the refutation text effect with analogies and graphics. *Discourse Processes*, *53*, 392-414.

Danvers, E. C. (2016). Criticality's affective entanglements: rethinking emotion and critical thinking in higher education. *Gender and Education*, *28*, 282-297.

DeBacker, T. K., Crowson, H. M., Beesley, A. D., Thoma, S. J., & Hestevold, N. L. (2008). The challenge of measuring epistemic beliefs: An analysis of three self-report instruments. *The Journal of Experimental Education, 76*, 281–312.

Dewey, J. (1933). *Philosophy and civilization*. Boston: D.C. Heath & Co.

Dole, J. A., & Sinatra, G. M. (1998). Reconceptualizing change in the cognitive construction of knowledge. *Educational Psychologist*, *33*, 109-128.

Ekman, P. (1984). Expression and the nature of emotion. *Approaches to Emotion*, *3*, 19-344.

Elgin, C. Z. (2008). Emotion and understanding. In G. Brun, U. Doguoglu, & D. Kuenzle (Eds.), *Epistemology and emotions* (pp. 33–50). Aldershot, UK: Ashgate.

Ellsworth, P. C. (2003). Confusion, concentration, and other emotions of interest: Commentary on Rozin and Cohen. *Emotion, 3,* 81-85.

Ellsworth, P. C. (2013). Appraisal theory: Old and new questions. *Emotion Review, 5*, 125–131.

Ellsworth, P. C., Scherer, K. R. (2003). Appraisal processes in emotion. In R. J. Davidson, K. R. Scherer, & H. H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 572–95). Oxford, UK: Oxford University Press.

Ennis, R. H. (1987). A taxonomy of critical thinking dispositions and abilities. In J. Baron a& R. Sternberg (Eds.), *Teaching thinking skills: Theory and practice* (pp. 9-26). New York, NY: Freeman.

Ennis, R. H. (2018). Critical thinking across the curriculum: A vision. *Topoi*, *37*, 165-184.

Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behavior Research Methods, Instruments, and Computers*, *28*, 1-11.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis*. Cambridge, MA: MIT press.

Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction (Research findings and recommendations).* Newark, DE: American Philosophical Association.

Facione, P. A., Facione, N. C. (2014). *The holistic critical thinking scoring rubric: A tool for developing and evaluating critical thinking*. Available online: http://www.insightassessment.com/pdf_files/Rubric%20HCTSR.pdf

Faul, F., & Erdfelder, E. (1992). *GPOWER: A priori, post-hoc, and compromise power analyses for MS-DOS*. Bonn University, Department of Psychology: Bonn, Germany.

Ferguson, L. E., & Bråten, I. (2013). Student profiles of knowledge and epistemic beliefs: Changes and relations to multiple-text comprehension. *Learning and Instruction, 25*, 49-61.

Ferguson, L. E., Bråten, I., & Strømsø, H. I. (2012). Epistemic cognition when students read multiple documents containing conflicting scientific evidence: A think-aloud study. *Learning and Instruction, 22,* 103-120.

Fisher, A. (2011). *Critical thinking: An introduction*. Second edition. Cambridge, MA: Cambridge University Press.

Foster, M. I., & Keane, M. T. (2015). Why some surprises are more surprising than others: Surprises as a metacognitive sense of explanatory difficulty. *Cognitive Psychology, 81*, 74-116.

Franco, G. M., Muis, K. R., Kendeou, P., Ranellucci, J., Sampasivam, L., & Wang, X. (2012). Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics. *Learning and Instruction, 22*, 62-77.

Funk, C., & Kennedy, B. (2016). The new food fights: US public divides over food science. *Pew Research Center*. Retrieved from http://www.pewinternet.org/2016/12/01/the-new-food-fights/

Garimella, K., De Francisci Morales, G., Gionis, A., & Mathioudakis, M. (2018, April). Political discourse on social media: Echo chambers, gatekeepers, and the price of bipartisanship. In *Proceedings of the 2018 World Wide Web Conference* (pp. 913-922). International World Wide Web Conferences Steering Committee.

Goetz, T., Frenzel, A. C., Hall, N. C., Nett, U. E., Pekrun, R., & Lipnevich, A. A. (2014). Types of boredom: An experience sampling approach. *Motivation and Emotion, 38*, 401-419.

Gordon, J. (2000). Congruency in defining critical thinking by nurse educators and non-nurse scholars. *Journal of Nursing Education, 39*, 340–351.

Gowda, M. V. R., Fox, J. C., & Magelky, R. D. (1997). Students' understanding of climate change: Insights for scientists and educators. *Bulletin of the American Meteorological Society, 78*, 2232–2240.

