Controversial science knowledge: A multi-study examination of how epistemic cognition relates to the ways we learn science

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Abstract

Epistemic cognition is increasingly becoming relevant for making decisions of personal and global significance, especially for socio-scientific issues where controversies often surround the role of science knowledge. However, epistemic cognition remains a notoriously difficult construct to study. A comprehensive literature review shows a consensus emerging among recent and influential theories that indicates a duality of epistemic cognition: one level represented by larger and relatively more stable dimensions of epistemic beliefs; and a second level represented by finer-grained and relatively more variable epistemic processes. Psychometric issues may stem from misalignment between these conceptualizations and methodological choices by researchers, which may be remedied by the use of methods that are more context-specific, capture process data, and account for the potential of mediating variables. On the basis of this review, three empirical manuscripts are presented that address these issues. The first manuscript reports on two studies that triangulate eye tracking, computer logs, and qualitative verbal reports and concludes epistemic cognition relates to important cognitive and metacognitive learning processes, including epistemic self-efficacy to critically evaluate science content. The second manuscript concludes that epistemic emotions are one set of mediators between epistemic cognition and learning from multiple conflicting documents on a socio-scientific issue. The last manuscript concludes that epistemic emotions are a further set of mediators between self-concept and learning from a refutation text on another socio-scientific topic. Theoretical contributions, implications, limitations and future directions are discussed.

Résumé

La cognition épistémique est de plus en plus pertinente dans la prise des décisions au niveau personnel, voire à une échelle plus grande, en particulier pour les questions socio-scientifiques où il y a des controverses quant au rôle de la connaissance scientifique. Cependant, la cognition épistémique reste une construction notoirement difficile à étudier. Un examen complet de la littérature révèle un consensus émergent parmi les théories les plus récentes et les plus influentes ce qui est de bon augure pour une dualité de la cognition épistémique: un niveau représenté par des dimensions plus grandes et relativement plus stables des croyances épistémiques; et un second niveau représenté par des processus épistémiques plus fins et relativement plus variables. Des questions psychométriques peuvent découler d'un décalage entre ces conceptualisations et les choix méthodologiques des chercheurs. On peut corriger cela en utilisant des méthodes qui sont plus spécifiques au contexte, des processus de cueillette des données, et un estimé pour le potentiel des variables médiatrices. Sur la base de cet examen, trois manuscrits empiriques qui abordent ces questions sont présentés. Les premiers manuscrits couvrent deux études qui triangulent le suivi du regard, les journaux d'exploitation et les rapports verbaux qualitatifs. Ils concluent que la cognition épistémique est associée à des procédés d'apprentissage cognitifs et métacognitifs importants, y compris l'auto-efficacité épistémique pour évaluer de manière critique le contenu de la science. Le deuxième manuscrit conclut que les émotions épistémiques sont un ensemble de médiateurs entre la cognition épistémique et l'apprentissage à partir de plusieurs documents contradictoires sur une question socio-scientifique. Le dernier manuscrit conclut que les émotions épistémiques sont une autre série de médiateurs entre le concept de soi et l'apprentissage d'un texte réfutationnel sur un autre sujet socio-scientifique. Les contributions théoriques, les implications, les limites et les orientations futures y sont abordées.

Dedication

I dedicate this dissertation to my parents, Pauline and Richard Trevors, to my uncle, John Trevors, and to my grandmother, Florence Currie – *thank you for your endless love, generosity, support, and encouragement to keep moving forward*.

Acknowledgements

There have been many people who have given generously so that I could be able to present this dissertation and to whom I am deeply indebted:

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To Dr. Roger Azevedo – you had welcomed me into your lab, first as a volunteer and then as a co-supervisor of my Ph.D. degree during your tenure at McGill, and your mentorship, expertise, and generosity that you have shown me since that time have directly contributed to my success – the most tangible example being Chapter 3 of this dissertation. Thank you for your extensive material support – access to data, research equipment (e.g., eye tracking equipment), participants, human resources (e.g., research assistants and post-docs), and generous personal financial support. Thank you for supporting my professional development, including opportunities to collaborate on manuscripts, grants, and with international teams of researchers. Most of all, I want to thank you, Roger, for your commitment to excellence in your mentorship. I am so very appreciative for all of your support.

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Beyond these contributions, to the people that I have been lucky to meet during my studies – John, Reza, Eric, Kyle, Meredith, Tara, Marianne, Jason, Lisa, Becca, Amanda, Mike – thank you for your friendship.

To Mel – *thank you everyday for your love, thoughtfulness, and strength*.

Preface and Contribution of Authors

I am the primary author on each manuscript and am responsible for their content. I wrote Chapters 1 and 6 independently and Dr. Krista R. Muis provided feedback. Similarly, I wrote Chapter 2 independently, the original version of which was prepared in partial fulfillment of my comprehensive exam, which Dr. Muis, Dr. Roger Azevedo, and Dr. Susanne P. Lajoie provided feedback in their roles as members on the exam evaluation committee.

Two of the manuscripts presented in this dissertation were primarily co-authored with Dr. Muis (Chapters 4 and 5). One (Chapter 3) was co-authored with Dr. Azevedo and reviewed by Dr. Muis as a part of this dissertation. The contributions made by myself and co-authors for each manuscript are summarized below. The conclusions drawn from these chapters are considered original and distinct contributions to knowledge.

Chapter 3

Citation

Trevors, G., Feyzi–Behnagh, R., Azevedo, R., & Bouchet, F. (revise and resubmit). Self-regulated learning varies as a function of epistemic beliefs and task conditions: Mixed method evidence from eye tracking, concurrent and retrospective reports. *Learning and Instruction*.

Contributions

The computer software used for the studies presented in Chapter 3 (Automated Testing System) was developed at the University of Memphis (Lehman, D'Mello, & Person, 2008). The research design is based on Burkett and Azevedo (2012). The second author assisted in research design and data collection. I was responsible for data analysis, conceptualization of research questions, and wrote the manuscript in its entirety. The co-authors provided expert feedback on

full drafts. The fourth author developed the software code used in analyzing eye tracking data and their alignment with the computer log-files.

Chapter 4

Citation

Trevors, G., Muis, K., Pekrun, R., & Sinatra, G. M. (revise and resubmit). Epistemic beliefs and epistemic emotions predict learning from multiple conflicting texts. *Journal of Educational Psychology*.

Contributions

The computer software used for the study presented in Chapter 4 (Smart Testing System) was developed at McGill University by Dr. François Bouchet under the supervision of the co-authors and Dr. Azevedo. The research design is based on Muis et al. (2015). Dr. Eric G. Poitras assisted with extracting text-mining values and Marianne Chevrier, Meredith Derian-Toth, Dr. Benjamin Heddy, and Cynthia Psaradellis assisted with coding participants' essays. I was responsible for conceptualization of research questions, data analysis, and wrote the manuscript in its entirety. The co-authors provided expert feedback on full drafts.

Chapter 5

Citation

Trevors, G., Muis, K. R., Pekrun, R., Sinatra, G., & Winne, P. H. (2015, July). *Interactions between self-concept and refutational texts on emotions and learning*. Paper presented at the 25th Annual Meeting of the Society of Text & Discourse, Minneapolis, USA.

Contributions

The research design is based off collaborations between co-authors. I was responsible for developing a measure of self-concept, conceptualization of research questions, data analysis, and wrote the manuscript in its entirety. The co-authors provided expert feedback on full drafts.

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Chapter 1

Introduction[1]

[1] Portions of Chapter 1 have been reproduced in: Trevors, G. (2015, May). *Diving into controversy and developing digital literacy*. Report from the SSHRC Imagining Canada's Future initiative. Retrieved from http://www.mcgill.ca/gps/files/gps/imagining_canadas_future_mcgill_print_1.pdf Montreal: McGill University.

Scientific insights into our world have never been as necessary as they are today. These insights form the basis of important decisions that have far-reaching personal and global implications. However, in schools, curricula often present a straightforward march of scientific facts, hiding debates between researchers behind closed laboratory doors. In contrast, scientific discourse is often depicted in the popular media as fabricated controversies, granting equal air time for dissonant claims as if they were a matter of personal opinion. These depictions create a misalignment between what individuals believe to be the nature of science knowledge and the underlying epistemology of science, which ultimately undermines the ability of individuals to make informed decisions. Kahan (2015) captures this dilemma in his illumination of the paradox that confounds the field of science communication: "Never have human societies *known so much* about mitigating the dangers they face but *agreed so little* about what they collectively know" (italics in original; p. 1). The result is many urgent questions without many actionable answers: Are we causing our climate to change? Are children safer if we forgo vaccinations? How should we teach evolution in our schools?

What I intend to demonstrate in the following chapters in this dissertation is that what underlies these questions is another set of more fundamental questions individuals implicitly pose that pertain to the nature of knowledge and knowing itself: How do we come to believe that we *know* something? Do knowledge claims need to seem absolutely certain and settled before we believe them? How do we judge who or what to trust as a good source of knowledge?

How these questions about knowledge and knowing are answered by individuals forms the foundation of their epistemic cognition. Epistemic cognition refers to the behavioural manifestation of individuals' beliefs about knowledge and knowing, including beliefs about complexity, certainty, sources, and ways of justifying knowledge. Research shows that how

successful individuals are in learning about important socio-scientific issues is affected by their expectation that science is composed of knowledge that is either simple or complex, complete or evolving, and derived via personal reflection, experts, or corroboration from multiple sources (Bråten, Anmarkrud, Brandmo, & Strømsø, 2014). Therefore, theoretical and empirical investigations into epistemic cognition form the foundation of this dissertation.

Three additional themes related to epistemic cognition also link together the chapters of this dissertation: (1) controversial knowledge; (2) epistemic emotions; and (3) new research methodologies. First, epistemic cognition is likely to be most active and influential for issues that are controversial, as inherent in these situations is a dispute over claims about what is known and by whom. Thus, the first connecting theme of this dissertation is an examination of individuals' processing of controversial knowledge at multiple levels of granularity (i.e., knowledge discrepancies within a source, discrepancies between sources, and discrepancies between individuals and sources). Second, during processing of conflicting knowledge claims it is plausible that individuals may feel surprise, curiosity, confusion, anxiety, frustration, or even boredom. In the ensuing chapters, I will empirically demonstrate that these heretofore overlooked epistemic emotions are a significant factor that mediates the relation between epistemic cognition and learning controversial knowledge. Third, in the chapters in this dissertation I will identify limitations in traditional research methodologies used to study epistemic cognition and apply new methodological strategies. Thus, the manuscripts contained in this dissertation address several complementary research questions:

1) What components of epistemic cognition are likely active in a particular learning context and how should they be measured? (Chapter 2. Literature Review)
2) How are epistemic beliefs and self-regulated learning related? (Chapter 3. Manuscript #1)

3) Is the relationship between epistemic beliefs and learning mediated by epistemic emotions? (Chapter 4. Manuscript #2)
4) How do other relevant educational constructs, like self-concept, relate to epistemic emotions and learning? (Chapter 5. Manuscript #3)

In addressing these questions, this dissertation elucidates specific relations between epistemic cognition and learning and may add important information with regard how to develop interventions that strengthen the ways we prepare students to evaluate and adjudicate between valuable and spurious knowledge and real and fabricated controversies.

Overview of the Chapters

To this end, Chapter 2 provides a comprehensive review of the literature on theories and methods of epistemic cognition. Here, I identify consensus positions across theories on the structures of epistemic cognition that are likely active in a given learning context. Further, this review serves as the basis from which I critique methods to measure epistemic cognition, including related educational constructs that may mediate its effects.

In Chapter 3, I present two empirical studies that employed eye tracking, metacognitive judgments, and verbal reports to show how fundamental learning processes vary as a function of epistemic cognition and discrepant information.

Chapter 4 introduces literature on epistemic emotions and empirically demonstrates how this set of emotions is predicted by epistemic beliefs. Two indices of learning from conflicting documents are estimated from human coding and text-mining of participants' essays, which are further empirically predicted by epistemic emotions.

Chapter 5 builds off the conception of epistemic emotions to show how conflicts between educational messages and identity generate emotions that negatively impact foundational aspects of knowledge revision.

Chapter 6 concludes with a summary of the substantive contributions to the advancement of knowledge of the research presented in this dissertation along with a discussion of the limitations and future directions for research.

References

Bråten, I., Anmarkrud, O., 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.

Kahan, M. (2015). What is the "science of science communication"?. *Journal of Science Communication*, *14*, 1-12. Retrieved 15 September 2015 from http://ssrn.com/abstract=2562025

Chapter 2

Literature Review of Epistemic Cognition Theories and Methods

In an attempt to learn about issues of personal and global significance – the causes and solutions to climate change, available medical treatment options, or the merits of a political candidate's policy positions – individuals will likely encounter and contend with dissenting voices. To reconcile diverse perspectives is a new challenge for present-day Internet-based learners. To further complicate matters, how individuals respond to the conflicting information is affected by their beliefs about whether they expect knowledge is simple or complex, definitive or tentative; if they seek out single answers or multiple answers, or if they critically evaluate or unquestionably accept knowledge claims.

Within the past few decades, research has been burgeoning on these beliefs and related cognitive activity concerning the nature of knowledge and knowing. For the current review, I focus on how researchers depict beliefs and cognitions in their theories, what research methodologies they use to study these constructs, and how they measure these constructs. In the literature, these psychological constructs are often referred to as epistemic beliefs or epistemic cognition, although researchers have used many other labels (see Briell, Elen, Verschaffel, & Clarebout, 2011, for an extensive review). The inconsistency in terminology is indicative of an analogous inconsistency in theoretical conceptualizations of these constructs (Greene, Azevedo, & Torney-Putra, 2008). This theoretical issue is core to research on epistemic beliefs/cognition; how it is resolved has implications for methodological choices and research designs. Thus, I will review the proliferation of theoretical assumptions related to epistemic beliefs/cognition and evaluate predominant methodological and measurement strategies of research in this area. Throughout this review, my objectives will be to show that traditional limitations in this area in part stem from a misalignment between the theoretical assumptions researchers adopt and methodologies they employ, and to highlight potential solutions and avenues for productive

future research. I turn now to elaborate on the significance of the area under review and the definitions of constructs to delineate its scope.

Definitions and Significance

There has been some debate about the terminology used to describe individuals' beliefs about the nature of knowledge and knowing. In line with Greene et al. (2008), I adopt the term *epistemic cognition* to refer to individuals' thinking that has as its subject the nature of knowledge or knowing since it comprehensively captures a broad range of epistemic constructs, including beliefs and behavioural manifestations of beliefs. In the following review, I provide further details about a possible delineation between epistemic beliefs and epistemic cognitive processes. To contextualize this review and demonstrate its need, I briefly present the societal and research significance of epistemic cognition.

Espousing constructivist epistemic cognition (e.g., beliefs that knowledge is complex, subject to revision, and personally constructed) is advantageous in two respects. First, a constructivist stance gives students an academic advantage since it enables them to effectively deal with challenging academic tasks (Muis et al., 2015). Second, constructivist epistemic beliefs are a desirable educational outcome in their own right, as these beliefs are more consistent with knowledge and problems encountered in real-world reasoning about personal and global issues of significance (Muis & Franco, 2010; Muis, Kendeou, & Franco, 2011). Overall, possessing constructivist perceptions of the nature of knowledge and knowing enables greater awareness of task complexity and a motivation to marshal a diverse repertoire of cognitive, metacognitive, and affective processes to adaptively respond to this complexity. However, many educational environments are not designed to promote change in epistemic cognition over the course of students' education and often reinforce the view that learning is entirely a mnemonic activity

guided externally by various experts (Muis, 2004).

Further compounding this educational issue are methodological issues (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008; Welch & Ray, 2012). Several persistent problems hinder research on epistemic cognition, which has stymied the development of theoretical insights and impact on educational practice. Leaders in this research area have called for improvements on current measurements of epistemic beliefs, which have poor construct validity, measure reliability, and subsequently and unsurprisingly, poor predictive validity of academic achievement (Schraw, 2013). Chinn, Buckland, and Samarapungavan (2011) argued that to address these methodological issues and move the field forward, in theory and in educational practice, requires expansion and refinement of epistemic cognition theories. Thus, guiding this review are two questions:

1) What are the recent and influential theoretical frameworks of epistemic cognition and how do they address core assumptions?
2) What research methodologies have been traditionally used to study epistemic cognition and how has it been traditionally measured?

To answer these questions, I will review existing theoretical frameworks on epistemic cognition to identify its structure and components that are likely active in a given learning context and methods to measure their effects. First, I will present a comprehensive review and synthesis of the literature wherein I identify consensus positions among contemporary researchers on the number and context specificity of epistemic cognition. Given the diversity of frameworks and the nomenclature used in each, I will adopt researchers' original terminology for epistemic cognition, which may include: personal epistemology; epistemological or epistemic beliefs; epistemological or intellectual development; or epistemological understanding (see Briell

et al., 2011, for an extensive review). This is followed by a review of traditional methodologies of epistemic cognition research wherein I will critique their alignment or misalignment with theoretical assumptions. I will conclude with future directions for new methods to examine theoretical considerations of epistemic cognition, including enacted cognition, process-level data, and the possibility of mediation.

Part One

What are the recent and influential theoretical frameworks of epistemic cognition and how do they address core assumptions?

Intellectual and ethical development: Perry (1970). Perry (1970) undertook one of the first and most comprehensive efforts to study epistemic cognition. Perry began this research with the objective to formalize a scheme that captured the progression and "variety of ways in which students responded to the relativism which permeates the intellectual and social atmosphere of a pluralistic university" (pp. 3-4); a learning environment that challenged students' perceptions about absolute "truths" about the world, morality, and their own identity. Perry accomplished this with the use of qualitative analysis of extensive interviews of undergraduates at Radcliffe and Harvard over the course of their four-year degree from which he described a progression through nine distinct stages or positions. Moore (2002) has grouped these stages into four major categories: Dualism (Positions 1-2), wherein individuals unquestionably accept authority figures and the absolute "truths" they relay, which are later viewed as wholly right or wrong; Multiplicity (Positions 3-4) wherein individuals first acknowledge uncertainty and undertake successive modifications of the right-wrong dualism to account for diversity of experiences or opinions (Perry, 1974); Contextual Relativism (Position 5 and beyond) wherein individuals make a qualitative leap from a view of a dualistic world with an increasing number of exceptions to a

relativist world (Moore, 2002) and wherein individuals begin to view themselves as active meaning-makers; Commitment within Relativism (Positions 6-9), wherein individuals commit to certain positions in the face of legitimate alternatives as a means to affirm aspects of self-identity. Although Perry's scheme was later critiqued for its reliance on a homogenous sample and strong assumption of a linear and hierarchical progression, it represents a seminal framework in the scholarly study of epistemic cognition.

Epistemological understanding and development: Kuhn and colleagues (Kuhn, 1991, 1999; Kuhn, Cheney, & Weinstock 2000). Building off Perry's (1970) developmental scheme, Kuhn et al. (1991, 1999; Kuhn, Cheney, Weinstock, 2000) proposed a developmental framework that consists of three levels of epistemological understanding: Absolutism, Multiplism, and Evaluativism. Absolutists view knowledge as objectively certain and stress the importance of expert opinion as a foundation for knowing. Multiplists reject certainty. Instead, they point to inconsistencies in expert opinion as justification for their generalized skepticism and belief that knowledge is subjective. Evaluativists also reject objectively certain knowledge and recognize its subjectivity. They balance these views with an additional belief that knowledge should be evaluated against objective standards to assess its merit. Therefore, individuals move along a course of beliefs about knowledge and knowing, from facts to be acquired, to opinions freely chosen, to judgments to be weighed (Kuhn & Weinstock, 2002). Further, Kuhn and colleagues (2000) also acknowledge that epistemological understandings are domain specific and demarcate among aesthetics, moral values, and truths in the social and physical worlds.

Epistemological belief system: Schommer-Aikins (Schommer, 1990, 1994; Schommer-Aikins, 2002, 2004). Although researchers who adopt developmental perspectives acknowledge finer-grain dimensions of epistemic cognition exist (such as the certainty and source of

knowledge), these researchers assume that such dimensions operate and develop in synchrony (Hofer & Bendixen, 2012). In contrast, Schommer (1990) pioneered a multidimensional framework of epistemological and learning beliefs that she contended may or may not operate and develop asynchronously. Schommer described five components of epistemological beliefs that she theorized exist along a bipolar continuum: (1) structure of knowledge, ranging from isolated facts to integrated concepts; (2) stability of knowledge, ranging from unchanging to tentative knowledge; (3) source of knowledge, ranging from omniscient authority to individuals' own reasoning and evidence; (4) ability to learn, ranging from innate to malleable ability; and (5) speed of knowledge acquisition ranging a belief that, if learning happens, it will be quick to a belief that learning is gradual (Schommer-Aikins, 2004). However, there was disagreement whether the last two components, which pertain to learning knowledge and not knowledge itself, should be included in epistemic cognitive frameworks (Hofer & Pintrich, 1997). In subsequent revisions to her framework, Schommer-Aikins (2004) accounted for this critique and proposed that both epistemological beliefs and learning beliefs are distinct but embedded in a larger, interrelated system of beliefs. She argued that epistemological beliefs do not operate in a vacuum but instead function in tandem with other aspects of cognition and affect. Specifically, she hypothesized that there may exist reciprocal relations between epistemological and learning beliefs, wherein individuals beliefs about knowledge would affect how they comport themselves in learning situations, the outcomes of which could either confirm or upend their epistemological beliefs. Moreover, Schommer-Aikins highlighted the importance of social relations as individuals negotiate meaning and evaluate the quality of knowledge with peers, teachers, and experts.

Further, Schommer (1994; Schommer-Aikins, 2002, 2004) elaborated on the original

concept of a bipolar continuum and suggested that each belief is better conceptualized as existing as a frequency distribution, wherein individuals have a propensity for a particular epistemological belief that they typically adopt but nonetheless possess a range of stances across this belief dimension that are activated less frequently. For instance, Schommer (1994) argued that individuals may believe that "there are few things in this world that are certain, some things that are temporarily uncertain, and many things that are either unknown or constantly evolving" (p. 29).

Epistemological theories: Hofer and Pintrich (1997). Building off seminal work by Schommer (1990), and after an extensive review of the literature, Hofer and Pintrich (1997) proposed a multidimensional theoretical framework for epistemological beliefs. In their review, Hofer and Pintrich identified two broad categories for epistemic cognition: beliefs about the nature of knowledge, which included beliefs about the simplicity and certainty of knowledge; and, the nature of knowing, which included beliefs about the source and justification for knowing. Students' nascent epistemic cognitions are broadly characterized by a set of beliefs about knowledge as isolated facts (i.e., simplicity dimension) that, once discovered remain unaltered by time or human intervention (i.e., certainty dimension). To learn such knowledge requires careful attention and memory to those who discovered it – experts and authorities in various fields – as the nature of knowing is believed to be a faithful reproduction of imparted facts (i.e., source and justification dimensions). In contrast, constructivist epistemic beliefs broadly comprise a perception of knowledge as networks of interconnected facts or concepts. Such knowledge is understood to evolve over time, becoming more refined with additional reasoning and new evidence. According to Hofer and Pintrich, rather than the source and justification of knowledge stemming from expert testimony, these students believe the nature of

knowing to require personal justification; to not only accurately recall a knowledge claim, but to be able to understand and evaluate the reasons and evidence in support of a knowledge claim.

Two important elaborations stemmed from Hofer and Pintrich's (1997) framework. First, Hofer (2004) undertook theoretical and empirical efforts to show the integration between epistemic cognition and metacognition. Extending the work by Kitchener (1983), Hofer argued that beliefs about knowledge (i.e., simplicity and certainty) may be integrated with metacognitive knowledge (e.g., knowledge of appropriate learning strategies). Beliefs about knowing (i.e., source and justification) may be integrated with metacognitive judgments and monitoring (e.g., metacomprehension while reading or evaluation of sources). Last, self-regulation of cognitive processes are hypothesized to have an epistemic component during knowledge construction, exemplified by self-questions such as "Do I know what I need to know or do I need to know more?" (Hofer, 2004, p. 49). This theoretical development has important implications for the study of real-time functioning of epistemic cognition in situ as it allows researchers to make predictions and understand how the moment-by-moment cognitive and metacognitive processes vary as a function of epistemic cognition. Recently, Barzilai and Zohar (2014) have elaborated on this theoretical line and provided more detail on the hypothetical links between these research traditions.