Greene, J. A., & Azevedo, R. A. (2009). A macro-level analysis of SRL processes and their relations to the acquisition of a sophisticated mental model of a complex system. *Contemporary Educational Psychology, 34*, 18-29.

Greene, J. A., Azevedo, R., & Torney-Purta, J. (2008). Modeling epistemic and ontological cognition: Philosophical perspectives and methodological directions. *Educational Psychologist, 43,* 142-160.

Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. *Journal of Educational Psychology*. Advanced online publication.

Greene, J. A., Muis, K. R., & Pieschl, S. (2010). The role of epistemic beliefs in students' self-regulated learning with computer-based learning environments: Conceptual and methodological issues. *Educational Psychologist, 45*, 245-257.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016a). *Handbook of epistemic cognition*. New York, NY: Routledge.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016b). Introduction to epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 1-16). New York, NY: Routledge.

Greene, J. A., Sandoval, W. A., & Bråten, I. (2016c). Reflections and future directions. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 495-511). New York, NY: Routledge.

Greene, J. A., Torney-Purta, J., & Azevedo, R. (2010). Empirical evidence regarding relations among a model of epistemic and ontological cognition, academic performance, and educational level. *Journal of Educational Psychology, 102,* 234.

Greene, J. A., & Yu, S. B. (2014). Modeling and measuring epistemic cognition: A qualitative re-investigation. *Contemporary Educational Psychology, 39,* 12-28.

Greene, J. A., & Yu, S. B. (2016). Educating critical thinkers: The role of epistemic cognition. *Policy Insights from the Behavioral and Brain Sciences*. Advanced online publication.

Greene, J. A., Yu, S. B., & Copeland, D. Z. (2014). Measuring critical components of digital literacy and their relationships with learning. *Computers and Education, 76*, 55-69.

Gregoire, M. (2003). Is it a challenge or a threat? A dual-process model of teachers' cognition and appraisal processes during conceptual change. *Educational Psychology Review*, *15*, 147-179.

Gross, J. J. (2014). Emotion regulation: Conceptual and empirical foundations. In J. J. Gross (Ed.), *Handbook of emotion regulation* (2nd ed.) (pp. 3-20). New York, NY: Guilford.

Halpern, D. F. (2014) *Thought and knowledge*. Fifth edition. NY: Psychology Press.

Hammer, D., & Elby, A. (2002). On the form of personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 169-190). Mahwah, NJ: Lawrence Erlbaum Associates.

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences, 12,* 53-90.

Harley, J. M., Pekrun, R., Taxer, J. L., & Gross, J. J. (in press). Emotion regulation in achievement situations: An integrated model. *Educational Psychologist.*

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis*. New York, NY: Guilford.

Hayes, A. F., & Preacher, K. J. (2013). *Statistical mediation analysis with a multi-categorical independent variable*. Unpublished white paper.

Heddy, B. C., Danielson, R. W., Sinatra, G. M., & Graham, J. (2017). Modifying knowledge, emotions, and attitudes about genetically modified foods. *Journal of Experimental Education*, *85*, 513-533.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology*, *25*, 378-405.

Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review, 13*, 353-383.

Hofer, B. K. (2004a). Epistemological understanding as a metacognitive process: Thinking aloud during online searching. *Educational Psychologist, 39,* 43-55.

Hofer, B. K. (2004b). Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology, 29*, 129-163.

Hofer, B. K. (2008). Personal epistemology and culture. In M. S. Khine (Ed.), *Knowing, knowledge and beliefs* (pp. 3-22). New York, NY: Springer.

Hofer, B. K. (2016). Epistemic cognition as a psychological construct: Advancements and challenges. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 19-38). New York, NY: Routledge.

Hofer, B. K., & Bendixen, L. D. (2012). Personal epistemology: Theory, research, and future directions. In K. R. Harris, S. Graham, & T. Urdan (Eds.), *APA Educational Psychology Handbook, Vol. 1* (pp. 227–256). Washington, DC: American Psychological Association.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 6*, 88-140.

Hofer, B. K., & Pintrich, P. R. (2002). *Personal epistemology: The psychology of beliefs about knowledge and knowing*. Mahwah, NJ: Lawrence Erlbaum Associates.

Hookway, C. (2008). Epistemic immediacy, doubt and anxiety: On a role for affective states in epistemic evaluation. In G. Brun, U. Doguoglu, & D. Kuenzle (Eds.), *Epistemology and emotions* (pp. 51–65). Aldershot, UK: Ashgate.

Hubbard, K., Hall, N. C., & Sverdlik, A (2019, April). Phenomenology of boredom coping: Understanding students' lived experiences of coping with boredom in college. AERA Annual Convention, Toronto, ON.

Huber, C. R., & Kuncel, N. R. (2015). Does college teach critical thinking? A meta-analysis. *Review of Educational Research*. Advance online publication.

Hulme, M. (2009). *Why we disagree about climate change: Understanding controversy, inaction and opportunity*. Cambridge, England: Cambridge University Press.

Hyytinen, H., Holma, K., Toom, A., Shavelson, R. J., & Lindblom-Ylänne, S. (2014). The complex relationship between students' critical thinking and epistemological beliefs in the context of problem solving. *Frontline Learning Research, 2*, 1-25.

Jaber, L. Z., & Hammer, D. (2016). Engaging in science: A feeling for the discipline. *Journal of the Learning Sciences*, *25*, 156-202.

Jirout, J., & Klahr, D. (2012). Children's scientific curiosity: In search of an operational definition of an elusive concept. *Developmental Review, 32*, 125-160.

Kahneman, D., (2011). *Thinking, fast and slow*. New York, NY: Farrar, Straus and Giroux.

Kammerer, Y., Amann, D. G., & Gerjets, P. (2015). When adults without university education search the Internet for health information: The roles of Internet-specific epistemic beliefs and a source evaluation intervention. *Computers in Human Behavior*, *48*, 297-309.

Kang, M. J., Hsu, M., Krajbich, I. M., Loewenstein, G., McClure, S. M., Wang, J. T. Y., & Camerer, C. F. (2009). The wick in the candle of learning: Epistemic curiosity activates reward circuitry and enhances memory. *Psychological Science, 20,* 963–973.

Kardash, C. M., & Scholes, R. J. (1996). Effects of preexisiting beliefs, epistemological beliefs, and need for cognition on interpretation of controversial issues. *Journal of Educational Psychology*, *88*, 260.

Kata, A. (2012). Anti-vaccine activists, Web 2.0, and the postmodern paradigm: An overview of tactics and tropes used online by the anti-vaccination movement. *Vaccine*, *30*, 3778-3789.

Kienhues, D., Bromme, R., & Stahl, E. (2008). Changing epistemological beliefs: The unexpected impact of a short-term intervention. *British Journal of Educational Psychology*, *78*, 545-565.

Kienhues, D., Stadtler, M., & Bromme, R. (2011). Dealing with conflicting or consistent medical information on the web: When expert information breeds laypersons' doubts about experts. *Learning and Instruction, 21*, 193-204.

Kincaid, J., Fishburne, R., Rogers, R., & Chissom, B. (1975). Derivation of new 268 learning word meanings from context readability formulas (Automated Readability Index, fog count, and Flesch Reading Ease Formula) for Navy enlisted personnel. *Navy Training Command Research Branch Report*, 8-75.

King, K. S., & Kitchener, K. S. (2002). The reflective judgment model: Twenty years of research on epistemic cognition. In Hofer, B. K., & Pintrich, P. R. (eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 37-61). Mahwah, NJ: Erlbaum.

King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. San Francisco, CA: Jossey-Bass.

King, P. M., & Kitchener, K. S. (2004). Reflective judgment: Theory and research on the development of epistemic assumptions. *Educational Psychologist, 39*, 5-18.

Kitchener, K. S. (1983). Cognition, metacognition, and epistemic cognition. *Human Development, 26*, 222-232.

Kitchener, K. S., & King, P. M. (1985). *Reflective judgment scoring rules*. Unpublished manuscript, Bowling Green State University and University of Denver.

Kuhn, D. (1991). *The skills of argument*. Cambridge, England: Cambridge University Press.

Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*, 319-337.

Kuhn, D. (1999). A developmental model of critical thinking. *Educational Researcher, 28*, 16-46.

Kuhn, D. (2001). How do people know? *Psychological Science, 12*, 1-8.

Kuhn, D. (2018). A role for reasoning in a dialogic approach to critical thinking. *Topoi, 37*, 121-128.

Kuhn, D., Cheney, R., & Weinstock, M. (2000). The development of epistemological understanding. *Cognitive Development, 15,* 309-328.

Kuhn, D., & Crowell, A. (2011). Dialogic argumentation as a vehicle for developing young adolescents' thinking. *Psychological Science, 22*, 545-552.

Kuhn, D., & Park, S. H. (2005). Epistemological understanding and the development of intellectual values. *International Journal of Educational Research*, *43*, 111-124.