Second, Greene, Torney-Putra, and Azevedo (2008) focused attention on the role of justification in epistemic cognition and reconceptualized this construct into finer-grained elements. Specifically, Greene et al. (2008) argued that the traditional bipolar measurement of justification beliefs assessed two endpoints that were not in fact antonymous (i.e., justification by authority vs. personal justification) and thus limited its validity. Greene et al. further noted that philosophers of epistemology more expansively conceive the concept of justification. The

researchers therefore argued for a more detailed conceptualization of epistemic justification beliefs that separated the conceptualization and measurement of justification by authority from personal justification. In so doing, Greene et al. predicted that these two distinct justification dimensions were then able to relate to learning separately and/or in tandem. Bråten, Ferguson, Strømsø and Anmarkrud (2013; Ferguson, Bråten, Strømsø, & Anmarkrud, 2013) recently elaborated on this line of theoretical development to argue for the inclusion of a third form of epistemic justification beliefs – justification from multiple sources – that they have productively used to study empirically the role of epistemic cognition in learning from multiple conflicting documents prevalent in knowledge-based societies.

Epistemic belief change: Bendixen (2002; Bendixen & Rule, 2004). Bendixen and Rule (2004) outlined a theoretical model of epistemic beliefs to delineate the underlying mechanisms responsible for belief change. These mechanisms included epistemic doubt, epistemic volition to resolve doubt, and the ability to enact the strategies to do so. Bendixen and Rule noted that cognitive incongruity may be a catalyst that instigates epistemic doubt and thus the change process. Such incongruity may occur when information is presented to individuals in such a way that it is inconsistent with some tenet of their previous beliefs about knowledge and knowing. For example, when presented with multiple conflicting documents on climate change, an individual who believes that knowledge in science is definitive and invariant may subsequently experience doubt about the robustness of their epistemic beliefs.

Epistemic doubt is a necessary but insufficient condition for change to occur. According to Bendixen and Rule (2004), individuals need to be motivated to resolve doubt in such a manner that does not avoid processing the core of the inconsistency between their beliefs about knowledge and the presentation of knowledge. However, as is often the case when individuals

are presented with discrepant information, this also may not be likely (Chinn & Brewer, 1993). In addition to epistemic volition, individuals need to be capable of enacting the appropriate strategies that reconstructs previous epistemic beliefs to accommodate the new information about the nature of knowledge and knowing. Such strategies include social interactions (e.g., debate) or metacognitive reflection.

Theory of integrated domains in epistemology (TIDE): Muis, Bendixen, and Haerle (2006). With the objectives to address prominent theoretical debates and incorporate new empirical evidence, following an extensive review of the literature, Muis et al. (2006) proposed a complex integrative framework of personal epistemology. Drawing upon developmental (e.g., Kuhn, 1999; Kuhn et al., 2000) and multidimensional (e.g., Hofer & Pintrich, 1997) research traditions in epistemic cognition, Muis et al. contend that epistemic beliefs develop from an absolutism stance (i.e., a belief that knowledge is certain, simple, and transmitted from authority) to an evaluativism stance (i.e., knowledge is tentative, complex, and justified through evaluation of the quality of supporting reasons and evidence). This integrative framework is useful to organize other theoretical perspectives, as it contains both developmental and multidimensional considerations of epistemic cognition. Furthermore, they described three levels of epistemic beliefs, each level embedded into the next, progressing in specificity from general beliefs to academic and domain-specific epistemic beliefs, which may be active and related to learning. Initially, academic beliefs are amalgams of general beliefs, but as students progress through their education, domain-specific beliefs are acquired and become dominant. Beliefs are proposed to exist at three levels of granularity: general, academic, and domain-specific epistemic beliefs. Muis et al. contend that the process of developing epistemic beliefs and domain-specific beliefs included social-construction processes like enculturation; as students progress through higher

levels of education they adopt more differentiated, refined, and advanced epistemic practices encouraged in their respective epistemic climates (Muis & Duffy, 2013). Indeed, the study of epistemic climates of classroom and other learning environments has proven to be a fruitful line of inquiry (Feucht, 2010; Muis & Duffy, 2013; Muis, Trevors, & Chevrier, 2016).

Epistemological resources: Hammer, Elby, and colleagues (Elby & Hammer, 2010; Hammer & Elby, 2002; Louca Elby, Hammer, & Kagey, 2004). In their theoretical framing, Hammer and Elby (2002) adopt a view of multiple dimensions of epistemic cognition similar to previously reviewed frameworks (e.g., Hofer & Pintrich, 1997), yet they differ on their assumptions on the nature of these dimensions. Their paradigm was inspired by conceptual change research that viewed the traditional concept of "misconception," that of a mental representation that had to be wholly refuted and replaced, as too limiting, and instead insisted that misconceptions are composed of multiple smaller elements that may be productive depending on the context. Likewise, Hammer and Elby (2002) describe previous theories as making presumptions on unitary consistency of epistemic constructs – that personal epistemologies are akin to aptitudes or traits, and that what is articulated by students and/or observed by researchers in an assessment context is active and influential in a learning context – and critique such assumptions as unrealistic and inadequate.

To address this issue, they proposed a conceptualization of epistemic cognition as a set of many fine-grained cognitive resources that all students possess. These resources are either activated or deactivated while learning depending on contextual elements, analogous to assumptions made about self-regulated learning as an event and not as a trait (Azevedo 2015; Winne & Perry, 2000). Eschewing the term "epistemic belief" due to its connotations with stability across contexts and ability to be articulated in favor of the term "epistemic resource,"

this perspective adopts a finer-grained and context-sensitive view of epistemic cognition than other theoretical frameworks. Categories of epistemic resources include understanding the nature and sources of knowledge (e.g., knowledge as fabricated stuff and knowledge as propagated stuff, respectively); resources for understanding epistemic activities (e.g., accumulation, formation, checking); understanding epistemic forms (e.g., stories, rules, facts); and understanding epistemic stances (e.g., belief, disbelief, doubt, puzzlement, acceptance). For example, instead of describing the counterproductive epistemic belief of the source of knowledge stemming from authority figures, Hammer and Elby (2002, p. 180) describe it as a potential overuse of some epistemic resources (knowledge as propagated objects that are accumulated) and the underuse of others (knowledge as a process of fabrication and knowing through verification). Importantly, within this framework, a range of resources may be active and productive depending on the contexts, such as processing knowledge as propagated stuff when understanding expert testimony, in contrast to a view of uniform activation and productiveness.

However, some have questioned how this perspective addresses the issue of individuals' consistency in their epistemic cognition across contexts. Schommer-Aikins (2002) critiqued that a strong situated perspective would allow for the possibility of radical variations in epistemic cognition as a function of different contexts. In contrast, she contended that individuals' epistemic cognition does show some consistency. Elby and Hammer (2010) concurred, and proposed the notion of epistemic frames as a potential solution to the issue of context-specificity versus consistency in epistemic cognition. They elaborated that epistemic frames are formed out of habitual patterns of epistemological resource activation that achieve structural stability across time through deliberate and repeated use. With this novel construct, the epistemological

resources perspective attains balance on issues of granularity and context-specificity of epistemic cognition.

Expanded epistemic cognition framework: Chinn and colleagues (Chinn, Buckland, & Samarapungavan, 2011; Chinn, Rinehart, & Buckland, 2014). Building off the landmark framework of Hofer and Pintrich (1997) and in response to several empirical shortcomings in the field, Chinn et al. (2011) sought to contribute novel philosophical and psychological considerations to achieve greater clarity of the construct of epistemic cognition. They attempted this in two ways: first, the authors argued for the inclusion of several new components of epistemic cognition and, second, they contended that these components required fine-grained, contextualized analysis. Thus, the dual themes of expansion and refinement characterize Chinn et al.'s theoretical contribution to understanding epistemic cognition.

Their framework includes five components: (1) epistemic aims and values; (2) the structure of knowledge; (3) the sources and justification of knowledge and related epistemic stances; (4) epistemic virtues and vices; and, (5) reliable and unreliable processes for achieving epistemic aims. Epistemic aims are akin to learning goals described in other learning theories (e.g., Winne & Hadwin, 1998), which are always present in learning environments and are the end to which all epistemic processes are directed. Moreover, like learning goals, epistemic aims are context-sensitive and therefore may not be congruent with broader epistemic beliefs about the domain of focus and may have the potential to influence learning above the effects of beliefs. For example, a student who believes knowledge in history to be complex may still aim not to achieve an understanding of historical knowledge that reflects this complexity for a variety of situation-specific reasons, like studying for a multiple choice test of recall. Epistemic values refer to the relative importance individuals ascribe to epistemic achievements. For example,

elegant and coherent explanations may be valued over memory of lists of information. The more valuable an epistemic aim is perceived, the more likely an individual will be motivated to pursue it.

Chinn et al. (2011) reconceptualised many traditional epistemic constructs. Expanding upon traditional conceptualization of the beliefs about the structure of knowledge as a one-dimensional dichotomy (between knowledge perceived as simple or complex), the authors included in their framework beliefs about knowledge as universal or situated, deterministic or probabilistic, and specific organizational structures like explanations, mechanisms, or causal processes. The traditional dichotomy of the source of knowledge, between personal, internal efforts and external authority was also refined to recognize a broader range of sources of knowledge that interact while individuals learn: perception, introspection, memory, reasoning, and testimony. This current reconceptualization highlighted how previous theories confounded multiple sources, like perception, memory, introspection, and reasoning, and acknowledged that reliance on testimony from others is one type of learning strategy that is not inherently maladaptive as has been previously described (cf. Hofer & Pintrich, 1997). According to Chinn et al., adaptive epistemic cognition is reflected in the ability to evaluate and integrate multiple sources of knowledge. Justification of knowledge claims is likewise achieved through the use of multiple evidentiary standards in contrast to the traditional dichotomy, as individuals are likely to weigh what evidence is necessary and sufficient in a particular context, such as using the broadest range of data, the simplest explanation (e.g., Occam's razor), or an explanation that best coheres with previous explanations. Depending on the outcome of these epistemic processes, an individual might adopt one of several possible epistemic stances, like belief, doubt, or tentative acceptance.

Although many of the previous categories present familiar albeit reconceptualized constructs from traditional epistemic cognition research, the last two categories, epistemic virtues/vices and reliabilism, were novel contributions to theory. An epistemic virtue is a learned but stable disposition directed at effectively accomplishing epistemic aims, such as intellectual conscientiousness (e.g., ensuring no logical errors are made and no relevant information is overlooked). An epistemic vice is another disposition, but one that impedes accomplishing epistemic aims, and includes, for example, closed-mindedness or dogmatism. Virtues are distinguished from vices insofar as they help or impede accomplishing aims. So a virtue may become vice given the right goals; for instance, assiduously advocating open-mindedness about the existence of climate-change. The authors contend that epistemic virtues might better predict some learning processes than other traditional constructs. For example, a student possessing epistemic conscientiousness might do very well in science laboratories, where precision is highly valued.

Reliabilism refers to beliefs about the individual or social processes to acquire knowledge. Four types of epistemic processes are described: cognitive processes, inquiry, interpersonal processes, and community processes. Human reasoning is one example of an epistemic process that is also subjected to biases and thus may not be believed to be an epistemologically reliable process. In contrast, other processes such as debate or peer review are social practices that may be believed to be more reliable and lead to justified truths.

Synthesis and Critique

Rationale for selection of theoretical assumptions for examination

The ten programs of research reviewed represent a broad spectrum of theoretical conceptualizations of epistemic cognition. Each makes assumptions about the underlying

structure and nature of epistemic cognition that have far-reaching implications for how empirical research is conducted. The objective of the following section is to critically examine and synthesize the convergences and divergences between programs of research on theoretical assumptions about how individuals mentally represent epistemic cognition.

For this brief section, I present a justification for the use of two key assumptions to organize my subsequent synthesis and critique of the previously reviewed literature. To this end, I build on Pintrich's (2002) concluding commentary in his co-edited volume with Hofer (Hofer & Pintrich, 2002). In this concluding chapter, Pintrich reviewed the contributors of 31 experts in epistemic cognition across 17 chapters, which discuss a wide diversity of conceptual, theoretical, and methodological perspectives and issues. Pintrich synthesized and critiqued this body of literature to identify points where he believed consensus was needed to map out avenues of productive future research and to advance the field. To accomplish this goal, he adopted a dialectical approach, identifying consensual theses and dissenting antitheses in order to encompass all perspectives. From this critique, I select two key assumptions about the underlying cognitive structure of epistemic cognition to organize my review: (1) the number and independence of components of epistemic cognition; and, (2) the context-specificity versus generality of epistemic cognition.

I have selected these assumptions since these are fundamental to conducting empirical research. How researchers address these issues in their own work determines how they formulate research questions, select measures, sample populations, apply analytical techniques, and what practical educational programs they develop. For instance, a researcher who started with the theoretical assumption of a unitary epistemic cognitive structure and who used qualitative interviewing and thematic analysis may be unlikely to identify evidence for distinct dimensions

of epistemic cognition. In contrast, a researcher who started with the assumption of a multi-dimensional epistemic structure, used self-report questionnaires designed to reflect such dimensions, and who employed a factor analytic technique may very likely find support for separable factors (Pintrich, 2002). The practical implications for classroom instruction and interventions that stem from such divergent results are likewise significant. Clearer knowledge about the number and organization of the structures of epistemic cognition will illuminate best practices for measurement and foci for educational interventions. Thus, addressing these two issues is a necessary precursor to advancement of theory, measurement, and impact on educational practice. In the ensuing section, I briefly describe the assumptions concerning the structure and specificity of epistemic cognition and then synthesize and critique how each of the ten previously reviewed programs of research have attempted to address these assumptions.

Components of epistemic cognition: Numbers and independence

The number and independence of epistemic cognitive components are issues defined by how many mental representations comprise individuals' epistemic cognition and how strong the coherence is between such mental representations. Specifically, such theoretical assumptions refer to a debate over the degree to which multiple dimensions of epistemic cognition are orthogonal to one another or if they strongly cohere together into fewer but larger cognitive structures. Pintrich (2002) summarizes the debate thusly:

> "For example, in more classic developmental models that assume a more unitary (or stage-like) central conceptual structure, then all these different cognitions and beliefs should be closely related and show similar change over time (even allowing for the perpetual problem of horizontal decalage). In contrast, other cognitive models might

> propose that cognitions about knowledge and learning are both relatively independent dimensions, or separable knowledge structures or "schemas," or distinct "nodes" in a network of cognitions and beliefs." (p. 393)

This issue speaks to how learners develop in their thinking of epistemic issues while learning and how researchers might measure and design educational interventions to promote epistemic proficiency. Do dimensions develop in unison or isolation? If together, is there a larger cognitive structure that organizes and interlinks them? What cognitive structure should be the focus of measurements and interventions for epistemic change? Which of these theoretical assumptions researchers adopt will constrain their subsequent empirical work, thus they are at the core of this research.

Schommer (1990) conceptualized epistemic cognition as a set of "more or less independent dimensions" (p. 498). This assumption of independence entails that epistemic dimensions do not necessarily change over time in synchrony (Schommer-Aikins, 2002). For example, at a given point in time an individual may believe that knowledge is complex while simultaneously espousing the belief that knowledge is invariant. According to Schommer-Aikins (2002), the notion of independence varies over the course of a lifespan. Schommer-Aikins contended that one structure is insufficient to represent the complexity of epistemic processes observed across development. However, Schommer-Aikins described the possibility that the earliest form of epistemic beliefs in young children may contain a singular, undifferentiated dimension. With additional life experiences and feedback from parents, peers, formal education, and culture, individuals differentiate among beliefs on the simplicity, certainty, source and

justification of knowledge, which may in turn again recombine into a "symbiotic synthesis" (Schommer-Aikins, 2002, p. 110) of a system of beliefs.

Such a system of beliefs is analogous to Hofer and Pintrich's (1997) assumption about beliefs organized into personal theories. In an attempt to strike a balance between broad, stage-like developmental frameworks that left little room for within-stage variation (e.g., Kuhn et al., 2000), and theorists that made a strong assumption of independence of belief dimension (e.g., Hammer and Elby, 2002), Hofer and Pintrich proposed a plausible compromise: beliefs can be organized into "structures of interrelated propositions" (Hofer, 2001, p. 360). For example, simplicity and certainty were described as separate and independent beliefs about knowledge, which could be theoretically distinctly observed, analyzed, and described. However, these components may not be analytically separable (Hofer, 2000), possibly indicating that such beliefs about the nature of knowledge may still cohere into a more comprehensive structure. In sum, Hofer and Pintrich argued that there existed four epistemic cognitive dimensions that are invariantly active in all learning contexts, but that individuals' stance on each of these four dimensions may vary as a function of contextual elements (Pintrich, 2002, p. 397).

The remaining programs of research can be situated relative to the balanced position that Hofer and Pintrich (1997) adopted. For example, Muis et al. (2006) and Bendixen and Rule (2004) adopted similar assumptions about the independence of epistemic cognitive dimensions. Namely, Muis et al.'s critical review and proposed framework was guided by Hofer and Pintrich's four dimensions of epistemic cognition: simplicity, certainty, source and justification.

Two dissenting positions exist in contrast to this semi-independent perspective of epistemic cognition. First, researchers like Kuhn et al. (2000) reject a strong version of the independence assumption (Pintrich, 2002). Rather, researchers within this developmental

tradition assume that epistemic cognition cohere into broad, unidimensional and hierarchical stages that reflect qualitatively different thinking between each stage that cannot be meaningfully decomposed into independent components. Kuhn and Weinstock (2002) took a relatively more nuanced perspective on this assumption, and remarked that a "common set of dimensions may or may not run through these [stages]" p. 122). Thus, while largely adhering to a strong assumption for the coherent or unitary dimension of epistemic cognition, Kuhn theoretically allows for the possibility of minor variation within stages. However, analysis of these minor variations by researchers who adopt the epistemological understanding and developmental perspective has not yet been reflected in the empirical efforts based on this theory (cf. Kuhn et al., 2000; Kuhn & Park, 2005).

Second, researchers like Hammer and colleagues (Hammer & Elby, 2002; Louca et al., 2004) and Chinn et al. (2011) have proposed theoretical frameworks that contain numerous epistemic cognitive dimensions (greater than 25 different resources) but which are proposed to be less interdependent than other frameworks. In their critique of the broader epistemic cognitive literature, Hammer and Elby (2002) highlighted what they referred to as the implicit assumption of "unitarity" made by many researchers in the field. Unitarity refers to the assumption for a relatively large, coherent, and singular cognitive structure of personal epistemology. Hammer and Elby argued that not only is this implicit assumption made by unidimensional stage theorists, advanced by Perry (1970), King and Kitchener (2004), and Kuhn et al. (2000), but it is also present in the multidimensional theories given that underlying many of these frameworks is an assumption of relative coherence in personal epistemology (e.g., epistemological theories; Hofer & Pintrich, 1997). Although their critique largely was centered on the insensitivity to context Hammer and Elby perceived in other frameworks, many dimensions in the alternative

epistemological resource framework they proposed are described as less coherently activated in contexts, with some dimensions present and others absent. However, the authors note that at times there is co-activation of epistemic resources:

> "The activation of a resource does not preclude the activation of other resources within that same category or, certainly, in other categories. In fact, as will be clear, there are close links between resources in different categories. It may well be that, in some cases, those close links would be better understood as single resources that lie across the categories we have drawn." (2002, p. 177).

Further, Hammer and Elby contend that the issue orthogonality of epistemic dimensions in their theory described above is a research question that requires empirical testing.

On methodological and analytical significance, the question of independent dimensions refers to the factor structure of epistemic cognition; specifically, the number of factors observed in analyses (Muis et al., 2006). Factor analysis refers to a statistical technique to describe unobservable constructs on the basis of correlations between observable variables. Such observations include responses to questionnaire items that are typically measured on a Likert scale. Questionnaires are based on theories with multiple dimensions. Factor analytic techniques reveal the statistical psychological reality underlying student responses to these items.

Schommer-Aikins (2002) remarked on the importance of the assumption of independence in the conclusions that are drawn in empirical research. If a researcher made the assumptions of multiple and independent dimensions of epistemic cognition (and used a quantitative instrument), then he or she might observe high correlations among dimensions and obtain results

that generated only one or two factors. In contrast, a researcher who obtained the same set of correlational results but who adopted a unidimensional framework would interpret high correlations as confirmation of fewer beliefs dimensions and not as multiple, conceptually distinct but highly coherent belief dimensions (Schommer-Aikins, 2002).

Beyond measurement, the issue of independence of epistemic dimensions is relevant to understanding how students develop in their epistemological thinking about how they learn. This theoretical knowledge is in turn relevant for the design of educational interventions intended to promote more proficient epistemic processing while learning. The assumptions researchers make about the independence of epistemic dimensions relate directly to what is targeted in such interventions. Is epistemic cognition a collection of independent propositions about knowledge and knowing? A series of propositions organized into a connected mental model? Or, at larger and qualitatively different grain-size, is epistemic cognition organized into a worldview that may be radically different between novice and expert learners? How researchers answer these questions will determine what cognitive structures to target for change and the educational methods designed to change them.

Once the number and relative independence of epistemic cognitive components are determined, and a clearer and more complete picture of epistemic cognition is known, researchers must then apply that knowledge to answer the questions about which components are active and influential across various learning contexts. The issue of how theorists have chosen to model the specificity of epistemic cognition to various learning contexts in their frameworks is addressed next.

Context-specificity of epistemic cognition

The assumptions about the nature and independence of epistemic cognition components refer to the underlying cognitive structure. Whereas the issues of number of epistemic components and their independence relate to how they are cognitively structured, the issue of specificity relates to how responsive these components are to features of learning contexts. This theoretical assumption refers to what extent epistemic cognitive factors adapt and are differentially active across various learning contexts as a function of unique conditions of contexts. For example, a student may believe that to come to know something in mathematics represents finding the one correct answer (Muis, 2004) whereas he or she may believe to know something in another domain like psychology may represent understanding multiple perspectives of a psychological phenomenon (e.g., dreaming) (Muis et al., 2014).

The issue of specificity of epistemic cognition represents a long-standing debate in the field, first elucidated by Hofer and Pintrich (1997) and extensively addressed by Muis et al. (2006). Despite this, disagreements still exist among prominent theorists. How researchers have addressed the assumption of context-specificity in their various frameworks has far-reaching implications for their subsequent methodological and educational decisions. Given a substantive evidentiary body establishing that epistemic cognition is sensitive to domains (e.g., mathematics, psychology; Hofer & Pintrich, 2002), what level of learning environments (e.g., formal schooling, academic disciplines, academic subjects, classrooms, assignments) does epistemic cognition respond to? What influential features of environments cause epistemic cognition to adapt?

Hofer and Pintrich (1997) highlighted specificity of epistemic cognition as a significant theoretical issue as an outcome of their critical review. Although noting that what constituted a domain or discipline might be relative to the extensiveness and organization of an individual's

personal knowledge, Hofer and Pintrich argued that there was sufficient empirical evidence to conclude domain-specificity in epistemic cognition. Further, this domain-specificity was described as being an accurate reflection of the different structures of knowledge and ways of knowing conveyed in various disciplines (e.g., English versus mathematics). Hofer and Pintrich contended that with their conceptualization of a theory-like cognitive structure, it is possible to conceive a multi-layered, hierarchical and interconnected network between domain-general and domain-specific epistemic cognition, yet further empirical work was needed to substantiate this claim.