Kuhn, D., & Weinstock, M. (2002). What is epistemological thinking and why does it matter? In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing*. (pp. 121-144). Mahwah, NJ: Erlbaum.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Kurfiss, J. G. (1988). *Critical thinking: Theory, research, practice, and possibilities* (Ashe-Eric Higher Education Report No. 2). Washington, DC: Association for the Study of Higher Education.

Lauriola, M., Litman, J. A., Mussel, P., De Santis, R., Crowson, H. M., & Hoffman, R. R. (2015). Epistemic curiosity and self-regulation. *Personality and Individual Differences, 83*, 202-207.

Lazarus, R. S. (1991). *Emotion and adaptation*. New York, NY: Oxford University Press.

Levinson, R. (2006). Towards a theoretical framework for teaching controversial socio-scientific issues. *International Journal of Science Education*, *28*, 1201-1224.

Lin, Y. C., Liang, J. C., & Tsai, C. C. (2012). The relationships between epistemic beliefs in biology and approaches to learning biology among biology-major university students in Taiwan. *Journal of Science Education and Technology*, *21*, 796-807.

Lipman, M. (1991). *Thinking in education.* Cambridge, UK: Cambridge University Press.

Litman, J. A. (2005). Curiosity and the pleasures of learning: Wanting and liking new information. *Cognition and Emotion*, *19*, 793-814.

Litman, J. A. (2008). Interest and deprivation factors of epistemic curiosity. *Personality and Individual Differences, 44*, 1585-1595.

Litman, J., Hutchins, T., & Russon, R. (2005). Epistemic curiosity, feeling-of-knowing, and exploratory behaviour. *Cognition and Emotion, 19*, 559-582.

Loewenstein, G. F. (1994). The psychology of curiosity: A review and reinterpretation. *Psychological Bulletin, 116*, 75-98.

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological Bulletin*, *127*, 267.

Lombardi, D., & Sinatra, G. M. (2012). College students' perceptions about the plausibility of human-induced climate change. *Research in Science Education*, *42*, 201-217.

Louca, L., Elby, A., Hammer, D., & Kagey, T. (2004). Epistemological resources: Applying a new epistemological framework to science instruction. *Educational Psychologist*, *39*, 57-68.

Lowry, N., & Johnson, D. W. (1981). Effects of controversy on epistemic curiosity, achievement, and attitudes. *The Journal of Social Psychology, 115*, 31-43.

Maggioni, L., Fox, E., & Alexander, P. A. (2010). The epistemic dimension of competence in the social sciences. *Journal of Social Science Education, 9,* 15-23.

Mansfield, A. F., & Clinchy, B. M. (2002). Toward the integration of objectivity and subjectivity: Epistemological development from 10 to 16. *New Ideas in Psychology*, *20*, 225-262.

Markey, A., & Loewenstein, G. (2014). Curiosity. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 228-245). New York, NY: Taylor & Francis.

Marks, J., Copland, E., Loh, E., Sunstein, C. R., & Sharot, T. (2019). Epistemic spillovers: Learning others' political views reduces the ability to assess and use their expertise in nonpolitical domains. *Cognition*, *188*, 74-84.

Mason, L. (2016). Psychological perspectives on measuring epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 375-392). New York, NY: Routledge.

Mason, L., Ariasi, N., & Boldrin, A. (2011). Epistemic beliefs in action: Spontaneous reflections about knowledge and knowing during online information searching and their influence on learning. *Learning and Instruction, 21*, 137-151.

Mason, L., Boldrin, A., & Ariasi, N. (2010). Epistemic metacognition in context: Evaluating and learning online information. *Metacognition and Learning, 5*, 67-90.

Mason, L., & Boscolo, P. (2004). Role of epistemological understanding and interest in interpreting a controversy and in topic-specific belief change. *Contemporary Educational Psychology, 29*, 103-128.

Mason, L., & Scirica, F. (2006). Prediction of students' argumentation skills about controversial topics by epistemological understanding. *Learning and Instruction,16*, 492-509.

McGinnis, D. (2016). Epistemological orientations and evidence evaluation in undergraduates. *Thinking Skills and Creativity, 19*, 279-289.

McPeck, J. (1981). *Critical thinking and education.* Toronto, Ontario, Canada: Oxford University Press.

Meinhardt, J., & Pekrun, R. (2003). Attentional resource allocation to emotional events: An ERP study. *Cognition and Emotion*, *17*, 477-500.