In response to this and other researchers' calls on the debate between the generality or specificity of epistemic cognition, Muis and colleagues (2006) concluded that there was evidence to indicate that epistemic cognition existed at both domain-general and domain-specific levels. They further proposed a theory of integrative domains in epistemology (TIDE) that contained a multi-layered, hierarchical structuring of epistemic cognition. Similarly, Kuhn et al. (2000) have found empirical demarcations between domains such as judgments made about personal taste, morality, aesthesis, and truth in social and physical worlds, and have identified different patterns of development as a function of these domains.

Methodologically, the assumption of the specificity of epistemic cognition speaks to how it should be measured and what cognitive structures should be the foci of interventions. Hammer and Elby (2002) have critiqued the prevailing theoretical assumptions and related methodological choices in the epistemic cognition literature. They outline how researchers working in these traditions often employ questionnaires with items that vary in their explicitness about the learning context of interest. For example, how students respond to items that ask about their preference for "movies that don't have endings" (Schommer, 1990) or the credibility of

textbooks in a particular subject (Hofer, 2000), relate very little to the epistemic processes undertaken while actually learning. To assume that questionnaire responses are related to learning contexts is to assume that there is some consistency in epistemic cognition that Hammer and Elby (2002) contend does not exist. They argue that responses in a research context are not a reliable indication of epistemological thinking in classrooms or while studying. Thus, Hammer and Elby argue for a highly specific epistemic cognition, evoked in direct response to varying elements of contexts. This degree of context specificity is a plausible stance, but is not represented by many current theories. Future efforts to achieve theoretical integration, much like Muis et al.'s (2006) efforts described in the TIDE framework, should include theoretical predictions about the operation of epistemic cognition at the level of classrooms and learning tasks.

However, such focus should not lose sight of the larger epistemic cognitive structures into which task-specificity is embedded. A clear knowledge of such structures relates to what Schommer-Aikins (2002) has argued against a strain of situatedness that she claimed is radical, stating that:

> "To assume that there is no domain generality of epistemological beliefs is like assuming we change like a chameleon from environment to environment. Even a chameleon only changes its color to fit in. It does not change its essence." (2002, p. 122).

Schommer-Aikins contends that individuals have a core epistemology from which specificity may be derived. She posits that individuals toggle between applying general and specific epistemic cognition across different context; the issue is thus reflected on which set of beliefs is

more dominant in a particular situation. Although much empirical research is needed to test these claims, such hypotheses point to the various levels of the cognitive structure that could be the foci of educational interventions.

In sum, theoretical advancement may be obtained through incorporating new specificity into our integrated theories but also ensuring that these perspectives are balanced. It appears that epistemic cognition may be productively represented as a cognitive process situated in learning activities and as a belief structure underlying these activities. Future theoretical directions for research should include specifying the nature of the links between various levels of constructs, predictions on which ones are active in various learning contexts, how should they be measured, and how they change over time.

Conclusions to Part One

In sum, empirical work is constrained by methodological choices, which are in turn constrained by theoretical assumptions. High quality scientific research and effective educational practice is contingent upon a clear perception of the phenomenon of interest. To elucidate how epistemic cognition is cognitively represented by students, the number of components, the strength of their interrelations, and which are active across domains and contexts requires that researchers step outside of their respective programs of study to use and directly compare and contrast the various methodologies that have proliferated along disparate research traditions, to seek out convergent and divergent evidence on the structure of epistemic cognition in order to come to know its boundaries and content. Only after researchers know the structure and specificity of epistemic cognition can they develop effective measurement instruments and interventions to promote and hasten its long-term change. On the basis of the current theoretical

review, a comprehensive theoretical framework of epistemic cognition may have been what Hofer (2001) had predicted over a decade earlier:

> "We may be moving toward an integration of ideas from multiple models: an identifiable set of dimensions of beliefs, organized as theories, progressing in reasonably predictable directions, activated in context, operating as epistemic cognition." (p. 377).

Thus is appears that epistemic cognition and change may be best conceptualized and measured as two complementary sub-problems operating on different timescales: the first, epistemic cognition, operates over the short-term as situated activities that vary as a function of contextual cues; the second, epistemic beliefs, operate over the long-term as a broader cognitive structure that shape the scope of epistemic cognitive activity the individual engages in and varies as a function of their enculturation and proficiency in epistemic climates (Muis et al., 2006). This conceptualization is analogous to what Briell et al. (2011) refer to as the "dual nature" of epistemic cognition (p.10). In the next section I review the predominant methodological strategies that researchers have chosen, critique misalignment between method and theory, and survey new and potentially better-aligned methods of research for epistemic cognition.

Part Two

What research methodologies have been traditionally used to study epistemic cognition and how has it been traditionally measured?

The measurement of epistemic cognition has been notoriously difficult. The challenges associated with measurement are manifold and likely stymie theoretical development and impact on educational practice. According to Schraw (Schraw & Olafson, 2008; Schraw, 2013),

epistemic cognition accounts for a small direct influence on various outcome measures (e.g., self-regulation, problem-solving, academic achievement), usually between 5-15% in terms of proportion of variance explained. Several possible explanations exist for this small direct relationship between epistemic cognition and academic outcomes: (1) the measurement of epistemic cognition may be flawed; (2) mediating or moderating variables may be overlooked; or (3) epistemic cognition may not be as important to learning as theorists might suggest. Any of these explanations may be true, but before we are able to make strong theoretical conclusions, we first must rule out methodological limitations. Therefore, researchers should reliably and validly measure epistemic cognition and account for any possible mediating or moderating variables. As I will show in the following review, only recently have researchers begun to address these issues: valid and reliable measurement has unevenly been achieved with the predominant method of traditional measurement – self-reported Likert-type questionnaires – and traditional research has overlooked the role of mediators. Following this review, I will then highlight new methods that are potentially more psychometrically sound and recent efforts to explore mediation in research on epistemic cognition. With a strong psychometric foundation to assess more fully various relations, researchers are then able to go about testing and better understanding the relationship between epistemic cognition and outcomes of interest.

Further, central to the current comprehensive review is the contention that the theoretical assumptions about the structure of epistemic cognition made by researchers constrain their methodological choices, which in turn impact empirical work and educational practice. In this section, I review the issue of alignment between measurement and theoretical assumptions about the structure of epistemic cognition.

Psychometric properties: A primer

To ground the subsequent discussion, I briefly describe core psychometric concepts that are central to issues related to the measurement of epistemic cognition. Specifically, I first review the concept of reliability and associated threats to reliability. Second, I review concepts of validity, including construct and predictive validity.

Reliability is the concept that refers to the consistency in individuals' responses to a psychological instrument (McIntire & Miller, 2007). If the instrument is reliable, researchers can trust that the items that compose it consistently measure the same psychological phenomenon of interest. For example, an epistemic cognition questionnaire will be said to be reliable if those items produce similar results under similar conditions (e.g., sample characteristics, modes of administration). Reliability is threatened by errors in measurement that are caused by the test itself, test administration, test scoring, or the test taker. When assessing the reliability of a measure, it is useful to first address whether the construction of the test itself is sound before looking to other sources of errors. Therefore, errors that affect reliability that stem from the construction of the test itself include ambiguously or poorly worded questions. For example, the item that makes a "doubled barrel" statement such as "I like teachers who present several competing theories and let their students decide which is best" (Schraw, Dunkle, & Bendixen, 1995) is problematic since it is impossible to know which part of the question was answered (Welch & Ray, 2012). Low reliability may prevent researchers from observing differences between groups that exist (Wood & Kardash, 2002).

Validity refers to if the instrument measures what it was intended to measure (McIntire & Miller, 2007). Validity is a multifaceted concept in psychometrics and can refer to several issues: whether the content of the test is representative of the construct of interest (content validity); whether the instrument relates to some criterion of interest (e.g., academic achievement), both

measured concurrently and in the future (concurrent and predictive criterion-related validity); and whether the instrument relates to other tests or observable behaviours of theoretically related constructs and does not relate to tests or observable behaviours of theoretically unrelated constructs (convergent and divergent construct validity).

Construct validity can be assessed in several ways. First, researchers can use information gained from examination of an instrument's content and criterion-related validity in support of its construct validity (McIntire & Miller, 2007). For example, Hofer and Pintrich (1997) specified four epistemic beliefs: simplicity, certainty, source, and justification. Instruments used to measure epistemic beliefs based on Hofer and Pintrich's theory should therefore include items that represent a connection to each part of these four constructs. Problems also arise when the construct is defined too narrowly in the context of the psychometric instrument. For example, a researcher might use a measure of job satisfaction to assess overall happiness. Further, evidence of the predictive power of an instrument to an outcome of interest also bolsters that instrument's construct validity, as when measures of epistemic cognition are shown to predict subsequent mediating variables like cognitive processes or outcome variables like grades.

Second, researchers can use a multi-trait multi-method design (Campbell & Fiske, 1959). Therein, researchers can obtain information on reliability, convergent and divergent validity. To do so, researchers select two or more theoretically related and unrelated constructs each and two or more methods to measure each construct. The goal of this process is to obtain evidence for "convergence across different measures […] of the same 'thing' […] and for divergence between measures […] of related but conceptually distinct 'things'" (Cook & Campbell, 1979, p.61).

Third, researchers can design an experimental intervention wherein the instrument of interest is used as an independent variable or as the criterion, dependent variable (McIntire &

Miller, 2007). If the underlying theory predicts that intervention-induced changes will vary as a function of scores on the instrument of interest, or alternatively that scores themselves change as the result of an intervention, then such evidence of change supports the construct validity of the instrument.

In all cases, evidence of reliability and validity is borne out of empirical investigations. Keeping these concepts in mind, next I conduct a critical review of the psychometric properties of measures of epistemic cognition. I demonstrate that to date measures of epistemic cognition have shown poor reliability, predictive validity, and thus poor construct validity. I will argue that these impoverished psychometric properties stem from misalignment between the cognitive structure of epistemic cognition, theorists' conceptualizations of epistemic cognition, and predominant types of measurements used in empirical research, specifically, self-report Likert-type questionnaires, and the failure to account for the effects of potential mediators.

The mis-measurement of epistemic cognition: A review of methods and issues in empirical research

The majority of empirical research into epistemic cognition has employed self-report questionnaires (Briell, Elen, Verschaffel, & Clarebout, 2011; Greene & Yu, 2014; Schraw, 2013). In recent reviews of the literature, Briel et al. (2011) and Schraw (2013) found that approximately two thirds of studies of epistemic cognition used Likert-type questionnaires. More specifically, as Briell et al. remark, the bulk of the studies they reviewed that used a questionnaire methodology also adopted a multidimensional perspective of epistemic cognition (e.g., Hofer & Pintrich, 1997; Schommer, 1990) and nearly all of these studies either used Schommer's (1990, 1998) Epistemological Belief questionnaire, a shortened version or it, a revised version, or a new questionnaire inspired by it, which suggests a great deal of

homogeneity and stagnation in the measurement of epistemic cognition. The instruments that were developed based on Schommer's program of research were criticized for the inclusion of other dimensions not purely epistemic (e.g., beliefs about learning and ability), or for their inconsistent factor analytic results.

In response to such criticisms, several other paper-and-pencil questionnaires were developed, including: Domain Focused Epistemological Belief Questionnaire (Hofer, 2000); Chan and Elliott's (2002) questionnaire; Epistemic Belief Inventory (Schraw, Bendixen, & Dunkle, 2002); Epistemological Beliefs Survey (Wood & Kardash, 2002); Jehng and colleagues' questionnaires (Jehng, Johnson, & Anderson, 1993); and, Connotative Aspects of Epistemological Beliefs (Stahl & Bromme 2007). However, even some of these attempts to develop psychometrically sound questionnaires have fallen short on assessments of reliability, replicability of factor structures, and thus, construct validity (Briell et al., 2011).

Researchers have recently made explicit efforts to examine these psychometric properties. For example, in a review of eight empirical studies across three continents with approximately 1600 participants that used the EBI, Welch and Ray (2012) found that factor analyses of this instrument resulted in a range between 3 to 5 factors and Cronbach's alpha coefficients ranging from .26 to .88, denoting both unstable factor structures and at times unacceptable reliability. In their own empirical investigation, Welch and Ray administered the EBI to 282 undergraduate students. The results of their exploratory factor analysis supported the trend in their literature review that demonstrated a lack of stability in the facture structure of this instrument. Although their factor solution contained the same number of epistemic components proposed by Schraw et al. (1995), the underlying constructs were not the same given that a different subset of items loaded onto each factor compared to the original model. Welch and Ray

thus concluded that until the factor structure of the EBI is consistently replicated, epistemic cognition researchers should continually re-analyze this instrument and potentially edit the individual items that comprise it in a manner consistent with epistemic cognition theory.

In a similar vein, DeBacker, Crowson, Beesley, Thoma, and Hestevold (2008) conducted a critical review and stringent psychometric evaluations of prominent epistemic cognition questionnaires that led them to draw dismal conclusions about the state of the field. DeBacker et al. (2008) comprehensively reviewed empirical research of three prominent questionnaires: the Epistemological Questionnaire (EQ; Schommer, 1990); the Epistemic Beliefs Inventory (EBI; Schraw et al., 2002); and the Epistemological Beliefs Survey (EBS; Wood & Kardash, 2002). The results of their review revealed that each instrument has poor psychometric properties. Past empirical studies frequently failed to replicate factor structures and reported low reliability coefficients. Although the number of factors would at times be similar across studies (frequently 3 or 4 factors were obtained), the factors were a recombination of subsets of items and thus often differed in their conceptual boundaries, which resulted in the creation of new and unexpected factors (e.g., Certain knowledge, Structure of Knowledge, Knowledge is Simple and Certain, none of which were consistently obtained across studies). Further, reliability statistics across studies were persistently low, ranging from .51 to .85, which DeBacker et al. remarked was "indicative of large proportions of measurement error and is related to difficulty in replicating findings across samples" (p.286).

In their own empirical study, DeBacker et al. (2008) administered three questionnaires to college students: the Epistemological Questionnaire (EQ; Schommer, 1990; $N = 935$), the Epistemic Beliefs Inventory (EBI; Schraw et al., 2002; $N = 795$), and the Epistemological Beliefs Survey (EBS; Wood & Kardash, 2002; $N = 795$). Exploratory factor analysis, confirmatory

factor analysis, and internal reliability estimates were calculated for each instrument. DeBacker et al. obtained numerous data of concern, including: low goodness of fit indices, which indicate theory was a poor match for data (construct validity); low factor loadings, which indicates that the instrument items are not good at predicting hypothesized factors (content validity); internal consistency estimates uniformly below .70, which indicate measurement error potentially stemming from ambiguously or poorly worded items; and high correlations among the latent variables calling into question whether epistemic factors were orthogonal.

Thus, DeBacker et al. (2008) concluded that there were serious psychometric problems with these three self-report instruments designed to measure epistemic cognition. In a review of the literature and in the current empirical findings, DeBacker et al. failed to obtain a consistent picture of the number or nature of epistemic cognition components. From the large amount of error variation and a dubious construct operationalization, DeBacker et al. urged caution when interpreting research based on these instruments. They further noted an undue influence of empiricism with a lack of theoretical moorings. Unguided by theory, instruments were sometimes developed and essentially recreated for each sample, which does not reflecting some underlying theory of epistemic cognition but the vicissitudes of specific samples. Although DeBacker et al. noted that a stronger theoretical grounding is not a panacea, they argued that "its absence will surely obscure understanding of the role of epistemic beliefs in the classroom" (p. 305).

On the basis of such critical reviews and in response to the ensuing questions raised about the soundness of self-reported instruments, other researchers have sought to investigate the online processes individuals engaged in while responding. Such investigations provide insight on whether questionnaire items activate valid cognitive processes. In parallel efforts Greene,

Torney-Putra, and Robertson (2010), Greene, Yu, and Copeland (2014), and Muis, Duffy, Trevors, Ranellucci, and Foy (2014) employed a cognitive interview technique to examine the construct validity of two epistemic cognition instruments. The cognitive interviewing technique is a method to examine in-depth the cognitive processes that instruments elicit to allow for the evaluation of their appropriateness. If questionnaire items are constructed correctly, they should be fully comprehensible, elicit memories of experiences that are valid to the current investigation, and lead to the selection of responses aligned with these memories (Karabenick et al., 2007; Muis et al., 2014). The results from Greene et al., and Muis et al. converged on several findings that called into question the validity of the use of questionnaires to examine epistemic cognition. First, several participants in these studies reported interpretations of item words that were unintended by the researchers who wrote them. “True,” “belief,” “expert,” and “complex” were all interpreted by participants at one time or another in a manner that deviated from the meaning that researchers typically understand them. Second, on a number of occasions, participants reported not understanding an item’s meaning, or holding several understandings active in mind at once. Third, such incomprehension or multiple examples lead to participants selecting the middle response of a Likert scale rather than espouse agreement or disagreement. For instance, one student reported: “I put 3 because it’s either sometimes I strongly agree for a certain scenario and sometimes I strongly disagree because there’s so many different scenarios” (Muis et al., 2014).

Synthesis and Critique

Sources of psychometric problems: Misalignment between phenomenon, theory, and method

The psychometric problems with prevalent measures of epistemic cognition, I argue, largely stem from misalignment between researchers' theoretical assumptions and their methodological choices. The empirical findings obtained from cognitive interviewing described above provide a possible explanation for the low predictive validity of epistemic cognition in educational research. Specifically, low reliability statistics are perhaps indicative of measurement error from poorly constructed items. Low construct validity values perhaps reflect poor operationalization of epistemic cognition components. These methodological choices – construction of questionnaire items and operationalization of constructs – are activities guided by theory.

In particular, theory guides what components are included in the instrument and the construction of particular items to represent them. For example, Hofer (2000) proposed four components in the design of the Domain Focused Epistemological Belief Questionnaire: simplicity, certainty, source and justification. Questionnaire items related to other potential epistemic cognition components, like epistemic aims or virtues, are therefore not created or piloted. If such components are in fact relevant for learning, then their exclusion will attenuate the predictive validity of the instrument. Further, items that are inconsistent in focus, not representative of the construct, or ambiguously worded will add unnecessary error variance to instrument scores that will reduce its utility for research. Thus, more complete conceptualizations of epistemic cognition should directly translate into methodological choices that heretofore seem to be lacking.

Recall the theoretical discussion surrounding two key assumptions of the cognitive structure of epistemic cognition addressed in Part One. The first assumption dealt with the components of epistemic cognition: how many components of epistemic cognition exist, and are

components activated in isolation or in unison? The second assumption dealt with the granularity or the sensitivity to context of epistemic cognition: once the components of epistemic cognition are determined, which are active and influential in a given context, and what features of the context are relevant for activation (e.g., well-structured versus ill-structured domains)?

To date, epistemic cognition has largely been conceptualized as a relatively unitary, stable, and articulable system of beliefs across contexts, research and educational contexts (Hammer & Elby, 2002). But if, on the other hand, the mental representation of epistemic cognition also includes other highly contextual cognitive activities, then questionnaires, those previously reviewed and as they are presently designed, will fail to fully capture this reality.

Proposed solutions: New observational methods of epistemic cognition in action and assessing indirect mediational effects

As other fields have done, most notably self-regulated learning (Azevedo & Greene, 2010; Azevedo et al., 2012; Winne & Perry, 2000), researchers can move away from largely decontextualized self-reports to collect non-reactive observational process data that may provide sufficient evidence to draw inferences and conclusions about the functioning and effects of epistemic cognition and related mediational constructs. Such data include computer log files of users' interactions with computer-based learning environments (CBLE); concurrent think-aloud protocols; eye tracking; facial recognition software; and electrodermal activity among other physiological measures. Such observational data I argue are more aligned with a fuller conceptual picture of epistemic cognition that would include the roles of mediators identified in recent empirical research and would likely buffer against some of the biases inherent in self-report instruments.

As Chinn et al. (2011) contend, epistemic cognition is likely far more expansive in terms of the number of components than it has been traditionally conceptualized. Extending this program of research are the theoretical foci of Hammer and Elby (2002; Elby & Hammer, 2010), Hofer (2001, 2004), Sandoval (2005, 2009), and Barzilai and Zohar (2014) on situating and refining epistemic cognition into a cognitive and metacognitive process embedded in contexts and activities. Applying these theoretical developments to empirical research and methodology are Greene, Muis, and Pieschl's (2010) proposal for the use of CBLEs to capture the fluctuations in activations of a multitude of specific epistemic cognition activities. Taken together, we begin to see the outline of a new program of research that leverages new theoretical developments of epistemic cognition as situated events aligned with innovative methodologies that capture multiple channels of related cognitive, metacognitive, and affective learning processes.

Several future directions in methodologies should be considered. First, measures that elicit reflection on epistemic cognition within clearly delineated contexts should be score higher on measures of internally consistency. Based on the findings of cognitive interviewing (Greene, Torney-Putra, & Robertson, 2010; Greene, Yu, & Copeland, 2014; Muis et al., 2014), presenting questionnaire items that depict very broad contexts can be interpreted by individuals inconsistently. Instead, the creation of more specific and concrete contexts allows less leeway for differences in interpretation by participants, potentially reduces variance associated with error, and thus improves reliability. Efforts by Bråten and colleagues (Bråten, Ferguson, Strømsø, & Anmarkrud, 2013; Bråten, Gil, Strømsø, & Vidal-Abarca, 2009) to develop topic-specific measures of epistemic beliefs and to refine conceptualization and measurement of epistemic dimensions are contributing to this goal.

Second, observations of epistemic cognitive processing made in context will inherently be valid to that context. Asking individuals to speculate on what they habitually do may be biased towards amalgamation of memories and responding in a socially desirable way rather than what they actually do. Rather, in situ observations of epistemic cognitive processing will not reflect individuals' memory or social desirability biases. The challenge for researchers is to devise or select one or more contexts that are representative of individuals' overall epistemic cognitive processing and to use methods of measurement that come close to fully capturing these processes. Early attempts at such empirical work are already underway. Hofer (2004), Muis (2008), and Greene and colleagues (Barzilai & Zohar, 2012; Greene & Yu, 2014; Greene, Yu, & Copeland, 2014) have found nascent evidence of epistemic cognition in think-aloud protocols. Evidence that is more complete comes from Barzilai and Zohar (2012) who found that epistemic cognitive processes were observable in concurrent verbalizations as 6th grade students studied multiple documents. Likewise, investigating concurrent verbalizations with college students, Bråten, Ferguson, and colleagues (Bråten, Ferguson, Strømsø, & Anmarkrud, 2013; Ferguson, Bråten, Strømsø, & Anmarkrud, 2013) found evidence for four active dimensions of epistemic cognition while reading multiple documents (i.e., a combined certainty/simplicity dimension, and three justification dimensions: authority, personal experience, and multiple sources), with the majority of their sample (n = 47/51) making utterances in relation to the nature of knowledge. Beliefs in the Internet as a reliable source of accurate and detailed knowledge negatively related to visually attending to, and verbally reflecting on credibility, source information, and further negatively related to accessing diverse sources (Kammerer, Bråten, Gerjets, & Strømsø, 2013; Kammerer, Amann, & Gerjets, 2015; Mason, Pluchino, & Ariasi, 2014). Further, other behavioural correlates of epistemic cognition have also been observable in the computerized log-

files of students' navigation and interactions with computer-based learning environments (Pieschl, Stahl, & Bromme, 2008) and with patterns of fixations from eye-tracking (Burton & Daneman, 2007).