Meyer, W. U., Reisenzein, R., & Schützwohl, A. (1997). Toward a process analysis of emotions: The case of surprise. *Motivation and Emotion, 21*, 251-274.

Meyers, L.S., Gamest, G., Guarino, A.J. (2017). *Applied multivariate research: Design and interpretation* (3rd ed.). Thousand Oaks, CA: SAGE Publications.

Mines, R. A., King, P. M., Hood, A. B., & Wood, P. K. (1990). Stages of intellectual development and associated critical thinking skills in college students. *Journal of College Student Development, 31*, 538−547.

Mintchik, N. M., & Farmer, T. A. (2009). Associations between epistemological beliefs and moral reasoning: Evidence from accounting. *Journal of Business Ethics, 84*, 259-275.

Moors, A., Ellsworth, P. C., Scherer, K. R., & Frijda, N. H. (2013). Appraisal theories of emotion: State of the art and future development. *Emotion Review, 5*, 119-124.

Morton, A. (2010). Epistemic emotions. In P. Goldie (Ed.), *The Oxford handbook of philosophy of emotion* (pp. 385-399). Oxford: Oxford University Press.

Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Educational Research, 74,* 317–377.

Muis, K. R. (2007). The role of epistemic beliefs in self-regulated learning. *Educational Psychologist, 42*, 173-190.

Muis, K. R. (2008). Epistemic profiles and self-regulated learning: Examining relations in the context of mathematics problem solving. *Contemporary Educational Psychology, 33,* 177–208.

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review, 18,* 3-54.

Muis, K. R., Chevrier, M., & Singh, C. A. (2018). The role of epistemic emotions in personal epistemology and self-regulated learning. *Educational Psychologist*, *53*, 165-184.

Muis, K. R., & Duffy, M. C. (2013). Epistemic climate and epistemic change: Instruction designed to change students' beliefs and learning strategies and improve achievement. *Journal of Educational Psychology, 105*, 213-225.

Muis, K. R., Duffy, M. C., Trevors, G., Ranellucci, J., & Foy, M. (2014). What were they thinking? Using cognitive interviewing to examine the validity of self-reported epistemic beliefs. *International Education Research, 2*, 17-32.

Muis, K. R., & Franco, G. (2010). Epistemic profiles and metacognition: Support for the consistency hypothesis. *Metacognition and Learning, 5,* 27–45.

Muis, K. R., Pekrun, R., Sinatra, G. M., Azevedo, R., Trevors, G., Meier, E., & Heddy, B. C. (2015). The curious case of climate change: Testing a theoretical model of epistemic beliefs, epistemic emotions, and complex learning. *Learning and Instruction, 39*, 168-183.

Muis, K. R., Psaradellis, C., Lajoie, S. P., Di Leo, I., & Chevrier, M. (2015). The role of epistemic emotions in mathematics problem solving. *Contemporary Educational Psychology, 42*, 172–185.

Muis, K. R., & Singh, C. A. (2018). The three facets of epistemic thinking in self-regulated learning. In D. Schunk & J. Greene (Eds.), *Handbook of self-regulated of learning and performance* (pp. 434–456). New York, NY: Routledge.

Muis, K. R., Trevors, G., & Chevrier, M. (2016). Epistemic climate for epistemic change. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 331-359). New York, NY: Routledge.

Munnich, E., & Ranney, M. A. (2018). Learning from surprise: Harnessing a metacognitive surprise signal to build and adapt belief networks. *Topics in Cognitive Science*, *11*, 164-177.

Muthén, L. K., & Muthén, B. O. (2015). *Mplus user's guide*. Los Angeles, CA: Muthén & Muthén.

Niu, L., Behar-Horenstein, L. S., & Garvan, C. W. (2013). Do instructional interventions influence college students' critical thinking skills? A meta-analysis. *Educational Research Review, 9*, 114-128.

Op't Eynde, P., De Corte, E., & Verschaffel, L. (2007). Students' emotions: A key component of self-regulated learning? In P. A. Schutz & R. Pekrun (Eds.), *Emotion in education* (pp. 185-204). San Diego, CA: Elsevier Academic Press.

Paul, R. W. (1990). *Critical thinking: What every person needs to survive in a rapidly changing world*. Santa Rosa, CA: Foundation for Critical Thinking.

Pekrun, R. (1992). The impact of emotions on learning and achievement: Towards a theory of cognitive/motivational mediators. *Applied Psychology*, *41*, 359-376.

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18*, 315-341.

Pekrun, R., Goetz, T., Daniels, L. M., Stupnisky, R. H., & Perry, R. P. (2010). Boredom in achievement settings: Control-value antecedents and performance outcomes of a neglected emotion. *Journal of Educational Psychology, 102,* 531-549.