Third, theorists have noted the effects of epistemic cognition may be better observed indirectly via various mediators (Bråten, Britt, Strømsø, & Rouet, 2011; Greene, Muis, & Pieschl, 2010; Muis, 2007). According to these models, stronger relations are expected between epistemic cognition and related motivational, affective, cognitive, and metacognitive processes and constructs (Bråten & Ferguson, 2015), which have a more direct influence on academic outcomes. Epistemic cognition shapes how learning tasks are defined, expectations, goals, and standards for knowledge and learning (Dong, Liang, Yu, Wu, & Tsai, 2015; Muis, 2007; Pieschl, Stallmann, & Bromme, 2014), that if confirmed by the epistemic nature of the learning task, may lead to higher levels of self-efficacy, positive emotions, motivation, and cognitive engagement (e.g., Muis et al., 2015). However, if there is inconsistency between epistemic beliefs and the epistemic nature of the task, (i.e., if definitions, expectations, goals, or standards are violated), then this may lead to momentary lower levels of these same constructs. Thus, there is theoretical reason to consider mediating variables when examining relations between epistemic cognition and academic outcomes. Indeed, initial investigations into examining mediators of epistemic cognition have shown that effects of epistemic cognition on various academic outcomes are mediated by a variety of constructs. An overview of this empirical work shows several promising future directions: the effects of epistemic cognition on information integration is indirectly mediated via comprehension (Barzilai & Eshet-Alkalai, 2015); the effects on memory are mediated by claim evaluation (Braasch, Bråten, Britt, Steffens, & Strømsø, 2014); effects on multiple text comprehension are mediated by learning strategies (Bråten, Anmarkrud, Brandmo,

& Strømsø, 2014); effects on enactment of learning strategies are mediated by preparatory phases of self-regulation (Chiu, Liang, & Tsai, 2013); effects on online search standards and strategies are mediated by cognitive load (Hsieh & Tsai, 2014); effects on grades mediate via achievement goals (Mason, Boscolo, Tornatora, & Ronconi, 2013; Muis & Franco, 2009); and effects on learning are mediated by emotions and learning strategies (Muis et al., 2015).

Conclusions to Part Two

We can consider methodologies to fall into one of two broad categories: self-report and observation. Self-report measures are valuable as they provide insights into participants' lived experiences of educational phenomenon, which may be potentially relevant to some conceptualizations. However, self-reports are subject to many threats to validity, including: social desirability, cognitive, and memory biases; participants' limited self-knowledge about an abstract and potentially tacit psychological construct; and the measurement of perceptions of a construct rather than measuring it more directly. Additionally, self-reports typically assess relatively stable attributes out of context when the reality of the construct may be sensitive to contexts. Further, the use of Likert-type questionnaires constrains individuals' responses to a unidimensional ordinal ranking, whereas the reality of the epistemic cognitive construct may be multidimensional. Thus, unfortunately there are numerous opportunities for self-report questionnaires to misalign themselves with some theoretical conceptualizations of epistemic cognition reviewed in Part One. Despite these limitations, self-report questionnaires remain the predominant and frequently the only methodological strategy of epistemic cognitive researchers. The potential misalignments between this measurement tool and the various levels of the construct of interest are a likely cause of the low reliability statistics and poor content, construct, and predictive validity observed in empirical research. In the assessment of a construct as elusive

as epistemic cognition it is likely a good practice to complement questionnaire data with the use of other observational methods of epistemic behaviours (e.g., think-aloud protocols, computer log-files, and eye tracking; Greene et al., 2010); refine the conceptualization and measurement items in questionnaires (Bråten, Ferguson, Strømsø, & Anmarkrud, 2013; Bråten, Gil, Strømsø, & Vidal-Abarca, 2009); and test for the effects of potential mediators (e.g., Muis et al., 2015). The importance of these methodological choices becomes paramount in the design of practical educational interventions; a goal of any intervention is to claim that the selection and operationalization of a construct measured at Time 1 is different in the expected direction when measured at Time 2.

Final Conclusions

Research has demonstrated that epistemic cognition is an active factor with meaningful relations to learning. As individuals encounter issues that are more complex – such as health treatment options, climate change policy, or the teaching of evolution in schools – possessing a constructivist epistemic cognitive stance will gain increasing relevance in a knowledge-based economy. However, as theories and assumptions about epistemic cognition have proliferated, methodological strategies have remained relatively homogenous and stagnant, leading to empirical findings open to doubt. Overall, the objectives for this comprehensive literature review were to study various theoretical frameworks and core assumptions about the underlying cognitive structure of epistemic cognition and review of current methodologies, new methodologies, and their alignment with theoretical insights. In addressing these issues, I hope to have illuminated points of consensus, concern, and paths forward to continue our advancement of knowledge on epistemic cognition and its adaptive change.

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Bridging Text

In Chapter 2, a comprehensive review and critique of the literature on epistemic cognition was presented. Two objectives guided this review: (1) to identify consensus positions among theorists about a likely structure and behaviour of epistemic cognition active in various learning contexts; and (2) to critique traditional methodologies that assess its influence and identify promising methodological trends. On the basis of this review, it was concluded that epistemic cognition may have a complex structure that operates on two different timescales: the first, epistemic cognition, operates over the short-term as situated activities that vary as a function of contextual cues; the second, epistemic beliefs, operate over the long-term as a broader cognitive structure that shape the scope of epistemic cognitive activity in which the individual engages. I contended that the level of cognitive activity has traditionally been overlooked in empirical research, as its direct effects on academic outcomes are challenging to measure with self-report instruments. I concluded with identifying new trends in research that point to reconceptualized and more specific measurement, observational techniques, and assessment of potential mediating factors to assess indirect effects.

The following chapter presents two empirical investigations that pick up on these threads. The studies in Chapter 3 employ a categorically different and domain-specific questionnaire on the connotative aspects of epistemic beliefs; triangulate eye tracking and concurrent and retrospective verbal reports; and assess study-time allocation, metacognitive judgments, and other relevant self-regulated learning variables along with a learning outcome variable. In so doing, the studies of Chapter 3 sought to address the methodological limitations identified in Chapter 2.

Within the broader dissertation, in addition to these methodological advancements, another theme the following chapter presents is an examination of epistemic cognition within the context of controversial knowledge, as these are important, real-world contexts wherein epistemic cognition is likely to be active and influential. In the studies presented in Chapter 3, these examine individual factors that underlie detecting and resolving conceptual discrepancies contained within an individual source.

Chapter 3

Manuscript #1

Self-Regulated Learning Processes Vary as a Function of Epistemic Beliefs and Contexts: Mixed Method Evidence from Eye Tracking and Concurrent and Retrospective Reports

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Abstract

The objective of the current studies was to investigate how epistemic cognition related to specific phases and components of self-regulated learning and its adaptation to learning conditions of varying quality. In a multi-study, mixed method design, we presented university students with science content that relayed conceptual discrepancies and collected quantitative and qualitative data to study how students responded to discrepancies. In Study 1 (n = 42), we collected eye tracking patterns, study times, and metacognitive ratings and found that participants adapted their behavioural processing as a function of their epistemic cognition and discrepancy type. In Study 2 (n = 20), we collected concurrent think-aloud protocols and retrospective interviews to further explore why discrepancies were noticed (or not) and how they were resolved. Results revealed that prior knowledge and epistemic self-efficacy in oneself as an evaluator of knowledge emerged as important themes to detecting and efficiently resolving discrepancies. We conclude with a discussion of theoretical and methodological implications.

Keywords: epistemic cognition; self-regulated learning; metacognition; process data.

Individuals in the 21st century who have access to increasingly complex, ill-structured, and evolving information are presented with new challenges to quality learning (Sinatra, Kienhues, & Hofer, 2014). This is especially true within the context of self-authored, Web 2.0 online content that is oftentimes not regulated by traditional "gate-keepers" and which may relay misinformation (Farrell, 2015; Kata, 2012; Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012). Thus, chief among these challenges to learning is refining digital literacy skills, such as planning, monitoring, and evaluating the use of learning strategies (i.e., self-regulated learning; Azevedo et al., 2012, 2013; Trevors, Duffy, & Azevedo, 2014) and assessing the accuracy of new knowledge and integrating its multiple sources (i.e., epistemic cognition; Greene, Yu, & Copeland, 2014). Facets of self-regulated learning and epistemic cognition are also closely linked constructs core to science literacy (Barzilai & Zohar, 2014; Zohar & Barzilai, 2013; Muis, 2007). Together, skilled self-regulation and the development of new literacies empower individuals to make informed decisions about medical treatments, controversial climate policies, or healthy lifestyle choices, among other important personal and global issues with a scientific basis.

Across many studies, individuals' beliefs about knowledge and knowing – their epistemic beliefs – and the self-regulation skills they enact during studying are known to separately relate to learning and achievement (Azevedo et al., 2012, 2013; Bouchet, Harley, Trevors, & Azevedo, 2013; Bråten, Anmarkrud, Brandmo, & Strømsø, 2014; Feyzi-Behnagh et al., 2014). However, what remains relatively unknown are specific empirical relations between self-regulated learning and epistemic cognition, particularly in conceptually rich computer-based learning environments of varying quality. Thus, we currently report on two studies wherein we experimentally manipulated the inclusion of discrepant information to induce active repair processing and

observed the relations between epistemic cognition and key aspects of self-regulation while individuals studied science content.

In the first section, we describe theories of self-regulated learning, including frameworks that integrate epistemic cognition (EC) and self-regulated learning (SRL). Next, we review early empirical evidence for the influence of SRL and EC on learning from conceptually rich computer-based learning environments. Then we review theoretical frameworks and evidence to understand the effects of conceptual discrepancies on SRL and EC to inform the hypotheses of the current study.

Self-Regulated Learning

Students' regulation of their learning processes is a critical determinant of academic achievement, particularly in conceptually rich multimedia environments (Azevedo, 2014, 2015; Greene, Moos, & Azevedo, 2011). Increasingly, learners are confronted with substantial amounts and multiple representations of information (e.g., text and graphs). These conceptually rich multimedia learning environments are often delivered online and offer learners access to important, complex, and evolving information. However, these environments may have multiple, questionable, and/or contradictory authors. In the face of potentially discrepant information, learners must enact skilled SRL processes to set appropriate learning goals, efficiently navigate across content, select relevant and reliable texts, diagrams, and learning strategies, and continually monitor and evaluate their emerging comprehension against their goals and constraints (e.g., time, conflicting sources). Failure to enact skilled SRL may diminish, or in the context of questionable discrepant content, jeopardize quality learning from these multimedia environments. Hence, inherent in effective learning from contemporary multimedia learning environments is an active and goal-directed process by learners to monitor and control their

cognition, metacognition, motivation, affect, and behavior in a manner that is sensitive and adaptive to specific features of learning contexts (Azevedo et al. 2012, 2013; Bannert & Mengelkamp 2013; Opfermann et al. 2013; Pintrich, 2000).

We use SRL theories to understand and predict the complexity and patterns of these learning processes within multimedia environments (Azevedo et al., 2012, 2013; Greene & Azevedo 2009). In particular, we make the assumption that SRL occurs as a series of events unfolding across time and adopt Winne and Hadwin's (1998, 2008) information-processing model of SRL. Therein, Winne and Hadwin proposed SRL to occur in four weakly sequential and recursive phases: 1) defining a learning task; 2) making goals and plans; 3) enacting learning strategies; 4) adjusting strategies through metacognitive monitoring. Within and across each of these phases are information-processing activities that occur during each phase and are responsible for movement between phases.

In the first phase of SRL, individuals form a perception of the task at hand, which may significantly differ from one learner to the next. For example, one student may define their task to be to understand all they can about climate change, whereas another may define their task to achieve some minimum grade on a subsequent test. In the second phase, individuals develop multifaceted learning goals, such as completing their task by a certain time or meeting a standard for understanding instructional content, and then form plans to achieve these various goals. In the third phase, individuals carry out their plans by enacting learning strategies, such as re-reading, paraphrasing, coordinating multiple sources of information, or generating inferences. In the fourth phase, individuals metacognitively reflect on their learning processes from phases 1 through 3 and use information gained from this reflection to regulate subsequent actions. If, for example, an individual judges her learning progress to be acceptable, she proceeds unabated.

However, if she judges that her learning progress is not satisfactory, whether it is in terms of spending too much time on one aspect or not meeting some standard for comprehension, she may decide to exert control through modifying aspects of subsequent definitions, goals, plans, or enacted strategies. Thus, central to this fourth phase is the recursive nature of Winne and Hadwin's (1998, 2008) model, as what metacognitive information is attended to by individuals affects all learning processes that follow. Taken together, Winne and Hadwin (1998, 2008) describe optimal SRL overall as exemplified by efficient movement between the four phases that is contingent upon monitoring and regulation of information-processing.

Indeed, one hallmark of SRL is the assumption that skilled learners will be adept at monitoring (themselves and the content) so that they can use information gained from activity to decide how to proceed next in their learning. Investigations into metacognitive monitoring is a burgeoning area of research and has highlighted the importance of several judgments learners will make while studying, including prospective ease-of-learning judgments (EOL), concurrent judgments of learning (JOL), and retrospective confidence judgments (RCJ) (Bjork, Dunlosky, & Kornell, 2013). The primary function of such judgments is to allow individuals to select what content to study and efficiently allocate study time across learning material (Dunlosky & Metcalfe, 2009). EOLs represent judgments made prior to starting and thus reflect the preparatory phases of SRL (e.g., task definitions, planning). JOLs represent learners' subjective self-evaluation of how well the content is learned and have important implications for study time allocation (Dunlosky & Metcalfe, 2009). Last, RCJ represent how confident the learner is that he or she performed well on a test of learning.

Researchers attempt to describe learners' overall strategy or agenda for studying. In one such theoretical account by Metcalfe (2002), she proposed that learners will allocate limited

study time to content perceived to be the easiest to learn. Referred to as the region of proximal learning model, learners will triage their scarce study time to content deemed to provide the greatest opportunity for learning. In addressing the question of learners' perseverance on tasks, Metcalfe and Kornell (2005) further proposed a new metacognitive marker that reflected an active, process-oriented approach to JOL. They theorized that learners will make judgments about the rate of learning (jROL) and will continue to study until they judge that the rate of knowledge acquisition has reached a standstill, or determine that some low criterion value reflecting diminishing returns have been met, at which point they will stop. In sum, metacognitive judgments made before, during, and after learning have important implications for what to study, how to study it and for how long, and thus reflect core phases and constructs of SRL. Although many factors affect students' performance at self-regulating (Azevedo et al., 2012), in the current research we propose that learners' tacit beliefs about the nature of knowledge, or epistemic beliefs, are an active and influential learner characteristic affecting SRL as it unfolds (Bromme, Pieschl, & Stahl, 2010; Muis, 2007).

Epistemic Cognition

We investigate EC under the multidimensional framework (Hofer & Pintrich, 1997; Stahl & Bromme, 2007). Individuals may believe knowledge to be isolated facts (i.e., *simplicity* dimension) that, once discovered, remain unaltered by time or human intervention (i.e., *certainty* dimension). To learn such knowledge requires careful attention and memory to those who discovered it – experts and authorities in various fields – as the nature of knowing is believed to be a faithful reproduction of relayed facts (i.e., *source* and *justification* dimensions). In contrast, epistemic cognition may also broadly comprise beliefs that knowledge is a network of interconnected facts. Such knowledge is believed to be updated over time with additional

reasoning and new evidence. Rather than the source and justification for knowing stemming from expert testimony, these individuals believe the nature of knowing to require personal justification; to not only accurately recall a knowledge claim, but to be able to understand and evaluate the reasons and evidence in support of that knowledge claim (Muis, 2007). We adopt the terminology from other researchers (e.g., Muis et al., 2015) and refer to *constructivist epistemic cognition* as comprising of beliefs in complex, unstructured, subjective, and dynamic knowledge congruent with a constructivist epistemology (Sawyer, 2006). In contrast, we refer to *less constructivist epistemic cognition* as comprising of beliefs in simple, structured, objective, and static knowledge.[2]

However, there is controversy in the field of epistemic cognition on the psychometric soundness of traditional methods of measuring EC. Extensive reviews of the psychometric properties of common EC self-report instruments have shown unstable factor structures and at times unacceptable reliability (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008; Welch & Ray, 2012). Further, insights from cognitive interviewing of participants' interpretation of EC questionnaires have also raised doubts of their validity (Greene, Torney-Putra, & Robertson, 2010; Greene, Yu, & Copeland, 2014; Muis, Duffy, Trevors, Ranellucci, & Foy, 2014). As Pieschl et al. (2014) note, these psychometric issues may be due to the possibility that not all participants have explicit-denotative knowledge of their epistemic cognition.

On the basis of this reasoning, Stahl and Bromme (2007) developed the Connotative Aspects of Epistemological Belief (CAEB) questionnaire. This semantic differential instrument consists of several antonym adjective pairs that reflect associative-connotative assumptions of knowledge and knowing (e.g., dynamic – static; Pieschl et al., 2014). This instrument produced

[2] We choose not to use the labels “naïve” and “sophisticated,” although frequently used in the past by researchers, to avoid making an evaluative commentary.

two reliable dimensions: beliefs about the *Texture* of knowledge (e.g., whether knowledge is assumed to be unstructured, ambiguous, and subjective) and beliefs about the *Variability* of knowledge (e.g., whether knowledge is assumed to be dynamic, uncompleted, and open). These dimensions share conceptual overlap with simplicity and certainty dimensions, respectively (Hofer & Pintrich, 1997), but the CAEB is selected for the current research given its potential to circumvent issues in traditional measurement methods.

Relations between Epistemic Cognition and Self-Regulated Learning

Theoretically, EC is related to SRL via the multifaceted standards learners set to achieve their learning goals (Bromme et al., 2010; Greene, Muis, & Pieschl, 2010; Muis, 2007). Standards for learning refer to multifaceted criteria that the learner seeks to achieve while learning, such as maintaining a particular level of comprehension while reading or finishing a task at a certain time. In these models, EC shapes the standards formed during the preparatory phases prior to learning. Standards are used during metacognitive monitoring (i.e., comparing standards with cognitive products), which subsequently mediates strategy-use (Chiu, Liang, & Tsai, 2013; Winne & Hadwin, 2008). If, for example, a student believes that knowledge is structured and static s/he may set a standard for learning that only requires sufficient memory of a single source in isolation, which rote memorization may achieve. In contrast, a belief in unstructured and dynamic knowledge may set a standard for learning that might motivate greater effort at uncovering and understanding complex interrelations among multiple sources and attempt to integrate them.

The relations between EC and SRL may be especially important within the context of encountering and resolving discrepancies in knowledge. Such discrepancies include inconsistencies between an individual and an external source of knowledge (e.g., textbook; Kendeou, Walsh, Smith, & O'Brien, 2014), inconsistencies between sources (e.g., disagreement

among experts; Muis et al., 2015) or within sources (e.g., conceptual discrepancies between a text and graph; Burkett & Azevedo, 2012). Such discrepancies put focus on questions about the structure, variability, and sources of knowledge, which likely activates individuals' epistemic cognition. Examining the effects of discrepancies on learning is particularly important given the increasing prevalence of self-authored, online content that may relay errors or misinformation (Kata, 2012; Lewandowsky et al., 2012). Successful learning is contingent on how well individuals respond to these events (D'Mello, Lehman, Pekrun, Graesser, 2014; Rapp & Braasch, 2014). Thus, to understand how learners effectively navigate questionable content online, it becomes valuable to study the fundamental resolution strategies that individuals initiate and regulate in response to discrepancies in knowledge they encounter.

Evidence for Epistemic Cognition and Self-Regulated Learning within Multimedia Environments

There is mounting empirical evidence that EC is an active and influential factor during SRL within conceptually rich multimedia environments. Recently, epistemic beliefs have been found to relate to self-reported task definition, planning, enactment, and evaluation phases of SRL (Chiu, Liang, & Tsai, 2013; Franco et al., 2012; Lee, Chiu, Liang, & Tsai, 2014) and relate to flexibility in calibrating complex learning strategies for complex tasks during these phases as well (Pieschl, Stallmann, & Bromme, 2014). Further, other recent studies that collected process data showed that EC is active during the process of learning with relations to computer navigation recorded in log-files (Hsu, Tsai, Hou, & Tsai, 2014; Pieschl, Stahl, & Bromme, 2008), concurrent think-aloud protocols (Greene & Yu, 2014; Ferguson, Bråten, & Strømsø, 2012; Trevors & Muis, 2015), and attention allocation recorded by eye tracking (Kammerer, Bråten, Gerjets, & Strømsø, 2013; Mason, Pluchino, & Ariasi, 2014).

For instance, Pieschl and colleagues (2014) investigated the relations between EC and adapting to tasks of varying complexity. These researchers hypothesized that less constructivist epistemic beliefs (e.g., beliefs in static and objective knowledge) will be associated with low adaptation to task complexity, whereas more constructivist epistemic beliefs (e.g., dynamic and subjective knowledge) will be associated with more pronounced adaptation. Their hypotheses were largely confirmed; learners with constructivist Texture beliefs showed an affinity for a deeper approach to learning overall (e.g., agreeing strongly that tasks involved "processing critically" and "cognitive effort"). Learners with constructivist Variability beliefs showed greater adaptation of their application of a deeper approach across all levels of task complexity (e.g., a reduced intention to enact a deep approach for memory tasks but a higher intention to enact a deep approach for creative tasks) compared to their less constructivist counterparts. Similar research showed that such metacognitive adaptation varied as a function of epistemic cognition only for tasks that are more complex but not for simpler tasks (Bromme et al., 2010).

Importantly, with regard to study time allocation and monitoring of comprehension, Pieschl et al. (2008) found that learners with constructivist EC reported lower comprehensibility ratings and spent less time on complex hypermedia pages compared to their less constructivist counterparts. In this study, the authors concluded that, paradoxically, participants with less constructivist EC seemingly calibrated more strongly to the complex learning conditions (i.e., by allocating more study time to more complex content). Pieschl et al. therefore speculated that perhaps participants with less constructivist EC were seduced by extraneous detailed information rather than more efficiently allocating limited study time to gain a more complete perspective of the content. In other words, whether learners calibrate their study time to either the immediate content or the more global and comprehensive task of learning as much as they can across all

content seems to vary as a function of EC. This adaptation of study time appears analogous to Metcalfe's (2002) description of region of proximal learning model that likewise stipulates learners will prioritize studying content that has the greatest chance of contributing to the overall learning goal.

However, it is still not well understood how and why these relations between EC and SRL emerge or if these patterns generalize to detecting and resolving discrepancies that learners may encounter online. Thus, we examine these relations within the context of processing discrepant knowledge claims, which are likely encountered in real-world situations (Kata, 2012; Lewandowsky et al., 2012; Rapp & Braasch, 2014) following a common experimental induction to study how learners initiate and regulate strategies to resolve resulting disequilibrium (D'Mello, Lehman, Pekrun, & Graesser, 2014).

Current Studies

Central to the current set of studies is the contention that successful learning is contingent upon skilled and adaptive self-regulation of cognitive, metacognitive, and motivational learning processes. We currently investigate epistemic cognition as one learner characteristic theorized to be influential in achieving skilled self-regulated learning. In general, we test the hypothesis forwarded by Greene et al. (2010) that aspects of learning tasks such as discrepancies can activate epistemic cognition, which in turn influence processes of self-regulated learning (Azevedo, Moos, Johnson, & Chauncey, 2010; Greene & Azevedo, 2009).

In the current research we report on two studies wherein we investigate the relations between epistemic cognition and several facets of self-regulated learning: metacognition, multimedia integration, study time allocation, and other active and influential cognitive and metacognitive learning strategies, as measured by concurrent think-aloud protocols and

retrospective interviews. We investigated the following research questions: First, does learners' regulation of cognitive and metacognitive strategies vary as a function of their epistemic cognition and discrepancies? We addressed this first research question in Study 1 by observing individuals' regulation of attentional allocation and multimedia integration, as measured by eye tracking and computer log-files, and metacognition, as measured by fine-grained judgments of learning. Congruent with theoretical models and empirical findings of the relations between SRL and EC by Azevedo et al. (2012, 2013), Bromme (2010), Greene et al. (2010), Muis (2007), and Pieschl et al. (2008, 2014), we hypothesize that learners with constructivist epistemic cognition (i.e., beliefs in dynamic, uncompleted, unstructured, and subjective knowledge) will adapt their processing more strongly to pages with discrepancies than those without and in particular, consistent with Pieschl et al. (2008), in the direction of lower ratings of comprehension, less study time, and as a result, fewer attempts to integrate multimedia on pages with discrepancies that those without.