Pekrun, R., Goetz, T., Frenzel, A. C., Barchfeld, P., & Perry, R. P. (2011). Measuring emotions in students' learning and performance: The Achievement Emotions Questionnaire (AEQ). *Contemporary Educational Psychology, 36*, 36-48.

Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educational Psychologist*, *37*, 91-105.

Pekrun, R., Lichtenfeld, S., Marsh, H. W., Murayama, K., & Goetz, T. (2017). Achievement emotions and academic performance: Longitudinal models of reciprocal effects. *Child Development, 88,* 1653-1670.

Pekrun, R., & Linnenbrink-Garcia, L. (2012). Academic emotions and student engagement. In S. L. Christenson, A. L. Reschly & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 259-282). New-York, NY: Springer.

Pekrun, R., & Linnenbrink-Garcia, L. (2014). *International handbook of emotions in education*. New York, NY: Routledge.

Pekrun, R., & Meier, E. (2011). *Epistemic emotion scales (EES)*. Munich, Germany: Department of Psychology, University of Munich. Unpublished manuscript.

Pekrun, R., & Perry, R. P. (2014). Control-value theory of achievement emotions. In R. Pekrun, & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 120-141). New York, NY: Taylor & Francis.

Pekrun, R., & Stephens, E. J. (2012). Academic emotions. In K. R. Harris, S. Graham, T. Urdan, S. Graham, J. M. Royer, & M. Zeidner (Eds.), *APA educational psychology handbook* (Vol. 2, pp. 3-31). Washington, DC: American Psychological Association.

Pekrun, R., Vogl, E., Muis, K. R., & Sinatra, G. M. (2017). Measuring emotions during epistemic activities: The Epistemically-Related Emotion Scales. *Cognition and Emotion, 31*, 1268-1276.

Perry, W. G. Jr. (1970). *Forms of intellectual and ethical development in the college years: scheme.* New York, NY: Holt, Rinehart and Winston.

Pham, M. T., Cohen, J. B., Pracejus, J. W., & Hughes, G. D. (2001). Affect monitoring and the primacy of feelings in judgment. *Journal of Consumer Research*, *28*, 167-188.

Piaget, J. *Introduction à l'épistémologie génétique*. Paris, France: Presses Universitaires de France.

Pierce, C. S., Houser, N., & Kloesel, C. (1992). The Essential Pierce. *Selected Philosophical Writings, 2*, 1893-1913.

Pieschl, S., Stallmann, F., & Bromme, R. (2014). High school students' adaptation of task definitions, goals and plans to task complexity: The impact of epistemic beliefs. *Psihologijske Teme, 23*, 31-52.

Pintrich, P. R. (2000). An achievement goal theory perspective on issues in motivation terminology, theory, and research. *Contemporary Educational Psychology, 25*, 92-104.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, *63*, 167-199.

Pintrich, P. R., Smith, D. A., Garcia, T., & McKeachie, W. J. (1991). *A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ)*. Ann Arbor, MI: University of Michigan.

Poitras, E., & Trevors, G. (2012). Deriving empirically-based design guidelines for advanced learning technologies that foster disciplinary comprehension/Définir des lignes directrices fondées sur des données empiriques pour les technologies d'apprentissage avancé qui favorisent la compr. *Canadian Journal of Learning and Technology/La revue canadienne de l'apprentissage et de la technologie*, *38*, 1-22.

Porsch, T., & Bromme, R. (2011). Effects of epistemological sensitization on source choices. *Instructional Science*, *39*, 805-819.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*, 879-891.

Preacher, K. J., Zyphur, M. J., & Zhang, Z. (2010). A general multilevel SEM framework for assessing multilevel mediation. *Psychological Methods, 15*, 209-233.

Quigley, K., Lindquist, K. A., & Barrett, L. F. (2014). Inducing and measuring emotion and affect: Tips, tricks, and secrets. *Handbook of Research Methods in Social and Personality Psychology*, 220–252.

Reisenzein, R., & Studtmann, M. (2007). On the expression and experience of surprise: no evidence for facial feedback, but evidence for a reverse self-inference effect. *Emotion, 7,* 612.

Richter, T., & Schmid, S. (2010). Epistemological beliefs and epistemic strategies in self-regulated learning. *Metacognition and Learning*, *5*, 47-65.

Rosenberg, E. (1998). Levels of analysis and the organization of affect. *Review of General Psychology, 2*, 247–270.