Second, if learners do regulate their cognitive and metacognitive strategies as a function of epistemic cognition as we predict, how and why does adaptation occur? We address this second research question in Study 2 by building on the findings from Study 1 through replication but with the addition of collecting concurrent think-aloud protocols and retrospective interviews to gain deeper insights to how and why patterns of relations between EC and SRL form (Van Gog & Jarodzka, 2013). For Study 2, we did not make specific hypotheses but rather planned to explore in-depth the relations between EC and SRL observed in Study 1 through the use of a mixed method design.

Study 1

Method

Participants

Forty-two undergraduate students were recruited from a large, public research university in North America ($N = 42$). Thirty-one self-reported as female (71%), eleven as male, and participants ranged in age from 18 to 26 years ($M = 20.0$ years).

Materials

This study extended the method of another recent study of conceptual discrepancies (Burkett & Azevedo, 2012) and thus adopted the materials and procedure reported therein with several additions. In brief, the current study used a within-subjects design to examine the effects of three conditions of conceptual discrepancies within multimedia science content presented in a computer-based multimedia learning environment (Burkett & Azevedo, 2012). Our unique additions to this study consisted of examination of students' epistemic cognition and eye-movements while learning.

Prior Knowledge. The general science knowledge test measured participants' prior knowledge about chemistry, physics, biology and physical science and consisted of 20 multiple-choice questions evenly distributed the four domains, which were compiled by Burkett and Azevedo (2012) from previous standardized tests (e.g., Scholastic Aptitude Test). A sample item includes: "Which of the following statements about catalysts is INCORRECT?".

Connotative Aspects of Epistemological Beliefs. Stahl and Bromme's (2007) Connotative Aspects of Epistemological Beliefs (CAEB; Appendix A) instrument was used in the current study to assess epistemic cognition, which is a 24-item semantic differential instrument that asked participants to rate antonym adjective pairs along a 7-point scale (e.g., "dynamic" – "static") for science knowledge in general. Following Stahl and Bromme's (2007) two-factor structure, responses to 17 items were used to assess students' epistemic beliefs on the *Texture*

(10 items) and *Variability* of scientific knowledge (7 items), which closely but not entirely correspond to Simplicity and Certainty dimensions, respectively. Cronbach's alpha statistics for Texture and Variability were acceptable (α = .65 and .66, respectively; see Appendix A for the items used in the current study).

Computer-Based Multimedia Learning Environment. Participants in the current studies were presented with twelve unique multimedia content pages each relaying a different complex science topic across various domains in science (e.g., viruses; atmosphere structures; projectile motion). Each topic was described in a short text (i.e., 240 to 250 words, M = 247 words) with a corresponding graphical representation that illustrated a concept discussed in the text. Across pages, three levels of conceptual discrepancies were presented to all participants in a repeated-measures design: No Discrepancy (ND), Within-Text discrepancies (WT; two separate conflicting sentences), and Between Text and Graph discrepancies (BTG; one text sentence conflicting with the graph trend line). The three discrepancy types were evenly distributed across the twelve pages and participants were not informed about the existence of discrepancies prior to or during the studies. For example, the page relaying content about enzymes contains a conceptual discrepancy within the text. Specifically, this WT discrepancy page relays discrepant information between the first and last sentences of the 2nd paragraph: "Enzymes speed reactions by lowering the energy of activation, the amount of energy required to start a reaction" […] By reducing the energy of activation, some enzymes decrease reaction rates a billion times" (see Figure 1). The experimental manipulation of conceptual discrepancies allowed us to examine how participants engaged in various facets of self-regulation in response to disruptions to learning and to examine how epistemic cognition relates to these SRL processes (D'Mello et al., 2014).

Metacognition. Several measures of metacognition were obtained throughout the experimental session. Prior to accessing each page, participants were presented with an open-ended inference question related to the content (e.g., "What is the relationship between energy and the function of enzymes?") and were asked to provide an evaluation of the ease with which they could learn the content necessary to answer the question (Ease of Learning; EOL). Dunlosky and Metcalf (2009) have noted that the accuracy of judgments of learning significantly improves after a short delay, therefore in the current study participants were prompted to respond to JOL prompts a second time after a short delay: 30 seconds after reading and inspecting the text and graph content and prior to proceeding on to the next page, participants were prompted to provide an evaluation of their learning (Judgment of Learning; JOL) from the text and graph separately (Text JOL Text; Graph JOL Graph). A sample JOL item includes: "How well did you understand the information about the function of enzymes in the text you just read?" Then, participants provided a written response to the content question posed at the start of the content page[3]. Upon completing their written response, participants were prompted to provide a final judgment of their confidence that their written response correctly and completely answers the question (Retrospective Confidence Judgment; RCJ). A sample item includes: "How confident are you that the answer you provided about energy and the function of enzymes is correct?" The completion of these metacognitive prompts represents one complete trial for one content page in the experimental session, which was repeated until all twelve content pages were processed. Computer generated log-files recorded participants' responses to metacognitive prompts. The average metacognitive rating response was calculated for each page type (e.g., average Text JOL rating for WT). From these judgment data we were able to calculate reliability coefficients,

[3] The materials we administered were more extensive than reported here; we excluded instruments from this paper if the constructs were not related our research questions. Unique research questions and data pertaining to metacomprehension are reported in AUTHORS (under review).

which were found to be acceptable for the ND condition (range of Cronbach's α = .60 to .72) and WT condition (Cronbach's α = .66 to .75) but the range for BTG showed unacceptable to substantial reliability (Cronbach's α = .30 to .81).[4]

Eye tracking. Tobii T-60 Eye-Tracker recorded eye fixations and movement patterns across science texts and related graphs with infrared cameras embedded in a computer monitor that displayed all content. Students' strategy-use for coordinating informational sources (COIS) was also extracted from eye-tracking data. COIS was operationalized as a sequence of two transitions between eye fixations on text and graph areas (e.g., text → graph → text), the frequencies of which were tallied for statistical analysis. We calculated the average COIS value for each of the three page types and for all pages overall.

Study time allocation. Computer generated log-files recorded the timing of participants' interactions with the system (e.g., time spent studying each content page). Study times in seconds were extracted from log-files and the average study time duration (Study Time) was calculated for ND, WT, and BTG pages.

Procedure

After completing informed consent, participants were seated in front of the Tobii Eye-Tracker computer monitor, which displayed the experimental content. Participants completed the prior knowledge measure, followed by the CAEB. The researcher then initiated the computer-based multimedia learning environment. The experimental session proceeded along a linear, self-paced progression through the twelve content pages that were presented in a randomized order. The study lasted approximately two hours, for which participants were compensated $20.

Data Analysis

[4] In the BTG condition, the Cronbach's α reliability coefficient of .30 for Graph JOL was the outlier, which likely represents inconsistency in participants' experience of the conceptual discrepancy between text-and-graph.

Does learners' regulation of cognitive and metacognitive strategies vary as a function of their epistemic cognition and discrepancies?

To answer this first research question we conducted canonical correlations among sets of predictor learner variables (i.e., EC, prior knowledge) and dependent learning variables (cognitive and metacognitive strategies) for each of the three discrepancy conditions (ND, WT, BTG). To understand significant multivariate relations, we examined significant bivariate correlations among EC variables and condition-specific cognitive and metacognitive variables. Although we calculated correlations among all the variables, for ease of presentation, correlation matrices are presented separately by discrepancy condition. We wanted to apply a parsimonious analysis that maintained the comprehensive array of variables of interest and also reduced the risk of Type I error in subsequent analyses. Therefore, we interpret subsequent condition-specific bivariate correlations between EC and SRL variables as meaningful only if the related multivariate canonical correlation was significant. Finally, we determined whether the magnitude of the correlation coefficients significantly differed between discrepancy conditions.

Results

Canonical Correlations

Canonical correlations estimate correlations between two sets of variables by calculating a linear combination of variables within each set that forms a latent dimension, similar to factor analysis (Shell & Husman, 2008). We calculated a canonical correlation between learning variables specific to each condition and individual characteristics. Specifically, the dependent variables were judgment of learning of text and graph comprehension, retrospective confidence judgments, coordinating informational sources, and time spent on pages[5]. The predictor variables

[5] EOL data were excluded as participants had no foreknowledge of the different conditions and therefore this variable was not expected to vary as a function of condition.

were Texture, Variability, and to assess its effects relative to epistemic dimensions, prior science knowledge.

Of the three possible functions extracted (equal to the number of variables in the smallest set), none were statistically significant in examining the relationship between sets of variables specific to the ND and BTG conditions, respectively ($p > .05$). The relationship between sets of variables specific to the WT condition was significant, Wilks' lamda = .45, $R_c^2 = .55$, Approximate $F(15, 94.26) = 2.08$, $p < .05$. Based on the Cramer-Nicewander (1979) index, approximately 22% of the overall variance associated with the set of dependent variables was explained by the predictor variables.

The first function was extracted and had a squared canonical correlation of $R_c^2 = .42$, indicating that the two sets of variable shared approximately 42% of variance. Eigenvalues, percentages of variance explained, and squared canonical correlation for all functions are presented in Table 1.

Similar to factor analysis, determining what the latent functions represent can be ascertained by interpreting the structure coefficients associated with each variable (Shell & Husman, 2008). Tables 2 and 3 display the structure coefficients for the dependent and predictor variables, respectively. The first predictor function is characterized by higher levels of Texture and lower levels of prior knowledge and Variability, although with a notably smaller contribution. The first dependent function is represented by lower levels of Text JOL, Graph JOL RCJ, COIS, and higher levels of Study Time. Taken together, the first function appears to indicate that reduced integrative behaviors between text and graphs, an overall longer page studying time, and lower confidence in comprehension is predicted by lower prior science knowledge, weaker beliefs in dynamic and open science knowledge (i.e., Variability), and

stronger beliefs in unstructured and ambiguous science knowledge (i.e., Texture). To better understand this multivariate relation within the WT discrepancy condition, we conducted bivariate correlations. Although we calculated all possible correlations, we only interpret those correlations between EC and SRL within the WT condition as meaningful.

Correlation Analyses

Correlational analyses were conducted to determine if the relations between epistemic cognition and learning variables were along hypothesized directions (see section 1.4). Recall constructivist epistemic cognition was expected to negatively relate to judgments of comprehension and processing variables (Pieschl et al., 2008). Therefore, one-tailed probabilities were used to examine the relations between epistemic cognition and learning variables: metacognitive judgments, page studying times, and informational integration strategy-use (i.e., COIS) specific to each of the three discrepancy types. Descriptive and correlational statistics for variables specific to No Discrepancy pages are presented in Table 3; Table 4 relays correlational statistics for Within Text discrepancy pages; Table 5 contains correlational statistics for Between Text and Graph discrepancy pages. We discuss each in turn.

With few exceptions, across all three conditions, positive correlations were observed among metacognitive judgment variables, indicating that participants were consistent in their ratings of comprehension within each condition. Likewise, across the three experimental conditions, page study times positively related to COIS, signifying that participants were consistently spending more time on the pages they more frequently engaged in COIS as a learning strategy. On pages with discrepancies (i.e., WT and BTG), prior science knowledge was found to negatively relate to page study times, indicating that participants with greater

knowledge of science spent less time on pages with discrepancies, regardless of their location in the multimedia content.

Within the WT discrepancy condition, in regard to relations between epistemic cognition and learning variables, Texture negatively related to three metacognitive judgment variables: Text JOL, Graph JOL, and RCJ. Thus, consistent with predications, individuals who believed that science knowledge was ambiguous and subjective consistently reported lower confidence that they had learned content. Further, again in the WT discrepancy condition, Variability negatively related to page processing time and the use of COIS. Thus, consistent with hypothesized relations, beliefs in dynamic and open science knowledge were related to shorter reading times and less frequent integration strategy-use compared to beliefs in static and closed knowledge.

We determined if correlation coefficients between epistemic cognition and learning variables were significantly different between conditions along expected directions. We thus used a procedure outlined by Lee and Preacher (2013) and Steiger (1980) to calculate differences between significant correlation coefficients across conditions. Constructivist epistemic cognition was expected to be more sensitive to discrepancies and thus more strongly negatively relate to learning variables (see section 1.4; Pieschl et al., 2008, 2014). Therefore, one-tailed probabilities were used to examine differences in coefficients between discrepancy conditions when there existed at least one significant correlation between a learning variable and an epistemic cognition variable. This resulted in ten comparisons between conditions (i.e., ND–WT and WT–BTG) of the relations between epistemic cognition and the following variables: Text JOL, Graph JOL, RCJ, Study Time, and COIS.

The correlation between Texture and Text JOL (WT) was more negative than Text JOL without discrepancies (ND), $z = 1.68$, $p < .05$. The correlation between Variability and page studying time for within text discrepancies was marginally more negative than the same relationship for no discrepancies, $z = 1.62$, $p = .052$. No other comparisons were found to be significant.

Discussion of Study 1

Overall, findings from Study 1 are consistent with our hypotheses that constructivist epistemic cognition negatively relates to comprehension judgments and processing behaviors while learning and raise important questions about the role of epistemic cognition on self-regulated learning in particular contexts. In general, canonical correlations showed that a linear combination that formed the predictor variate consisting of more constructivist Texture beliefs, lower prior knowledge, and less constructivist Variability beliefs was significantly related to a dependent variate consisting of lower metacognitive judgments of comprehension, lower frequency of COIS, and longer page studying times. This relationship was observed for variables from Within-Text discrepancy condition and not the control (i.e., No Discrepancy) condition, which supports the view that constructivist epistemic cognition entails sensitivity to learning contexts and flexibility in adapting to contextual demands (Elen, Stahl, Bromme, & Clarebout, 2011; Hammer & Elby, 2002, 2003, 2010; Pieschl, Stahl, & Bromme, 2013). Based on the standardized coefficient, it appears that Texture and prior knowledge make the largest and most meaningful contributions to the latent predictor variable that relates to an array of important cognitive and metacognitive self-regulated learning variables. To unpack and interpret this multivariate relationship, individual bivariate relations between WT condition variables are discussed below.

Texture Epistemic Beliefs and Processing Within-Text Discrepancies

Stronger beliefs in unstructured, subjective, and ambiguous science knowledge (i.e., constructivist Texture beliefs) related to lower levels of self-evaluated comprehension. In the case of Text JOL, this relationship was stronger when studying pages with discrepancies embedded within the text compared to pages without discrepancies, suggesting that participants with stronger constructivist Texture beliefs were more sensitive to such discrepancies compared to their less constructivist counterparts. This finding is consistent with current hypotheses and previous research (Pieschl et al., 2008, 2014). JOL are known to have important implications for study time allocation, as the information gained from this metacognitive self-evaluation phase – that is, if learning is proceeding well or not – is used to regulate subsequent behavior (Dunlosky & Metcalfe, 2009; Metcalfe, 2002; Metcalfe & Kornell, 2005). By virtue of being more sensitive to contextual conditions such as discrepancies, participants with constructivist epistemic Texture beliefs are better positioned to be more metacognitively aware and to be more adept at regulating their behaviors. Moreover, subjective self-evaluations of comprehension are one indication of learners' assessment of whether their learning is deviating from ideal levels of comprehension. Through showing that these metacognitive judgments covary with epistemic cognition, the current findings indirectly support theoretical models that claim epistemic cognition act as one set of inputs to learners' standards for learning and the consequences when these standards are not met (Bromme et al., 2010; Muis, 2007). Further, the current findings refined these theoretical models by adding a higher degree of specificity between metacognitive and epistemic constructs.

Variability Epistemic Beliefs and Processing Within-Text Discrepancies

Additionally, stronger beliefs in dynamic, open, and uncompleted science knowledge (i.e., constructivist Variability beliefs) related to lower frequency of integrating multimedia and

less time spent studying content pages. With regard to time spent studying pages, the magnitude of the negative relationship between Variability and study time was larger for pages with Within-Text discrepancies compared to those without discrepancies, suggesting that participants with stronger constructivist Variability beliefs were more sensitive to these discrepancies compared to their less constructivist counterparts. These findings are consistent with predictions and previous research showing that constructivist epistemic cognition relates to lower study allocation time for complex material (Pieschl et al., 2008). In particular, Pieschl et al. (2008) speculated that individuals with constructivist Variability beliefs spent less time studying hypermedia pages with detailed and complex content because they calibrated their study time allocation to the global task of learning as much as they could rather than calibrating to the local task of understanding a detailed page. Pieschl et al. noted that by differentiating between pages that would or would not contribute substantially to achieving the task of a global understanding, individuals with constructivist beliefs were more efficient with their study time. A novel contribution of the current study is to demonstrate that this effect, originally observed with complex content, is extended to content that contains discrepancies, and is observable by examining patterns of eye tracking.

Relations between Epistemic Cognition, Metacognition, and Study Time Allocation

This strategy for study time allocation is analogous to Metcalfe's (2002) region of proximal learning model, which states that learners will devote limited study time to content that is judged to be contributing most meaningfully to learning (i.e., a high rate of learning) and cease studying content that is judged not to be contributing meaningfully to learning (i.e., a low rate of learning) or stop when they feel that they are 'laboring in vain' (Metcalfe & Kornell, 2005). We interpret the current findings under these theoretical models, and speculate that constructivist

Variability beliefs inform an apprehension structure (Bromme et al., 2010) that allows individuals to be more sensitive to and identify cues from the content that indicate that it is not worth much of their time studying. In the case of the current study, with our use of unresolvable discrepancies, these individuals would be correct. Thus, we speculate that participants with constructivist Variability beliefs more readily recognized cues in Within-Text discrepancy pages that signaled that they could be more efficient with their study time if they quickly abandoned the current page they were viewing and proceeded onto new content. However, it should be noted that prior knowledge also negatively correlated with page studying times and canonical correlations revealed that prior knowledge contributed more meaningfully to the variate that related to page studying times. Thus, open questions remain on the relative roles of prior knowledge and epistemic cognition in the process of detecting cues of content quality and regulating subsequent learning.

Moreover, what remains unknown are what these cues are, whether participants actually notice the conceptual discrepancies in the current design, and the mechanisms that account for differences in patterns of eye tracking, study times, and metacognitive judgments observed in the current study. To identify the self-regulation processes that were undertaken in response to discrepancies and understand how and why correlational patterns emerged, further research was needed to triangulate current behavioral measures with verbal data channels, such as think-aloud protocols and retrospective interviews, which leading researchers have called for as important for the advancement of knowledge in these fields (Van Gog & Jarodzka, 2013; Greene et al., 2010; Magliano & Graesser, 1991). Thus, we undertook a second mixed method study with the objective to build off current insights to investigate these remaining questions (Creswell, 2014). Thus, our second research question that is addressed by Study 2 was: Given that learners regulate

their cognitive and metacognitive strategies as a function of epistemic cognition, how and why does such adaptation occur?

Study 2

Method

Participants

Twenty undergraduate students were recruited from a large, public research university in North America ($N = 20$). Twelve self-reported as female (60%) and eight as male; age ranged from 18 to 30 years ($M = 21.4$ years) with an average self-reported GPA of 3.2/4.0 ($SD = 0.6$). Students were paid $30 for their 3-hour participation.

Materials and Procedure

The materials and procedure for Study 2 replicated that of Study 1 with several additions. EC and SRL were examined with concurrent think-aloud protocols and retrospective interviews. Concurrent think-aloud protocols and retrospective interviews were supervised and conducted by the first author. Screen and audio recordings of these data were collected using Snagit® software (TechSmith®). More specifically, participants were instructed to think-aloud while studying the content pages (Ericson & Simon, 1993) and were interviewed about their learning thoughts and behaviours immediately following completion of the learning session. Participants were instructed to read out loud and to vocalize everything that they were thinking and everything that they were doing while they studied the content. Prior to commencing, participants went through a brief think-aloud training session. During the concurrent think-aloud, participants were prompted to "keep talking" if they were silent for more than 3 seconds (Ericson & Simon, 1993). During the retrospective interview, participants were asked about their learning behaviours during the experimental session, their thoughts and beliefs about factors that might affect these

behaviours (e.g., prior knowledge), and whether they noticed conceptual discrepancies. Specifically, to avoid leading questions, the interviewer asked the following three questions in order: (1) “How would you judge the quality of the content?” (2) “Why or why not would you recommend its future use?” (3) “Did you encounter any errors or inaccuracies?”

Data Analysis and Credibility

Given evidence from Study 1 that learners regulate their cognitive and metacognitive strategies as a function of epistemic cognition, how and why does such adaptation occur?

Concurrent think-aloud protocols and retrospective interviews underwent qualitative thematic analysis (Creswell, 2007; Greene & Yu, 2014; McCrudden & Kendeou, 2014). We sought to gather insights into why discrepancies were or were not noticed and how they were resolved, which we considered to be processes of self-regulated learning. Further, we examined how epistemic cognition relates to these regulation processes of detection and resolution. We describe the process of this qualitative analysis in the following section.

To establish credibility in our analysis, we followed data analytic procedures described by Greene and Yu (2014), Creswell (2007), and Whittemore, Chase, and Mandle (2001). Concurrent think-aloud protocols and retrospective interviews were analyzed by the first author. The author watched screen recordings, listened to verbal reports for all participants in iterative cycles, and transcribed relevant segments. Relevant segments were identified and classified by low-inference indicators based on SRL and EC theories. Specifically, segments were transcribed if participants: (1) mentioned or engaged in behavior that reflected some aspect of the nature of knowledge or knowing (including aspects that reflected beliefs or cognitions about the simplicity or certainty of knowledge and the source and justification for knowing); or (2) mentioned or engaged in behavior that reflected awareness or control of cognitive, metacognitive, and/or

motivational learning processes (including task definitions, standards or goals, enacted learning strategies, and evaluations). We adopted wide theoretical perspectives of SRL and EC to allow us to be open to new codes to emerge from the data not prefigured by current specific SRL or EC models.

We considered for analysis relevant segments that occurred either concurrently with the learning session or retrospectively in response to the interviewer's question. These data were then categorized into groups that shared common theoretical constructs mentioned above (e.g., beliefs about the source of knowledge). The first author iteratively returned to the original recordings to determine if additional data changed the boundaries of the codes. Once stability had been determined and no new meaningful codes appeared, transcription and coding ceased and overarching themes were inferred from the current set of codes (Creswell, 2007)[6]. To establish accuracy in our interpretation of the participants' meaning we present direct quotations from participants, triangulate our data, and present rich, thick descriptions where appropriate (Creswell, 2007; Whittemore, Chase, & Mandle, 2001)[7].

Results and Discussion of Study 2

Qualitative Analysis

Discrepancy detection. Overall, even after explicitly prompted to reflect on the quality and accuracy of the content, only eight participants (40%) reported noticing inaccuracies, with some of those participants providing direct and unequivocal responses about the existence of inaccuracies and others providing qualified responses (see below). However, the majority of participants in this second study (n = 12; 60%) did not report noticing errors or inaccuracies in the content even after an explicit prompt to reflect on their potential existence. Beyond whether

[6] For details, see Creswell (2007, pp. 148-154).
[7] For details, see Creswell (2007, pp. 202-209).

participants noticed discrepancies, we sought to explore *why* or *why not* discrepancies were detected, if detection occurred, *how* were they resolved, and if these regulation processes related to epistemic cognition.

Prior knowledge emerged as an important construct related to noticing discrepancies and regulation of resolution strategies. For those participants who reported not noticing discrepancies, many referred to their limited prior knowledge as a reason why they would not be able to do so. In response to being asked if they encountered any errors or inaccuracies, participants stated:

> Participant Number 01 (PN01): I wouldn't be able to tell because I don't specialize.

> PN17: Based on my prior knowledge of science which is pretty minimal I didn't [...] I don't think I would have caught them even if I was looking.

Further, beyond limited prior knowledge, participants also remarked on their capacity (or lack thereof) to evaluate science knowledge. Thus, we also interpreted that participants felt they lacked an epistemic self-efficacy or authority to question the science knowledge claims relayed in the content:

> PN16: I know I’m not good in sciences, so I just followed what it said.