Rosenberg, S., Hammer, D., & Phelan, J. (2006). Multiple epistemological coherences in an eighth-grade discussion of the rock cycle. *The Journal of the Learning Sciences, 15,* 261-292.

Royer, J. M., Carlo, M. S., Dufresne, R., & Mestre, J. (1996). The assessment of levels of domain expertise while reading. *Cognition and Instruction, 14*, 373-408.

Sá, W. C., Stanovich, K. E., & West, R. F. (1999). The domain specificity and generality of belief bias: Searching for generalizable critical thinking skill. *Journal of Educational Psychology*, *91*, 497–510.

Sandoval, W. A., Greene, J. A., & Bråten, I. (2016). Understanding and promoting thinking about knowledge: Origins, issues, and future directions of research on epistemic cognition. *Review of Research in Education, 40,* 457–496.

Scheffler, I. (1977). In praise of the cognitive emotions. In I. Scheffler (Ed.), *In praise of the cognitive emotions and other essays in the philosophy of education* (pp. 3-7). New York, NY: Routledge.

Schommer, M. (1990). Effect of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology*, *82*, 498–504.

Schommer, M. (1994). An emerging conceptualization of epistemological beliefs and their role in learning. In R. Garner & P. A. Alexander (Eds.), *Beliefs about text and instruction with text* (pp. 25-40). Hillsdale, NJ: Erlbaum.

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology*, *84*, 435.

Schommer-Aikins, M. (2002). An evolving theoretical framework for an epistemological belief system. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 103-118). Mahwah, NJ: Erlbaum.

Schommer-Aikins, M., & Hutter, R. (2002). Epistemological beliefs and thinking about everyday controversial issues. *The Journal of Psychology, 136*, 5-20.

Schraw, G. (2010). Measuring self-regulation in computer-based learning environments. *Educational Psychologist*, *45*, 258-266.

Schraw, G., Bendixen, L. D., & Dunkle, M. E. (2002). Development and validation of the Epistemic Belief Inventory (EBI). In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 103-118). Mahwah, NJ: Erlbaum.

Schroeder, S., Richter, T., & Hoever, I. (2008). Getting a picture that is both accurate and stable: Situation models and epistemic validation. *Journal of Memory and Language*, *59*, 237-255.

Schwarz, N., & Clore, G. L. (2007). Feelings and phenomenal experiences. In E. T. Higgins & A. W. Kruglanski (Eds.), *Social psychology: Handbook of basic principles* (2nd ed.) (pp. 385-407). New York, NY: Guilford Press.

Scriven, M., & Paul, R. (1996). *Defining critical thinking: A draft statement for the National Council for Excellence in Critical Thinking*. Available HTTP: http://www. Criticalthinking. org/University/univlibrary/library. nclk p-01.

Shuman, V., & Scherer, K. R. (2014). Concepts and structure of emotions. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 13–35). New York: Routledge.

Siegel, H. (1988). *Educating reason: Rationality, critical thinking, and education*. New York, NY: Routledge.

Silvia, P. J. (2010). Confusion and interest: The role of knowledge emotions in aesthetic experience. *Psychology of Aesthetics, Creativity, and the Arts, 4,* 75-80.

Simpson, E., & Courtney, M. D. (2002). Critical thinking in nursing education: Literature review. *International Journal of Nursing Practice*, *8*, 89-98.

Sinatra, G. M. (2005). The "warming trend" in conceptual change research: The legacy of Paul R. Pintrich. *Educational Psychologist*, *40*, 107-115.

Sinatra, G. M. (2016). Thoughts on knowledge about thinking about knowledge. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *International handbook of epistemic cognition* (pp. 479-492). New York, NY: Routledge.

Sinatra, G. M., & Broughton, S. H. (2011). Bridging reading comprehension and conceptual change in science education: The promise of refutation text. *Reading Research Quarterly*, *46*, 374-393.

Sinatra, G. M., Kienhues, D., & Hofer, B. K. (2014). Addressing challenges to public understanding of science: Epistemic cognition, motivated reasoning, and conceptual change. *Educational Psychologist, 49*, 123-138.

Sîrbu, A., Pedreschi, D., Giannotti, F., & Kertész, J. (2019). Algorithmic bias amplifies opinion fragmentation and polarization: A bounded confidence model. *PloS one, 14*, e0213246.

Slovic, P. (1987). Perception of risk. *Science, 236*, 280-285.

Stahl, E., & Bromme, R. (2007). The CAEB: An instrument for measuring connotative aspects of epistemological beliefs. *Learning and Instruction, 17*, 773-785.