We interpret these statements on prior knowledge and self-efficacy within theoretical frameworks of epistemic cognition (Greene, Azevedo, & Torney-Putra, 2008; Hofer & Pintrich,

1997; Muis, 2007). Specifically, we interpret these statements to be consistent with epistemic beliefs that the source and justification for knowing stems from external authority figures, like teachers or textbooks, in contrast to a belief that knowing stems from active personal construction using logic and evidence (Hofer & Pintrich, 1997). As some participants had noted, the content in the current study could be interpreted as being "presented in an authoritative manner" (PN18) and thus reduced the likelihood that its claims were critically scrutinized by all participants. Relatedly, an epistemic belief in the infallibility of science knowledge was reported as another reason not to question content:

> PN02: Science is kind of taken to be true [...] so I wasn't really looking for quality.

Taken together, low prior knowledge, low self-efficacy, and less constructivist epistemic beliefs are some potential mitigating factors that may account for the low rates of discrepancy detection observed in the current study (i.e., 40%).

Indeed, other participants in this study who reported noticing discrepancies but who qualified their responses nonetheless echoed these themes. Despite clearly experiencing interruptions to learning, some participants would report having engaged in self-doubt over doubting the content. For example, when encountering a discrepancy in the content, one participant concurrently noted:

> PN12: I'll read this over again because I'm clearly not paying enough attention. Oh my god I'm so unfocused.

Later, this participant recall retrospectively:

> PN12: I don't know if this is just me clearly not getting but there were sometimes when I thought the graph was wrong or had bad information, then I would get really confused and I would question my ability to think, so that would affect it. Then I guess if I found the topic more difficult, but if I had prior knowledge in a subject that would make it more easier.

Others who experienced interruptions to learning but stopped short of referring to them as flaws with the content likewise expressed episodes of self-doubt:

> PN15: Reading new information kind of challenges [my prior knowledge] ‘cause you’re wondering like you start to doubt yourself.

> Interviewer: Did you encounter any errors or inaccuracies?
> PN18: I think I did, I’m constantly putting it back on myself because I’m not sure, but I think that some of the graphs were backwards, showed the reverse of what the text was saying.
> Interviewer: Why would you put it back on yourself?
> PN18: If it was a test on [omitted] history, which I think I know really well, I would be like, no that’s straight up wrong, and I would consider myself a better authority than that, but when it comes to science I just don’t consider myself a better authority […] it could

> be right but I don’t see how it’s right but I’m willing to believe there’s an explanation that I just don’t have.

> PN08: I pretty much trusted it, which is funny because in my answer on the survey I was like, question everything! But then I really didn't question it, because I don’t consider myself knowledgeable but although I guess there were a couple parts that were contradicted but that doesn't mean like there isn't a connection.

These participants reported experiencing interruptions or discrepancies, but attributed these shortcomings in comprehension to personal efforts or characteristics rather than definitively attributing interruptions to flaws in the content. The self-doubt or the lack of doubt of the content we inferred seems to be again in reference to the privileged epistemic status or authority of the experimental content over the self-perceived relative lack of expertise.

In contrast, other participants provided direct and unequivocal responses about the existence of discrepancies in the text.

> PN04: Some of the contradictions seemed fairly obvious […] it was more pronounced on the questions where I had like some prior knowledge, where I was like I definitely know this and it's definitely wrong.

> PN15: As I went through and saw more discrepancies I was more inclined to stick with my own intuition rather than the writing.

Overall, it became apparent that there was a strong relationship between prior knowledge, self-confidence, and unequivocal declaration of noticing discrepancies. Although we did not collect data on self-efficacy, to further substantiated a part of this relationship, we correlated prior knowledge test scores with dummy codes of whether or not participants explicitly reported noticing a conceptual discrepancy and found a large positive correlation, $r = .58$, $p < .01$[8]. Thus, on the basis of triangulating our data, we conclude that noticing conceptual discrepancies in science content is related to prior knowledge. We further conclude on the basis of retrospective interviews that epistemic self-efficacy is likely also an active and influential construct worthy of future research.

Discrepancy resolution strategies. The themes described above – whether participants noticed discrepancies and how they interpreted their cause – are meaningful because they are intrinsically connected to the quality of resolution strategy that participants enacted. Indeed, when encountering discrepancies in the current study, participants initiated and regulated several diverse learning strategies. First, in reviewing screen and audio recordings of concurrent processing we did not observe any extraordinary pattern of resolution strategies for participants who did not report noticing discrepancies and for No Discrepancy content pages. For those who did express experiencing interruptions to their learning, participants enacted resolution strategies of various qualities. For example, some judged that the discrepant information is not relevant to achieving their goal to answer the question:

[8] Similar analysis between explicit remarks of discrepancy detection and epistemic cognitive variables showed no significant correlations, $p > .5$. We interpret this non-significant result as indication that constructivist epistemic cognitive variables are not a sufficient condition to enable greater explicit detection, however, given the small sample analyzed ($n = 20$), more empirical research is needed to verify this claim. Further, this non-significant result does not rule out other possible responses to processing discrepancies beyond explicit verbal remarks of detection, including experiencing disequilibrium while learning.

> PN12: Wait that probably makes sense…whatever it's not relevant to the question […] Ok just move on. I feel like I do understand and I don't understand.
>
> PN12: If I thought the graphs didn't make sense I brought it back to the goal [to answer the question].

We interpret these and similar statements in accordance with self-regulated learning theory, and more specifically, as skilled SRL as it both demonstrates accurate judgments of content relevancy and goal-directed behaviour (Azevedo et al., 2012, 2013).

Given processing times, fixations, and integrations between multimedia representations, we also focused on how participants in this study reported regulating these behaviours in concurrent and retrospective records. After noticing discrepancies, some participants reported deciding to quickly navigate away from the content given the irreconcilable nature of the current discrepancies:

> PN07: Once again I am just going to disregard this graph because it goes against everything that I've learned, let's see if I can find a direct quote in the text that contradicts the graph […] The graph doesn't make any sense so I'm going to stop trying to think about that.

> PN18: A couple of them I went through faster because I felt like I got it, and a couple of them the graph made no sense and I was like, without new info there is only so long I'm going to spend on something I don't understand so it doesn't make sense so I'm going to move on.

These concurrent and retrospective reports may explain differences observed in processing times and fixations on content from Study 1. Specifically, when encountering a conceptual discrepancy and making the judgment that the discrepancy is logically irreconcilable with available resources, the most effective SRL strategy under those conditions would be to proceed to new content. Based on Study 1, participants who appeared to adopt this study time allocation strategy were those who reported the strongest constructivist Variability beliefs.

Further, although some individuals may report adopting the same strategy, they may differ in the efficiency with which they enact them. For example, when encountering the same conceptual discrepancy on the same page, both Participant #11 and #15 enacted COIS strategy in an attempt to resolve it. However, they differed in their efficiency in doing so:

> PN11: [Inspecting graph] Oh, the number of protons shouldn't change, right? […] Let me reread this… [scrolls to view text] where's the part about protons never being lost […] "Notice when an ion is formed, the number of protons is unchanged." [scrolls to view graph] "Notice when an ion is formed, the number of protons is unchanged…" that doesn't match up [scrolls to view text] "Notice when an ion is formed, the number of protons is unchanged. It is the number of electrons that increases or decreases." [scrolls to view graph] So number of electrons, there, increases and decreases, so that seems to be consistent. Alright, so why [scrolls to view text] are the protons changing? Am I getting this wrong? [rereads text] skimming, skimming. Either I'm getting this wrong or the graph is incorrect. "Notice when an ion is formed, the number of protons is unchanged." [scrolls to view graph] Alright, hm. Perhaps I've got that wrong, but maybe not. [scrolls

to view text] I'm pretty sure protons never change though. Pretty sure. Ok cool. [exits content page] [129 seconds]

PN15: [Inspecting graph] But the protons should stay the same [scrolls to view text] it says that somewhere over here… yeah "Notice when an ion is formed, the number of protons is unchanged" [scrolls to view graph] so that's a little strange. And here, the cation, the number of electrons, 12, yeah the number of electrons would be 10, and the protons should stay the same, so that's right. But the number of protons should be the same [scrolls to view text] throughout. So "why are ions called charged molecules?" [rereading question][exits content page][60 seconds]

Overall, Participant #11 took more than twice as long to enact the same strategy and reach a similar conclusion as Participant #15 (129 seconds vs. 60 seconds, respectively). This is possibly due to ineffective or redundant re-reading or coordinating of informational sources that may also have represented a low rate of learning (Metcalfe, 2002). In the context of an unresolvable discrepancy relayed in the above example, such additional efforts may represent what Metcalfe and Kornell (2005) refer to as 'laboring in vain,' which in Study 1 individuals with constructivist epistemic cognition were more sensitive to and more likely to avoid rather than persevering on pages with discrepancies embedded in the text. Notably, with reference to the Study 2 sample, PN11 scored approximately on the 25th percentile of their constructivist Variability beliefs whereas PN15 scored approximately on the 90th percentile on the same measure. Further, PN15 engaged in effective goal reinstantiation by focusing back onto the question for the page, further displaying skilled SRL. This example also supports Pieschl et al.'s (2008) contention that

individuals with constructivist epistemic cognition are more sensitive to calibrate their efforts to the global learning task rather than individuals with less constructivist epistemic cognition who calibrate their efforts to the immediate and local learning contexts. We discuss this possibility and an integration of the findings from Studies 1 and 2 next.

General Discussion

The current studies sought to uncover specific empirical links between epistemic cognition and self-regulated learning within the context of processing conceptual discrepancies in a science multimedia environment. In brief, findings showed that individuals with constructivist epistemic cognition in science were more sensitive to adapting their cognitive and metacognitive learning processes in response to discrepancies in science texts, as evinced in fine-grained analysis of eye tracking, computer log-files, and metacognitive judgments, and specifically towards the direction of allocating less studying time and lower judgments of learning, supporting Hypothesis 1. Additionally, detection of discrepancies was linked to the combined effects of prior science knowledge and epistemic self-efficacy. Qualitative analysis from Study 2 provided further insights into how and why quantitative findings from Study 1 were obtained. We address each point in turn and conclude with a discussion of the limitations of the study and directions for future research.

Relations between Epistemic Cognition and Self-Regulated Learning

Awareness and adaptation to external conditions are pillars of self-regulated learning (Azevedo et al., 2012, 2013; Greene, Hutchison, Costa, & Crompton, 2012; Pieschl et al., 2012, 2013). This is especially important when processing inaccurate or discrepant knowledge claims, as misinformation on vital socio-scientific issues is increasingly becoming more prevalent online (Kata, 2012; Lewandowsky et al., 2012; Rapp & Braasch, 2014) and the misconceptions this

engenders remain formidable barriers to developing the public's understanding of science (Kahan, 2015; Sinatra et al., 2014). Thus, we explored how cognition about knowledge and knowing and self-regulated learning interacted within the context of detecting and resolving conceptual discrepancies in science multimedia.

For some time, researchers have proposed theoretical models that stipulate that constructivist epistemic cognition consistently yields more complex task definitions, more advanced learning standards and goals, use of deeper-level learning strategies, and more critical evaluations (Bromme et al., 2010; Greene et al., 2010; Muis, 2007). These predictions are gaining increasing evidentiary support by large-scale, primarily survey-based studies that have tested their validity (Chiu, Liang, & Tsai, 2013; Franco et al., 2012; Muis et al., 2015). However, the current studies contribute to the growing trend of in-depth, fine-grained research that relays findings that complicate this relatively straightforward depiction of the relations between EC and SRL (Hammer & Elby, 2002, 2003, 2010; Pieschl et al., 2008, 2014). With the addition of the second qualitative study, we were able to generate explanations for how and why quantitative patterns emerged and novel hypotheses that future research can address. Thus, the current findings refine and advance theories of EC and SRL and extend these frameworks to consider the increasingly important context of processing conceptual discrepancies.

Specifically, on pages without discrepancies, we did not observe meaningful patterns of relations between epistemic cognition and SRL variables, in contrast to pages with discrepancies in the text. We surmised this difference reflected that individuals' epistemic cognition was not relevant or notably active while processing relatively straightforward expository science texts. However, when individuals in these studies encountered pages with text discrepancies, they expressed a range of reactions.

Participants with stronger constructivist Texture and Variability beliefs were more sensitive to such discrepancies compared to their less constructivist counterparts, and responded with lowered study time, fewer instances of coordination of informational sources, and lower judgments of learning, which are key variables in self-regulated learning (Dunlosky & Metcalfe, 2009; Metcalfe, 2002; Metcalfe & Kornell, 2005). By virtue of being more sensitive to contextual conditions such as discrepancies participants with constructivist epistemic cognition demonstrate higher levels of metacognitive awareness and control. These findings are both consistent with previous research and support theories that show relations between EC and SRL (Bromme et al., 2010; Muis, 2007; Pieschl et al., 2014).

Individuals who believed in vague and imprecise science knowledge did provide lower confidence of judgments of learning for texts that contained discrepancies compared to texts without discrepancies. This finding suggests that individuals were aware of increased processing difficulty associated with text discrepancies, and that individuals who believed in vague knowledge were especially sensitive to fluctuations in increased processing difficulty. Viewing knowledge as more complex is linked to perceiving tasks as more complex generally (Pieschl et al., 2013), yet the current findings demonstrate that beliefs about the Texture of knowledge also relate to calibrating post-task evaluations as well, which theoretically influences subsequent enactment of strategies in SRL models (Azevedo et al., 2012, 2013; Dunlosky & Metcalfe, 2009; Winne & Hadwin, 1998, 2008).

Further, individuals who believed in dynamic science knowledge responded differently to conceptual discrepancies by reading for a shorter time compared to their counterparts who believed in static science. Other items on the CAEB Variability factor – “completed,” “irrefutable,” “permanent” – indicate that a strong belief in static science knowledge may be

associated with a belief that science represents enduring truths that have stood the test of time and are infallible. Presumably, such a belief would underprepare an individual to anticipate discrepancies in science texts and persist in trying to achieve resolution if they did, believing that they themselves were mistaken. Conversely, an individual who believed in temporary, refutable, and uncompleted science knowledge would be more likely to anticipate discrepancies, interpret them as such, and enact strategies appropriate to the situation, like proceeding on to new content. An analogous strategy of study time allocation was described in the region of proximal learning model by Metcalfe (2002). Based on the Study 1 findings, one possibility is that individuals with constructivist Variability beliefs more readily apprehended an unresolvable knowledge discrepancy and more efficiently allocated their time to achieve their overall learning goal.

Qualitative analyses from Study 2 showed that, except for a small subsample in the second study, most did not explicitly detect that an error had occurred. For those that did detect an error, they were dividedly equally between those who explicitly mentioned that the content contained a discrepancy and those that did not explicitly doubt the veracity of the content but who reported experiencing an interruption to their learning, similar to previous studies that sought to induce cognitive disequilibrium or confusion (D'Mello et al., 2014). A primary objective of the current studies was to determined if epistemic cognition distinguished these three subgroups and their range of responses to discrepancies. Based on our quantitative and qualitative analyses, what appeared to discriminate between these subgroups was their level of prior science knowledge and epistemic self-efficacy.

Individuals reported that their level of prior knowledge facilitated or constrained how quickly they could process and evaluate the content. One possibility is that existing knowledge schema allowed high prior knowledge students to engage in relatively quick knowledge

verification behaviour. This entails checking incoming information against what is already known to evaluate its consistency and accuracy (Moos & Azevedo, 2008) and potentially freeing up cognitive resources to devote to metacognitvely monitoring the quality of the content and comprehension difficulties (Hacker, 2014; Wang & Chen, 2014). In contrast, lacking such schema, low prior knowledge students may have had to engage in relatively slower and more cognitively demanding knowledge construction behaviours.

Another possibility related to participants' epistemic self-efficacy with evaluating science texts, which appeared inextricably linked to their prior science knowledge. In our discussion, we use the term epistemic self-efficacy to refer to individuals' confidence in their ability to question the veracity of knowledge claims conveyed by external sources and themselves as the source of knowledge. This construct is therefore closely linked to theories that discuss individuals' beliefs about the source of knowledge (Belenky, Clinchy, Goldberger, & Tarule. 1986; Chinn, Buckland, & Samarapungavan, 2011). The finding that self-efficacy and prior knowledge are linked and relevant factors for learning is consistent with previous research that shows the confluence of confidence, self-efficacy, and prior knowledge function in parallel to influence subsequent achievement (Cordova, Sinatra, Jones, Taasoobshirazi, & Lombardi, 2014). Beyond prior knowledge – which Hacker (2014) points to as one explanation for why individuals fail to detect textual problems – if epistemic self-efficacy were to function in tandem with constructivist Variability beliefs, such as acknowledging the tentativeness of science knowledge, then self-confidence in one's ability to adjudicate between valuable and spurious knowledge may be heightened. The combination that results may lead to a strong stance with which to critically and efficiently assess the epistemic value of new content. However, overconfidence in epistemic self-efficacy may offer one account for the negative effects that stem from individuals relying on

personal justification over expert knowledge (Bråten, Ferguson, Strømsø, & Anmarkrud, 2013; Kahan, 2014). Overall, these findings provide specific evidence of how epistemic cognition interacts with learning conditions to relate to the enactment phase of SRL.

In sum, the current studies found specific relations between epistemic cognition and self-regulated learning as individuals studied science multimedia with knowledge discrepancies. Specifically, using a multi-study, mixed method design, we obtained evidence that epistemic cognition relates to behavioural measures of self-regulated learning, evinced in eye tracking, study times, and metacognitive judgments, in the context of processing conceptual discrepancies within texts. Taken together, the two studies reported are among the first to provide empirical evidence for relations between epistemic cognition and specific phases and components of self-regulated learning at a fine-grained and process level of analysis. Overall, we found several important findings: a belief in variable science knowledge related to lower text processing times and lower enactment of coordinating multiple media; a belief in subjective and ambiguous science knowledge related to lower confidence judgments of learning; and prior knowledge and epistemic self-efficacy in a specific domain emerged as important themes for detection of discrepancies and enactment of resolution strategies.

Unique Contributions of the Current Studies

Findings from the current studies present unique theoretical and methodological contributions. In particular, with our use of fine-grained measures of self-regulated learning we were able to show how theories of the relations between EC and SRL could be refined by specific phases (e.g., enactment) and components (Retrospective Confidence Judgments). Additionally, from qualitative analysis we were able to discern other active and relevant constructs, like epistemic self-efficacy, heretofore not yet directly investigated. Further, we

extend theoretical frameworks of EC and SRL to the increasingly important context of processing conceptual discrepancies. In this effort, we respond to calls to assess the functioning of EC with research that adopts a "double track" approach (Bromme et al., 2010) that reflects its fine-grained, contextualized nature (Hammer & Elby, 2002, 2010). Specifically, this approach pairs an analysis of EC and related learning processes with an analysis of the nature learning content to ascertain how well individuals adapt the former to suit the latter (Bromme et al., 2010). In so doing, researchers obtain a clearer picture of how EC might affect SRL adaptation. In terms of methodology, we were able to extract and triangulate fine-grained analysis from eye tracking data, computer log-files, metacognitive judgments, and concurrent and retrospective verbal reports to inform our conclusions about relations between EC and SRL.

Limitations and Future Directions

The conclusions of the current studies are limited in several ways. First, the small sample sizes limit statistical power and generalizability of the findings. Therefore, caution is recommended when interpreting the results. Second, the psychological responses to the current conceptual discrepancies may not encompass all possible reactions to discrepant knowledge. Beyond conflicts relayed within a single source, other discrepancies include conflicts between multiple sources (Bråten, Anmarkrud, Brandmo, & Strømsø, 2014) and conflicts between source and individual knowledge, most clearly exemplified in refutational texts (Kendeou, Smith, & O'Brien, 2013; Kendeou, Walsh, Smith, & O'Brien, 2014). Despite this potential limitation, we note that experimentally inducing interruptions to learning is a common and useful research paradigm (e.g., D'Mello et al., 2014; Hacker, 2014) to study how individuals initiate and regulate important resolution strategies, which are valuable to investigate in their own right. Further, as

individuals gain access to online content that is increasingly authored by non-refereed sources, encountering discrepancies may become more prevalent.

Future research should test the utility of epistemic self-efficacy as an active and influential construct for learning about controversial socio-scientific issues, such as climate change and vaccinations. Further, precisely delineating the pattern of epistemic cognition and self-regulated learning that are adaptive in which context is needed to design effective interventions (Bromme et al., 2010). Educationally, the current findings highlight the importance of epistemic cognition on quality learning and provide variables of self-regulated learning for interventions to target and measure as metrics for success (e.g., confidence to question content, vigilance in detecting discrepancies, coordinating informational sources to resolve them) to support the development of 21st century literacies. However, future work should examine how the current body of empirical findings can be fruitfully applied to other naturalistic environments.

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Table 1
Eigenvalues, Cumulative Percentage of Explained Variance, and Squared Canonical Correlations for each Canonical Function.

Function	Eigenvalue	Percent Variance Explained	Squared Canonical Correlation
1	**.74**	**74.52**	**.42**
2	.17	17.39	.15
3	.08	8.09	.07

Table 2
Structure Coefficients for the First Predictor Canonical Variate.

Predictor Variable	Function 1
Prior Knowledge	-.62
Variability	-.07
Texture	.82

Table 3
Structure Coefficients for the First Dependent Canonical Variate.

Dependent Variable	Function 1
JOL_T	-.50
JOL_G	-.52
RCJ	-.59
COIS	-.47
PAGE TIME	.31

Table 4

Descriptive and correlation statistics between epistemic cognition and metacognitive judgments, page studying times, and eye-gaze pattern on No Discrepancy pages.

	1	2	3	4	5	6	7	8	9
1. Variability [a]	4.71 (.89)	.14	.28	-.03	.11	.02	.06	-.09	-.16
2. Texture [a]		2.74 (.63)	-.06	.04	-.19	-.42**	-.26	.17	-.16
3. Prior Knowledge [b]			.46 (.14)	.01	.23	.11	.10	-.21	.20
4. EOL [c]				63.93 (16.62)	.52**	.19	.40**	.13	.02
5. DJOL text [c]					74.41 (15.34)	.56**	.74**	.01	.31*
6. DJOL graph [c]						79.05 (15.82)	.63**	-.14	-.04
7. RCJ [c]							71.55 (15.64)	.11	.18
8. Study Time [d]								138.71 (51.49)	.40**
9. COIS [e]									2.99 (.81)

Note. Variables represent data specific to No Discrepancy pages; Means and standard deviations displayed on the diagonal; Significance of Variability and Texture coefficients estimated with one-tailed probability; EOL = Ease of Learning; DJOL = Delayed Judgment of Learning; RCJ = Retrospective Confidence Judgment; Study Time = Average Study Duration; COIS = Coordinating Informational Sources.

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

[a] 0-7 Likert scale

[b] proportion correct

[c] 0-100 Likert scale

[d] in seconds

[e] frequency count, square-root transformation

Table 5
Descriptive and correlation statistics between epistemic cognition and metacognitive judgments, page studying times, and eye-gaze pattern on Within-Text discrepancy pages.

	1	2	3	4	5	6	7	8	9
1. Variability [a]	4.71 (.89)	.14	.28	.02	-.01	.06	.04	-.32*	-.28*
2. Texture [a]		2.74 (.63)	-.06	-.08	-.38**	-.36**	-.42**	.03	-.29*
3. Prior Knowledge [b]			.46 (.14)	.15	.05	.09	.09	-.30*	.14
4. EOL [c]				66.55 (18.10)	.39**	.46**	.54**	.17	.08
5. DJOL text [c]					73.10 (13.57)	.73**	.73**	.14	.12
6. DJOL graph [c]						80.83 (14.77)	.64**	.17	.18
7. RCJ [c]							75.60 (14.32)	.05	-.01
8. Study Time [d]								131.02 (47.59)	.49**
9. COIS [e]									3.49 (1.08)

Note. Variables represent data specific to Within-Text discrepancy pages; Means and standard deviations displayed on the diagonal; Significance of Variability and Texture coefficients estimated with one-tailed probability; EOL = Ease of Learning; DJOL = Delayed Judgment of Learning; RCJ = Retrospective Confidence Judgment; Study Time = Average Study Duration; COIS = Coordinating Informational Sources.
* $p < .05$. ** $p < .01$.
[a] 0-7 Likert scale
[b] proportion correct
[c] 0-100 Likert scale
[d] in seconds
[e] frequency count, square-root transformation

Table 6

Descriptive and correlation statistics between epistemic cognition and metacognitive judgments, page studying times, and eye-gaze pattern on Between Text and Graph discrepancy pages.

	1	2	3	4	5	6	7	8	9
1. Variability [a]	4.71 (.89)	.14	.28	-.18	.07	-.19	.10	-.23	-.20
2. Texture [a]		2.74 (.63)	-.06	-.05	-.21	-.18	-.26*	.06	-.20
3. Prior Knowledge [b]			.46 (.14)	.01	.30	-.08	.41**	-.31*	.08
4. EOL [c]				60.60 (14.95)	.46**	.09	.48**	.18	.01
5. DJOL text [c]					77.86 (13.26)	.10	.75**	.03	-.13
6. DJOL graph [c]						60.24 (15.89)	-.02	-.11	-.14
7. RCJ [c]							73.81 (18.86)	-.05	-.07
8. Study Time [d]								140.21 (53.26)	.32*
9. COIS [e]									2.87 (1.02)

Note. Variables represent data specific to Between Text and Graph discrepancy pages; Means and standard deviations displayed on the diagonal; Significance of Variability and Texture coefficients estimated with one-tailed probability; EOL = Ease of Learning; DJOL = Delayed Judgment of Learning; RCJ = Retrospective Confidence Judgment; Study Time = Average Study Duration; COIS = Coordinating Informational Sources.
* $p < .05$. ** $p < .01$.
[a] 0-7 Likert scale
[b] proportion correct
[c] 0-100 Likert scale
[d] in seconds
[e] frequency count, square-root transformation

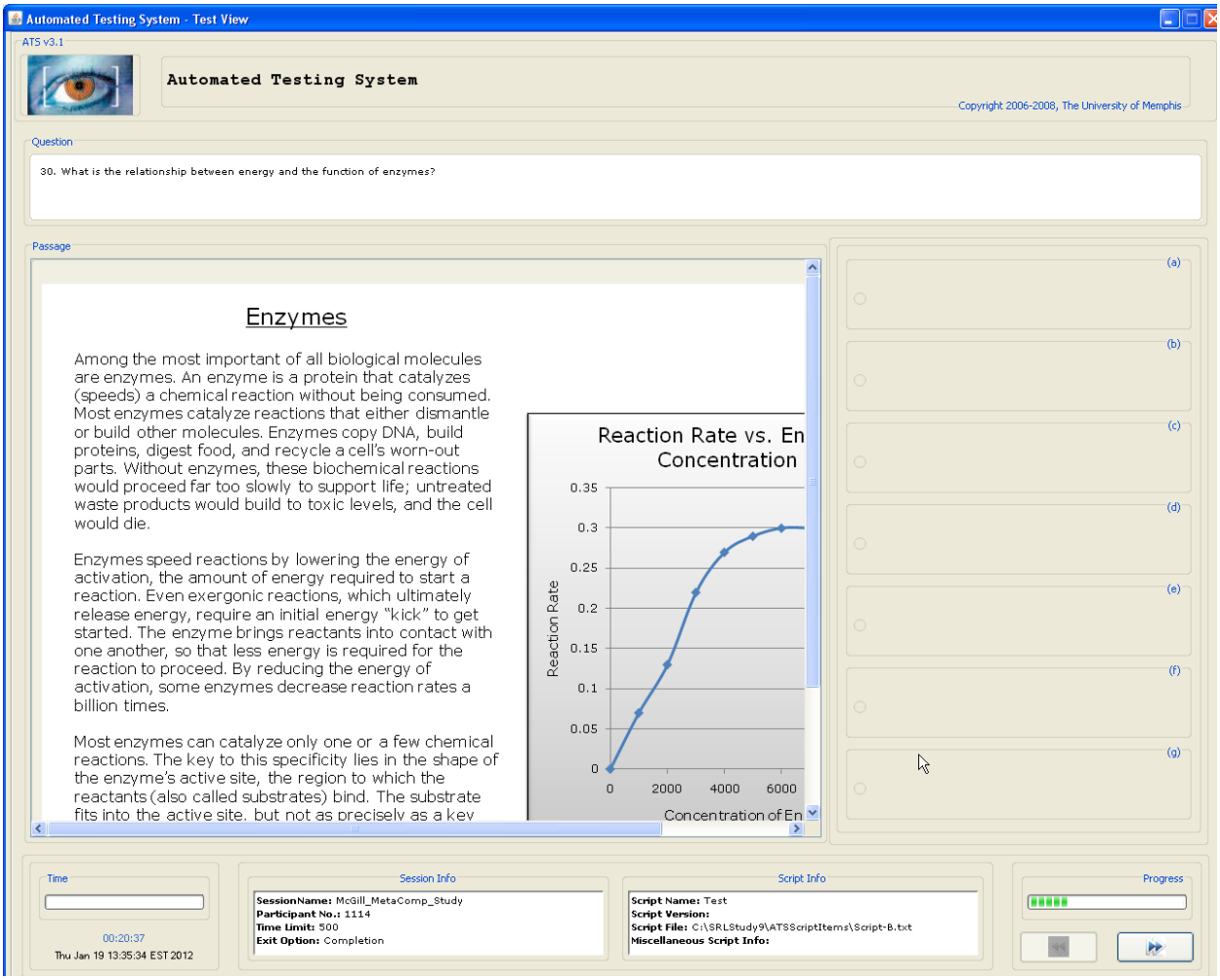

Figure 1. Screenshot of multimedia learning environment. This page on enzymes contained a conceptual discrepancy within the text between the first and last sentences in the 2nd paragraph.

Appendix A
Science Test

Please circle the response that BEST answers each of the following questions. Choose ONE and only one answer for each question. Please be sure to answer EVERY question to the best of your ability.

1. The process in which a plant loses water through its leaves is called:
   a. Photosynthesis
   b. Precipitation
   c. Respiration
   d. Percolation
   e. Transpiration
2. An atom of Silicon has a mass number of 29 and an atomic number of 14. How many neutrons does it have?
   a. 14
   b. 15
   c. 43
   d. 28
   e. 29
3. Which of the following is constant in all inertial reference frames?
   a. Time
   b. Mass
   c. Length
   d. Kinetic Energy
   e. Speed of Light
4. The magnetism of a substance is due essentially to which of the following?
   a. The magnetic properties of its atoms
   b. The arrangement of its atoms
   c. The position of its poles
   d. Both A & B
   e. All of the above
5. Which of the following is paired incorrectly?
   a. HCL – strong acid
   b. HNO_3 – weak acid
   c. $Ba(OH)_2$ – strong base
   d. HI – strong acid
   e. NH_3 – weak base
6. According to the Ideal Gas Law, which of the following may decrease when the volume of a gas is increased?
   a. The temperature of the gas

b. The number of molecules in the gas
c. The pressure of the gas
d. The average kinetic energy of the gas molecules
e. The atomic number of atoms in the gas

7. A plant in a windowsill bends toward the light. This is an example of:
   a. Photoperiodism
   b. Thigmotropism
   c. Gravitropism
   d. Photorespiration
   e. Phototropism
8. The moon is in a nearly circular orbit above the Earth's atmosphere. Which statement is true?
   a. It is in equilibrium and has no net force
   b. It has constant velocity
   c. It continues to use up its energy rapidly like a spaceship and is falling back to Earth
   d. It is accelerating toward Earth
   e. Its acceleration is in the same direction as its velocity
9. Almost all interactions of matter result from the operation of which of the following forces?
   a. Gravitational force
   b. Electromagnetic force
   c. Nuclear force
   d. All of the above
   e. None of the above
10. When light from the air enters a glass prism, which of the following changes?

    I. The speed of the light
    II. The frequency of the light
    III. The wavelength of the light

    a. I only
    b. II only
    c. I & II only
    d. I & III only
    e. I, II, and III
11. What is the empirical formula of a compound that contains 0.05 moles of Magnesium (Mg), 0.05 moles of Sulfur (S) and 0.20 moles of oxygen?
    a. MgSO
    b. $MgSO_2$
    c. $MgSO_3$

d. $MgSO_4$
e. MgS_2O_2

12. How many gametes can be produced by an individual with the genotype XXYyZz?
    a. 2
    b. 4
    c. 6
    d. 8
    e. 12
13. Balanced chemical equations imply which of the following?

    I. The number of molecules are conserved in chemical change
    II. The number of atoms are conserved in chemical change
    III. Mass is conserved in chemical change

    a. I only
    b. II only
    c. I & III only
    d. II & III only
    e. I, II, & III
14. What kind of energy includes light and radio waves?
    a. Radiant
    b. Heat
    c. Electrical
    d. Mechanical
    e. Nuclear
15. The function of the sinoatrial node is to:
    a. Create red blood cells
    b. Stimulate cardiac muscles to contract in a regular and controlled rhythm
    c. Remove carbon dioxide from the blood
    d. Separate the atria from the ventricles
    e. Manufacture antigens
16. Which of the following phrases best describes convection?
    a. An exchange of particles that increases the disorder in a system
    b. An exchange of heat between a hot solid object and a cold solid object
    c. An exchange of heat between warmer and cooler regions in a gas or liquid
    d. An exchange of gas particles between higher pressure and lower pressure regions
    e. An exchange of momentum between a moving particle and a still particle in a collision
17. Which of the following are methods of heat transfer?

I. Conduction
II. Radiation
III. Diffraction

a. I only
b. II only
c. I & II only
d. I & III only
e. I, II & III

18. Mitosis and meiosis are similar because they both:
    a. Result in the production of gametes in humans
    b. Involve independent assortment
    c. Result in the production of two identical daughter cells
    d. Involve replication of DNA
    e. Have two cell divisions
19. Which of the following statements about catalysts is INCORRECT?
    a. They have no effect on the value of the equilibrium constant
    b. They increase the amount of product present at equilibrium
    c. They provide an alternate pathway for effective collisions
    d. They lower the activation energy
    e. They are reusable since they are regenerated at the end of the reaction
20. If a homogeneous mixture is combined with a heterogeneous mixture, what type of matter would result?
    a. A homogeneous mixture
    b. A heterogeneous mixture
    c. A pure substance
    d. The two mixtures will not combine because they are too different
    e. A new type of matter will result that has not yet been classified

Appendix B
CAEB Instrument

Variability of Knowledge								
Stable*	1	2	3	4	5	6	7	Unstable
Dynamic	1	2	3	4	5	6	7	Static
Temporary	1	2	3	4	5	6	7	Permanent
Flexible	1	2	3	4	5	6	7	Inflexible
Completed*	1	2	3	4	5	6	7	Uncompleted
Refutable	1	2	3	4	5	6	7	Irrefutable
Open	1	2	3	4	5	6	7	Closed
Texture of Knowledge								
Confirmable	1	2	3	4	5	6	7	Unconfirmable
Definite	1	2	3	4	5	6	7	Ambiguous
Exact	1	2	3	4	5	6	7	Vague
Objective	1	2	3	4	5	6	7	Subjective
Precise	1	2	3	4	5	6	7	Imprecise
Sorted	1	2	3	4	5	6	7	Unsorted
Structured	1	2	3	4	5	6	7	Unstructured
Superficial	1	2	3	4	5	6	7	Profound
Discovered	1	2	3	4	5	6	7	Negotiated
Absolute	1	2	3	4	5	6	7	Relative

*Reverse coded

Bridging Text

Chapter 3 presented two empirical studies that examined the fundamental detection and resolution strategies individuals engage in when encountering discrepant information. Notably, this manuscript adopted a mixed method design to triangulate the findings from quantitative analysis of eye tracking and metacognitive judgments and qualitative analysis of concurrent and retrospective reports. Findings from these studies showed that detection and resolution strategies varied as a function of epistemic beliefs and other important learner characteristics. Thus, within the broader context of the dissertation, Chapter 3 presents themes on the application of new methodologies to the study of epistemic cognition while learning about controversial knowledge. These findings provided insights into fundamental learning processes related to epistemic cognition and controversial knowledge. However, these were focused on cognitive and metacognitive aspects and therefore how epistemic cognition relates to other important educational processes like emotion remain unknown. Chapter 4 addresses these shortcomings by reviewing literature that introduces the concept of epistemic emotions and presenting an empirical study that shows that this set of emotions mediates the relations between epistemic cognition and learning from multiple conflicting documents. Beyond examining controversial knowledge and emotions, Chapter 4 also addresses a third theme of the current dissertation and responds to limitations identified in Chapter 2 by applying new methodologies, specifically, text-mining software to examine reading comprehension and the inclusion of mediational analysis.

Chapter 4

Manuscript #2

Epistemic Beliefs and Epistemic Emotions Predict Learning from Multiple Conflicting Texts

Trevors, G., Muis, K., Pekrun, R., & Sinatra, G. M. (revise and resubmit). Epistemic beliefs and epistemic emotions predict learning from multiple conflicting texts. *Journal of Educational Psychology.*

Abstract

Within the context of learning from conflicting texts, beliefs about knowledge and knowing and emotional responses may be important factors for success. The current study examined the mediational role of epistemic emotions between epistemic beliefs and learning from multiple *conflicting* documents about a controversial topic. Undergraduate university students ($N = 282$) self-reported their epistemic beliefs and were given three conflicting documents to read. Immediately following each document, they self-reported the emotions they experienced. Two measures of learning while reading were extracted from participant-generated summaries. Path analyses revealed that epistemic beliefs were consistent predictors of epistemic emotions, which in turn predicted surface and textbase levels of reading comprehension. Complex mediational relations between epistemic beliefs and emotions were observed on comprehension measures as well as unanticipated effects of various emotions. Theoretical and methodological implications are discussed for research on the relations between epistemic beliefs, emotions, and learning from multiple conflicting documents.

Keywords: multiple conflicting texts; epistemic beliefs; emotions; learning from texts.

With near ubiquitous access to evolving and, at times, controversial information, individuals in the 21st century are presented with new challenges to learning about socially relevant science content. Rather than a lack of knowledge, chief among these challenges are biases in reasoning and evaluation of knowledge claims (Joslyn & Haider-Markel, 2014; Kahan, 2015; Kahan, Peters, Dawson, Slovic, 2013; Sinatra, Kienhues, & Hofer, 2014), particularly in contexts with multiple conflicting perspectives (Bråten, Britt, Strømsø, & Rouet, 2011; Hart & Nisbet, 2012; Lewandowsky, Ecker, Seifert, Schwarz, & Cook, 2012). Nevertheless, addressing these challenges is vital. Overcoming biases in reasoning and reconciling diverse perspectives empowers individuals to make informed decisions about issues of personal and global importance, like climate change, vaccinations, and genetically modified foods.

How individuals learn from conflicting information is affected by their expectation that answers are simple or complex, definitive or tentative, derived through personal reflection or via experts, or corroborated by multiple sources (Bråten, Anmarkrud, Brandmo, & Strømsø, 2014). However, while contending with dissenting viewpoints, these expectations about the nature of knowledge and knowing may be challenged, threatened, upended, or reaffirmed. The degree of incongruity of such experiences with individuals' personal beliefs may cause them to feel surprised, curious, frustrated, confused, anxious, or even bored (Muis et al., 2015), which in turn affects learning and academic achievement (Pekrun, 2006; Pekrun & Linnenbrink-Garcia, 2014).

Debates on socio-scientific issues are predominantly experienced via reading different online sources presenting multiple conflicting documents (Bakshy, Messing, & Adamic, 2015; Barberá, 2014; Gentzkow & Shapiro, 2011; Kata, 2012). Inherent in learning from multiple documents are the psychological processes involved in extracting and constructing a coherent mental representation of the information contained across texts. Across many studies,

individuals' beliefs about knowledge and knowing – their epistemic beliefs – and the emotions they experience during reading are known to separately relate to the outcomes of knowledge construction and learning while reading (Barzilai & Eshet-Alkalai, 2015; Bohn-Getter & Rapp, 2014; Bråten, Anmarkrud et al., 2014; Bråten, Ferguson, Strømsø, Anmarkrud, 2014; Graesser & D'Mello 2012; Daley, Willet, & Fischer, 2014). However, what remains relatively unknown are what mediational mechanisms account for the effect of epistemic beliefs on learning from reading and if emotions play a role in this process. Thus, in the current study we are among the first to test the propositions that, in the context of reading multiple conflicting knowledge claims, epistemic beliefs give rise to emotional experiences that act as one such set of mediational mechanisms between epistemic beliefs and subsequent learning from multiple conflicting science texts.

In the first section, we outline theories of learning from reading, including a proposed framework that integrates epistemic beliefs and multiple document comprehension. Next, we review theories and empirical evidence for relations between emotions and learning from multiple conflicting documents. Then we review theories and evidence supporting the predictive relations between epistemic beliefs, emotions, and learning from multiple documents to inform the hypotheses of the current study.

Learning from Conflicting Documents

Learning from multiple documents is both a quantitative and qualitative extension of single text comprehension. Commonly, successful learning from reading is defined by the construction of a coherent representation of the text information in a reader's memory (W. Kintsch, 1988, 1998) The construction-integration model assumes the reader engages in various cognitive processes on text information to transform it into mental representations of varying

levels: the *surface* level represents the explicit wording and grammar of the text; the *textbase* level represents the meaning of each clause in the text; and the *situation model* represents what the text is about in its entirety.

To arrive at such mental representations, readers will engage in several online processes, which are performed in service of the construction of a coherent mental representation of what the text is about. Many factors influence inference generation processing, including text properties (e.g., text structure, rhetorical devices), reader characteristics (e.g., epistemic beliefs, emotions, working memory), and environmental factors (e.g., assigned tasks; Kendeou & Trevors, 2012; Trevors & Muis, 2014). The types of these processes and the extent to which they are engaged determine the quality of the resultant mental representations. The attempt to reconcile diverse viewpoints expressed in multiple documents is a new and real challenge to present-day internet-based learners when they attempt to form a coherent understanding of a topic of interest.

To understand how reading comprehension processes form various mental representations with multiple documents, Bråten and colleagues (2011) describe and build from the Multiple Documents – Task-based Relevance Assessment and Content Extraction model (MD-TRACE; Rouet & Britt, 2011). Specifically, in addition to the surface, textbase, and situation model levels contained in the construction-integration model, the MD-TRACE model contains an additional level of representation, the *documents model*, which is composed of two components: the *intertext model*, which represents the relationships readers form between sources (e.g., information on authors, venues) and between text contents and sources; and the *situations model*, which represents the integration of the information or situations described across multiple documents (Bråten et al., 2011). When provided with multiple texts on the same

topic from different perspectives or tasks to integrate texts, readers will often attempt to form the documents model level of representation. Readers engage in strategic processing to form the documents model through corroborating information across texts to detect consistencies or discrepancies (Bråten et al., 2011).

The MD-TRACE model accounts for a large body of empirical findings on learning from multiple conflicting documents. For example, spontaneous processing of source information while reading about a controversial topic relates to references to those sources in subsequent essays (Strømsø, Bråten, Britt, & Ferguson, 2013). This increased sourcing may be related to noticing and attending to discrepancies across multiple documents. When summarizing consistent or discrepant narratives, readers included information about the source of the stories twice as often when reading discrepant stories as when reading consistent stories (Braasch, Rouet, Vibert, & Britt, 2012). Relatedly, Stadtler, Scharrer, Brummernhenrich, and Bromme (2013) found that multiple documents led to better memory for conflicting information than a single document. Memory of conflicting information may also be affected by the reader's evaluation of the texts. Kobayashi (2014) found that the credibility of the text and, to a lesser extent, the credibility of the source affected the inclusion of controversial information from texts in subsequent essays.

Further, Strømsø, Bråten, and Britt (2010) found that memory for the original source of information from multiple conflicting documents predicted achievement on tests of comprehension across and within texts. The authors concluded that attending to and remembering source information, like author credentials and venue of publication, from multiple conflicting documents assisted readers in their attempt to delineate the conflict between diverse explanations, thereby aiding to represent and structure a coherent documents model (Strømsø,

Bråten, & Britt, 2010). In sum, being presented with multiple conflicting documents from various sources and of varying credibility affects subsequent memory and learning of controversial knowledge. Building from this line of research, Bråten and colleagues (2011) describe how readers' beliefs about knowledge and knowing are predicted to affect how conflicting information is more specifically processed and represented in memory.

Epistemic cognition and learning from multiple conflicting documents

Bråten et al. (2011) describe how cognitive resources available to readers are brought to bear on learning from multiple documents. In particular, the authors offer a theoretical account of how readers' epistemic cognition affects coherence-building processes. Epistemic cognition refers to cognitive manifestations of individuals' epistemic beliefs (Chinn, Buckland, & Samarapungavan, 2011; Greene & Yu, 2014; Sinatra & Chinn, 2012; Sinatra et al., 2014), which can be specific to academic, domain, or topic knowledge (Muis, Bendixen, & Haerle, 2006). For example, individuals may believe knowledge to be isolated facts (i.e., *simplicity* dimension) that, once discovered, remain unaltered by time or human intervention (i.e., *certainty* dimension). To learn such knowledge requires passive attention to experts and authorities in various fields and faithful recall from memory of relayed facts or reflection on personal opinion (i.e., *source from passive construction* and *justification by personal opinion* dimensions). In contrast, epistemic beliefs may also broadly comprise a perception of knowledge as networks of interconnected facts organized into broader concepts (i.e., *complexity* dimension). Such knowledge is understood to evolve over time and become more refined with additional reasoning and new evidence (i.e., *uncertainty* dimension). Rather than the source and justification for knowing stemming from expert testimony or personal opinion, these individuals believe the nature of knowing to require justification by rules of inquiry and to not only accurately recall a knowledge claim, but to be

able to evaluate and corroborate the reasons and evidence in support of that knowledge claim (i.e., *source from active construction* and *justification by inquiry* dimensions; Bråten et al., 2011; Muis, 2007).

Bråten and colleagues (2011) expand the MD-TRACE model to include the influence of epistemic beliefs on reading comprehension processes and products. They propose that beliefs in the complexity and uncertain nature of knowledge facilitate the construction of a coherent and integrated representation across texts. A reader who espouses beliefs in complex and uncertain knowledge would perceive the task of reading multiple conflicting documents as a challenge to integrate and corroborate disparate information, rather than a simple search for and catalogue of isolated answers that cannot be disputed. Following from this task definition, such a reader would likely engage in processes that support the completion of this task: processing sources more actively that acknowledge complexity over simplicity, monitoring and representing in memory corroboration or disagreements among sources, generating bridging inferences across texts, and producing an abridged overview of the texts. Finally, the reader would reflect on his/her understanding and would be satisfied when it reflects an integrated and coherent perspective beyond simple and stable facts; failing this, the reader would return to the texts for additional processing.

Further, beliefs about the source and justification for knowing are likewise proposed to be influential in multiple document comprehension. Bråten and colleagues (2011) differentiate among the source of knowledge as transmitted by experts versus constructed by the self. Those who believe that knowledge is transmitted by experts define the task of reading multiple documents as seeking to understand expert opinion. To accomplish this, individuals differentiate among sources to give prominence to trustworthy information and to process it more actively. In

contrast, a belief in the self as the source of knowledge is predicted to be linked to defining the task as forming or confirming a personal view. Thus, external perspectives are generally viewed with skepticism and less effort is made to differentiate between more and less trustworthy sources. Additionally, those who believe that knowledge claims are justified via critical thinking, inquiry practices, and validation through corroboration of multiple pieces of evidence attend to the conceptually overlapping elements in the descriptions between texts and generate bridging inferences to mentally represent those relations. Such processes are predicted to result in a more thoroughly integrated documents model (Bråten et al., 2011).