Stathopoulou, C., & Vosniadou, S. (2007). Exploring the relationship between physics-related epistemological beliefs and physics understanding. *Contemporary Educational Psychology*, *32*, 255-281.

Strømsø, H. I., & Bråten, I. (2014). Students' sourcing while reading and writing from multiple web documents. *Nordic Journal of Digital Literacy, 2*, 92-111.

Strømsø, H. I., Bråten, I., & Britt, M. A. (2010). Reading multiple texts about climate change: The relationship between memory for sources and text comprehension. *Learning and Instruction*, *20*, 192-204.

Strømsø, H. I., Bråten, I., & Britt, M. A. (2011). Do students' beliefs about knowledge and knowing predict their judgment of texts' trustworthiness? *Educational Psychology, 31,* 177-206.

Strømsø, H. I., Bråten, I., Britt, M. A., & Ferguson, L. E. (2013). Spontaneous sourcing among students reading multiple documents. *Cognition and Instruction, 31*, 176-203.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Boston, MA: Allyn Bacon.

Tiedens, L. Z., & Linton, S. (2001). Judgment under emotional certainty and uncertainty: The effects of specific emotions on information processing. *Journal of Personality and Social Psychology, 81*, 973–988.

Tippett, C. D. (2010). Refutation text in science education: A review of two decades of research. *International Journal of Science and Mathematics Education*, *8*, 951-970.

Tremblay, K., Lalancette, D., Roseveare, D. (2012) AHELO Feasibility Study Report. Volume 1: Design and Implementation. Organization for Economic Co-operation and development

(OECD). Retrieved from http://www.oecd.org/edu/skills-beyond-school/AHELOFSReportVolume1.pdf

Trevors, G. J., & Kendeou, P. (2018). *The effects of positive and negative emotions on knowledge revision.* Available at SSRN 3274111.

Trevors, G. J., Muis, K. R., Pekrun, R., Sinatra, G. M., & Winne, P. H. (2016). Identity and epistemic emotions during knowledge revision: A potential account for the backfire effect. *Discourse Processes, 53,* 339-370.

Veenman, M. V., Van Hout-Wolters, B. H., & Afflerbach, P. (2006). Metacognition and learning: Conceptual and methodological considerations. *Metacognition and Learning, 1*, 3-14.

Weber, E. U., & Stern, P. C. (2011). Public understanding of climate change in the United States. *American Psychologist*, *66*, 315.

Weiner, B. (2007). Examining emotional diversity on the classroom: An attribution theorist considers the moral emotions. In P. A. Schutz & R. Pekrun (Eds.), *Emotion in education* (pp. 73–88). San Diego, CA: Academic Press.

Whitman, D. B. (2000). *Genetically modified foods: Harmful or helpful?* Canadian Standards Association: Discover Guides. Government of Canada, Ottawa, ON.

Winne, P. H. (2001). Self-regulated learning viewed from models of information processing. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (Vol. 2, pp. 153-189). Mahwah, NJ: Lawrence Erlbaum Associate.

Winne, P. H. (2014). Issues in researching self-regulated learning as patterns of events. *Metacognition and Learning, 9*, 229-237.

Winne, P. H., & Hadwin, A. F. (1998). Studying as self-regulated learning. *Metacognition in Educational Theory and Practice*, *93*, 27-30.

Winne, P. H., & Jamieson-Noel, D. (2002). Exploring students' calibration of self reports about study tactics and achievement. *Contemporary Educational Psychology*, *27*, 551-572.

Winne, P. H., Jamieson-Noel, D. L., & Muis, K. R. (2002). Methodological issues and advances in researching tactics, strategies, and self-regulated learning. In M. L. Maehr & P. R. Pintrich (Eds.), *Advances in Motivation and Achievement* (Vol. 12, pp. 121-158). Greenwich, CT: JAI.

Winne, P. H., & Perry, N. E. (2000). Measuring self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 531–566). San Diego, CA: Academic Press.

Wood, P., & Kardash, C. (2002). Critical elements in the design and analysis of studies of epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 231-260). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Yang, F., & Tsai, C. (2010). Reasoning about science-related uncertain issues and epistemological perspectives among children. *Instructional Science: An International Journal of the Learning Sciences, 38,* 325-354.

Zeidner, M. (1998). *Test anxiety: The state of the art.* New York, NY: Plenum Press.

Zeidner, M. (2014). Anxiety in education. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 265–288). New York: Routledge.

Zimmerman, B. J. (1998). Academic studying and the development of personal skill: A self-regulatory perspective. *Educational Psychologist, 33*, 73-86.