Empirical evidence supports the notion that epistemic beliefs relate to learning from multiple documents. For example, across a series of studies, Bråten and colleagues have found that beliefs in justifying knowledge claims with multiple sources, logic, and prior knowledge, rather than personal opinion or experience, positively predicted text recall and related to more complete summaries of and higher quality written arguments based on multiple documents (Bråten, Anmarkrud et al., 2014; Bråten, Ferguson et al., 2014; Bråten & Strømsø, 2010; Kammerer, Bråten, Gerjets, & Strømsø, 2013). Additionally, beliefs in the complexity and tentativeness of knowledge have been found to relate to comprehension across documents (Bråten & Strømsø, 2010). These results were magnified when readers were given a task to summarize or generate an argument based on multiple texts, as opposed to a task to form a general comprehension (Gil, Bråten, Vidal-Abarca, & Strømsø, 2010). Breaking justification into multiple sub-dimensions, Bråten, Ferguson, Strømsø and Anmarkrud (2013) further found that justification by authority and justification by multiple sources uniquely contributed to multiple document comprehension, whereas personal justification did not. Moreover, experimental studies that gave direct instruction to individuals about how to evaluate the epistemic reliability and

veracity of multiple online sources resulted in essays that used information from texts in a more sophisticated argument structure (Mason, Junyent, & Tornatora, 2014).

In sum, there is a growing body of empirical evidence that supports theoretically predicted relations between epistemic cognition and various components of learning from multiple documents. Self-reported epistemic beliefs are found to relate to achievement on tests of subsequent multiple document comprehension, and epistemic cognitive processes are evident as an active component of reading multiple documents (Ferguson & Bråten, 2013; Greene, Yu, & Copeland, 2014; Kammerer et al., 2013). However, as noted by Schraw (2013), despite positive correlations between epistemic beliefs and a host of academically-related outcomes, the effects tend to be small. One possible explanation for this finding is that the effects of epistemic beliefs may be better observed as transmitted via mediators (Zhao, Lynch, & Chen, 2010). As Bråten et al. (2011) remarked, there is little understanding on the mediational mechanisms that account for relations between epistemic beliefs and learning. They note that emotions experienced while learning could be one such mediational mechanism, however, to our knowledge, only one study has tested this possibility at a fine-grained level (Muis et al., 2015). Therefore, in the next section, we review the theoretical and empirical research on the role of emotions in learning from reading and as a potential mediator between epistemic beliefs and learning.

Emotions and learning from reading

Emotions that individuals experience permeate academic achievement settings, and recent research on achievement emotions has revealed some of the varied but important antecedents and consequences they have during learning (Pekrun & Linnenbrink-Garcia, 2014; Schutz & Pekrun, 2007). To integrate multiple perspectives on the role that emotions play in learning, Pekrun and colleagues (Pekrun, 2000, 2006; Pekrun, Frenzel, Goetz, & Perry, 2007;

Pekrun & Perry, 2014) proposed the control-value theory of achievement emotions. As Pekrun (2006) contends, control and value appraisals of achievement situations jointly function as proximal antecedents of emotions. Appraisals of control refer to perceived controllability over actions and outcomes, whereas appraisals of value refer to perceived intrinsic (e.g., interest) or extrinsic (e.g., utility) value of an activity or outcome (Pekrun & Perry, 2014). Emotions, in turn, are predicted to affect learning achievement indirectly, mediated through various psychological mechanisms that include cognitive resources (e.g., attention and working memory), motivation to learn, use of learning strategies, memory processes, and self-regulation of learning (Pekrun, 2006; Pekrun, Elliot, & Maier, 2009; Pekrun & Perry, 2014).

According to Pekrun (2006), achievement emotions are experienced in relation to their object of focus: achievement activities and past or future achievement outcomes. Pekrun further delineates emotions along their physiological arousal (i.e., activating or deactivating) and valence (i.e., positive or negative) dimensions. This theoretical organization renders four groups of emotions, including positive activating emotions (enjoyment, pride, hope), negative activating (anger, shame, anxiety), positive deactivating (relaxation, relief, contentment), and negative deactivating (boredom, disappointment, hopelessness). As an example, anxiety is predicted as the joint product of low perceived control over a situation with high perceived value, which in turn predicts ineffective strategy use and inability to encode information (Cassady, 2004; Zeidner, 2014). Recent empirical research has substantiated some of the theorized links between emotions, reading comprehension processes, and learning outcomes, and in particular with respect to the arousal dimension of emotions (Bohn-Gettler & Rapp, 2011; Daley et al., 2014).

Presumably, emotions are more active and relevant when individuals read conflicting documents as the resulting cognitive incongruity may trigger epistemic emotions. Epistemic

emotions are produced from cognitive qualities of knowledge tasks and knowledge-generating activities (Pekrun & Linnenbrink-Garcia, 2014; Pekrun & Stephens, 2012). Emotions that are caused by cognitive incongruity may include surprise, curiosity, enjoyment, confusion, anxiety, frustration, or boredom. Philosophers of epistemology have long noted that such emotions can provide individuals useful insights into some phenomenon (e.g., anxiety may be evidence that new information is perceived as a threat to an existing cognitive scheme in the case of severe incongruity; Pekrun & Linnenbink-Garcia, 2014), and can direct perceived salience and attention (Brady, 2013; Elgin, 2008; Morton, 2010). Recent empirical evidence shows that epistemic emotions are active (D'Mello & Graesser, 2012, 2014) and influential during learning, affecting intrinsic motivation (Kang et al., 2009), type of strategies used (Muis et al., 2015), and learning outcomes (D'Mello, Lehmann, Pekrun, & Graesser, 2014).

Building on recent research (Muis et al., 2015), we contend that epistemic beliefs form a logical antecedent to epistemic emotions, given their shared focus on knowledge and knowing. In particular, we contend that epistemic beliefs create expectations for the types of knowledge and knowing that a particular task may require (Muis, 2007) and form an aspect of individuals' appraisals of control and value (Pekrun & Perry, 2014). Cognitive incongruity represents a sudden loss of perceived control and its novelty may heighten its perceived value and situational interest (Broughton, Sinatra, & Reynolds, 2010). These varying perceptions are predicted to lead to different emotional experiences. Thus, sudden loss of perceived control predicts surprise, which, in regaining control and paired with perceived success in achieving valued outcomes, may stimulate curiosity and enjoyment (Markey & Lowenstein, 2014; Pekrun, 2006). In contrast, moderate perceived control paired with perceived failure in achieving valued outcomes predicts anxiety (Pekrun, 2006; Pekrun & Perry, 2014). Further, Bråten et al. (2011) argue that searching

for a singular and settled answer across multiple conflicting accounts of a situation may cause confusion and frustration for an individual who expects knowledge to be absolute and certain, which may in turn lead them to spend less time reading the material compared to another who expects knowledge to be uncertain and evolving and may value and find interest in the complexity of the task. To date, few studies have explored this possibility. As such, the current study sought to shed light on the relationship between epistemic beliefs, epistemic emotions, and learning from multiple conflicting documents.

The Current Study

Central to the current study is the contention that the relationship between epistemic beliefs and learning from multiple conflicting documents is mediated by epistemic emotions. The current theoretical and empirical literature describes and demonstrates relations between epistemic beliefs and epistemic emotions that occur in response to the qualities of knowledge-generating activities. As concluded by Muis, Kendeou, and Franco (2011), the consistency between epistemic beliefs and how knowledge is represented in texts was related to individuals' cognitive and metacognitive processing of those texts. Thus, we contend that when epistemic beliefs are relatively well aligned with the epistemic nature of the learning task (e.g., when an individual expects complex and uncertain knowledge, actively constructed and justified by inquiry subsequently encounters multiple conflicting documents), greater perceived control is predicted. When beliefs are not aligned with tasks, a sudden loss of perceived control is predicted, however, intrinsic value may increase due to the unexpected novelty. The joint effects of these perceptions of control and value predict different emotional experiences. According to Pekrun and Perry (2014), an increase in perceived control is predicted to lead to greater positive emotions, like curiosity and enjoyment, whereas a loss in perceived control is predicted to lead to

greater experience of the neutral emotion of surprise and negative emotions, like confusion, anxiety, frustration, and boredom. In turn, the valence and arousal of emotions is a known determinant of the mental representations formed while reading (Bohn-Gettler & Rapp, 2011). However, emotion has received far less empirical attention in the context of learning from reading than it deserves (Bohn-Gettler & Rapp, 2014), and to our knowledge only one study has examined its potential mediational role between epistemic beliefs about knowledge and learning from multiple conflicting documents.

Thus, based on theoretical and empirical considerations from Bråten et al. (2011; Bråten, Anmarkrud et al., 2014), Muis (2007; Muis, Kendeou, & Franco, 2011), Pekrun (2006; Pekrun et al., 2009; Pekrun & Perry, 2014), and Bohn-Gettler and Rapp (2011, 2014), we propose the following hypotheses (see Figure 2):

Hypothesis 1: Epistemic beliefs will predict learning outcomes from reading multiple conflicting documents. Specifically, epistemic beliefs in complexity, uncertainty, justification by inquiry and source from active construction will predict higher learning scores.

Hypothesis 2: Epistemic beliefs will predict epistemic emotions while reading multiple conflicting documents. Specifically, beliefs in complexity, uncertainty, justification by inquiry and source from active construction, which are relatively well aligned to the epistemic nature of learning from multiple conflicting texts, will positively predict curiosity and enjoyment and negatively predict surprise, confusion, anxiety, frustration, and boredom while reading.

Hypothesis 3: Epistemic emotions will mediate relations between epistemic beliefs and learning outcomes from reading multiple conflicting documents. Specifically, epistemic emotions will mediate relations between beliefs and outcomes wherein surprise, curiosity, and

enjoyment will predict higher learning scores, and confusion, anxiety, frustration, and boredom will predict lower learning scores.

To examine relations, participants reported on their topic-specific epistemic beliefs and were presented with conflicting information from four texts about climate change. Participants reported on their emotions immediately following each text. Upon completion of reading all four texts, they were asked to summarize the content of the four texts in a brief essay. Summarization was selected as a measure of learning from multiple conflicting documents since its quality varies as a function of recall and of the organization of information in memory, which are important products of reading comprehension that are also fundamental to learning (E. Kintsch, 1990).

Method

Participants

The sample consisted of $N = 282$ post-secondary undergraduate students. Recruitment was achieved through a combination of advertisement in online university classifieds and from participant pools where students are required to participate in research studies for course credit. To broaden generalizability of the results, participants included students from Canada ($n = 151$) and the United States ($n = 131$), with 224 who identified themselves as female (79.4%), 57 as male (20.2%), and 1 as other (0.4%). Mean age of participants was 21.0 years ($SD = 3.2$ years) and the numbers in each year of university were as follows: 44 in first year (15.6%), 75 in second year (26.6%), 71 in third year (25.2%), 55 in fourth year (19.5%), 16 in fifth year (5.7%), and 21 graduated or pursuing a second degree (7.4%). The percentages of race/ethnicity were as follows: 102 Asian/Pacific Islander (36.2%), 13 Black/African American (4.6%), 21

Hispanic/Latino (7.4%), 9 Middle East/Indian (3.2%), 7 multiracial (2.5%), and 130 White/Caucasian (46.1%).

Materials

Computer-based learning environment. All content was presented on desktop computers via the Smart Testing System (STS), a computer-based learning environment that was developed for the purposes of this study. The STS presented all written instructions to the participants, questionnaires, tests, and texts in a fixed, linear, and self-paced order. Responses to questions were recorded in computerized log-files.

Epistemic beliefs. Bråten and Strømsø's (2009) 24-item Topic-Specific Epistemic Beliefs Questionnaire (TSEBQ) was used to measure participants' epistemic beliefs about climate change. The TSEBQ was designed to assess four common epistemic belief dimensions on a 10-point Likert scale ranging from 1 ("strongly disagree") to 10 ("strongly agree"): six items assessed beliefs about the complexity of knowledge, six for uncertainty of knowledge, and five and seven items, respectively, assessed beliefs about the source and justification for knowing. Complexity items were written to measure the degree to which participants perceived knowledge about climate change as consisting of individual versus connected information (e.g., "Within climate research, various theories about the same will make things unnecessarily complicated" [reversed]). High scores reflect that individuals believe knowledge about climate change consists of integrated conceptual knowledge (i.e., *complexity*), whereas low scores reflect a belief that knowledge is an accumulation of facts. Three items with low inter-item correlations were excluded from analysis and the resulting three-item measure showed moderate reliability (Cronbach's $\alpha = .57$). Uncertainty items assessed knowledge about climate change as fixed or tentative (e.g., "The results of climate research are preliminary"). High scores reflect a belief that

knowledge is evolving (i.e., *uncertainty*), whereas low scores reflect a belief that knowledge is absolute and unchanging. This measure showed good reliability (α = .74).

Source items were designed to measure the extent to which participants perceived climate change knowledge as passively versus actively constructed (e.g., "When I read about climate problems, I only stick to what the text expresses" [reversed]). High scores reflect a belief that knowledge is actively constructed (i.e., *source from active construction*), whereas low scores reflect a belief that knowledge originates outside the self, is passively constructed, and resides in external authorities. This measure showed good reliability (α = .70). Justification items assessed to what degree participants believed knowledge claims should be critically evaluated (e.g., "To be able to trust knowledge claims in texts about issues concerning climate, one has to check various knowledge sources"). High scores reflect a belief that knowledge claims about climate change should be based on rules of inquiry and the evaluation and integration of multiple sources (i.e., *justification by inquiry*). Low scores reflect the belief that knowledge claims can be justified through personal experience or one's own opinion. This measure showed good reliability (α = .73).

Texts. Four conflicting texts on the causes and effects of climate change were presented in a fixed linear order to participants, which were adopted from Strømsø and colleagues (Strømsø, Bråten, & Britt, 2010; Strømsø, Bråten, & Samuelstuen, 2008). The first pair of texts presented conflicting information on the causes of climate change, and the second pair presented conflicting information on the nature of the consequences of climate change. The first text, published by the Center for International Climate and Environmental Research at the University of Oslo (314 words), attributed the greenhouse effect to human production of climate gases that radically upsets the sensitive and complex balance of the climate system (anthropomorphic

causes text). In contrast, the second text (325 words), written by a professor of astrophysics and published in a research magazine, explained historical variations in climate as due to a host of astronomical causes like solar radiation and magnetism, therefore outside of human control, and concluded on a note of uncertainty of the causes of climate change (natural causes text). The third text (356 words), a journalistic news article, detailed several negative consequences of a changing climate, from tumultuous weather, impacts on farming and forestry, and rising ocean levels endangering coastal communities (negative consequences text). The fourth and final text (271 words), another newspaper article, described the positive consequences of climate change, which included the opening of arctic passageways for shipping and greater access to northern natural resources. Following Strømsø et al. (2008, 2010), each text was presented separately with the author's name and credentials.

Epistemic emotions. The emotions participants experienced while reading were measured using the Epistemic Emotions Scales – Short-Form (EES-SF; Muis et al., 2015), a 7-item self-report questionnaire each consisting of a single adjective (e.g., "Enjoying"), to measure seven epistemic emotions: curiosity ("Curious"), enjoyment ("Enjoying"), surprise ("Surprised"), confusion ("Confused"), anxiety ("Anxious"), frustration ("Frustrated"), and boredom ("Bored"). Each item consisted of a single word describing one emotion. Immediately after reading the first three of four texts, participants were asked to rate along a 5-point Likert scale how strongly they felt each of the emotions while reading. Responses ranged from 1 ("not at all") to 5 ("very strong"). The short-form measure was not given after the fourth and last text since the full version of the EES was administered to measure emotions experienced over the entire reading portion of the study, which includes three items per emotion (Muis et al., 2015).

Thus, data from the full EES measure do not represent text-specific emotions and were not included in subsequent analyses.

Learning outcomes. To derive measures of learning from multiple conflicting documents, participants were asked to write a short summary of all four texts. Specifically, participants were instructed to "Type a short essay (minimum 2-3 paragraphs in length) summarizing the texts you read on climate change."

Procedure

After completing informed consent, participants were seated in front of the desktop computer and the researcher initiated the STS. Participants then proceeded through the content in a fixed, linear, and self-paced order. They first completed demographic information, followed by the prior knowledge pre-test on climate change, and then the TSEBQ. Following this, all participants were presented the four conflicting texts, one at a time, in the order described. Prior to reading, participants were given an overview of the topics of each text and the conflicts between them were explicitly highlighted. During reading, participants were provided a text entry box within which they could take notes while studying. Participants were told that their notes would not be available during summary writing. After studying each of the first three texts, participants were asked to report on the emotions they experienced during reading with the EES-SF. Finally, after the fourth text and completing the full EES, participants were asked to write their summary. The research session lasted approximately one hour, for which participants were compensated with course credit or $10.

Construction of Indices for Learning Outcomes

Two indices of learning were extracted from the summaries that assessed the surface level and textbase representations of reading comprehension (E. Kintsch, 1990; W. Kintsch,

1998). The surface level cognitively represents the explicit wording of the text in memory and the textbase represents the underlying meaning of each clause from the text. We selected these levels of representations since we did not explicitly instruct participants to integrate content across documents to form a situations model (cf. Bråten et al., 2011) and instead sought to investigate representations fundamental to reading comprehension and learning. Text mining software was used to assess the lexical similarity (surface level representation) between participants' written summaries and each of the original conflicting texts they were presented. Human coding was conducted to assess the semantic similarity (textbase representation) between the summaries and the experimental texts. Procedures for deriving these indices are described in more detail in the following sections. Importantly, an index of the lexical and semantic similarities between participants' summary and experimental texts was only calculated for the first three experimental texts, as it was only after reading these texts were participants asked to report on their text-specific epistemic emotions using the EES-SF (the full EES measure was administered after the fourth and final text to assess epistemic emotions experienced over the entire reading portion of the study). Thus, we focused on constructing indices of learning for the first three texts where we could align these outcomes with text-specific data on epistemic emotions.

Surface level representation: text-mining. A series of text preprocessing algorithms were used to represent text documents as vectors of term occurrences with RapidMiner© software (RapidMiner, 2015). Text documents and written summaries were first transformed to lower case. Entire texts were then segmented to isolate individual terms. The resulting terms, referred to as tokens, were separated by non-characters, including spaces, line breaks, and punctuation characters.

Following Verma, Renu, and Gaur (2014), a series of filtering algorithms were applied to capture the underlying meaning of each document. Tokens were filtered on the basis of their length, excluding tokens with more than 25 characters and less than four. Common stop words or function words were also excluded, which consisted of articles, prepositions, conjunctions, auxiliary verbs, and pronouns used in the English language (e.g., *the, an, a,* and so on). The resulting list of tokens contained content or lexical words, such as nouns, verbs, adjectives, and adverbs, which convey the meaning of the text.

To ensure that the text documents were comparable, we relied on the Porter stemmer algorithm to remove common morphological and inflexional endings from words (Porter, 1980). The stemming algorithm reduced terms to a common stem to account for the different variations that may occur in relation to a single token (e.g., *argued, argues, argument,* and *arguing* is reduced to *argu*). Text documents and written summaries were segmented through a series of text processing algorithms to represent documents as vectors, where the value of each dimension corresponded to the frequency of word mentions. This was done to focus the analysis on the information that was the most representative of the entire set of documents.

$$Cosine\ simi,arity = \frac{\sum_{i=1}^{n} Term_{i,Doc1} \times Term_{i,Doc2}}{\sqrt{n}\sum_{i=1}^{n} Term_{i,Doc1}^{2} e \times \sqrt{n}\sum_{i=1}^{n} Term_{i,Doc2}^{2} e}$$

An average similarity value of cosine angles was calculated for each participant. The similarity cosines of two vectors is derived using the formula shown above, wherein *n* is defined as the total terms (Salton & Buckley, 1988). The resulting similarity index ranged from 0, meaning that both documents are independent, to a value of 1, meaning that the documents have the exact same tokens or terms mentioned. We calculated three average cosine similarity indices, comparing the surface level similarity between a given participant's summary and each of the

first three experimental texts (i.e., Text 1: anthropomorphic causes; Text 2: natural causes; and Text 3: negative consequences of climate change).

Textbase representation: human coding. A coding scheme was developed iteratively in weekly discussions over the course of six weeks between the first and second author and four raters. Chi's (1997) guide for quantifying qualitative analyses of verbal data was used to direct these efforts. The objective of the coding scheme was to determine to what degree participants relied on the semantic content of the original texts in constructing their summaries and on which source they relied.

Summaries were first segmented by participants' sentences for coding. Next, to obtain evidence of semantic overlap between participants' summaries and original texts, coders determined whether a particular sentence was semantically identical to a corresponding sentence in one of the original texts or if the sentence introduced new semantic information beyond what was explicitly stated in the texts. In the case where the coder determined semantic similarity, he or she labeled the segment as "Reproduction" and noted the original source (i.e., Text 1, 2, or 3)[9]. Where new information had been introduced, the segment was labeled as "Elaboration." The determination of whether a particular summary segment introduced new semantic content or not was concluded in one of two ways: first, if the participant reproduced a verbatim copy of the original text from memory this received a "Reproduction" code; second, if the participant paraphrased the original text, it was determined whether the paraphrase represented synonymous concepts. When it did (e.g., "particles from previously exploded stars" and "astronomical influences"), this received a code of "Reproduction," and when it did not represent synonymous concepts (e.g., "manmade discharges of CO2" and "climate change"), this received a code of

[9] It was also recorded if summaries contained semantically reproduced content originally from Text 4, but these data are not included in the present study.

"Elaboration." An index of textbase similarity between a given participant's summary and each of the three experimental texts was operationalized as the number of segments that were a semantic reproduction of content originally contained in one of the three experimental texts. Thus, each participant had three scores that represented the degree of semantic reproduction between his/her summary and each of the three conflicting texts under current consideration.

Over the course of the six weeks, the research team used a small subset of summaries to develop, test, and receive training with the coding scheme. The coding scheme was developed iteratively though discussion and training continued until 100% agreement was reached. The first author guided these meetings and the second author served as a content expert. To establish reliability, the first author and one graduate research assistant coded the same thirty summaries independently (roughly 10% of total), and the coding scheme was found to have substantial reliability ($\kappa = .66$). Discrepancies were resolved through discussion and the final codes were used for analysis. Following this, the remaining summaries were divided equally among five members of the research team who received training for independent coding.

Results

Preliminary Analyses

We examined each variable for skewness and kurtosis. Textbase similarity scores were positively skewed. Following Tabachnick and Fidell (2013), we conducted a square-root transformation on these variables to normalize each distribution. All other variables were within a normal range (absolute values were less than 3). Descriptive and correlational statistics specific to Text 1, 2, and 3 are reported separately in Tables 7 to 9, respectively.

Treatment Fidelity

To ensure the conflicting texts had the effect needed to generate cognitive incongruity to trigger specific epistemic emotions, participants' emotions were compared across the first three texts using a repeated measures analysis. Results revealed participants' self-reported levels of surprise ($F(2,280) = 26.36$, $p < .001$, $\eta^2 = .16$), curiosity ($F(2,280) = 15.05$, $p < .001$, $\eta^2 = .10$), enjoyment ($F(2,280) = 15.12$, $p < .001$, $\eta^2 = .10$), confusion ($F(2,280) = 62.68$, $p < .001$, $\eta^2 = .31$), anxiety ($F(2,280) = 22.88$, $p < .001$, $\eta^2 = .14$), frustration ($F(2,280) = 5.77$, $p < .01$, $\eta^2 = .04$), and boredom ($F(2,280) = 20.35$, $p < .001$, $\eta^2 = .13$) significantly changed over the three texts. Follow-up post-hoc analyses for each of the emotions using LSD revealed that surprise and confusion significantly increased between the first and second texts (ps < .005) and, with frustration and boredom, significantly decreased between the second and third texts (all ps < .05). Curiosity, enjoyment, and anxiety showed the reverse pattern, wherein these emotions significant decreased from the first to second text and then significant increased between the second and third texts (all ps < .01). See Figure 3 for plotted change in emotions over the three texts. Based on these patterns, we conclude support for the hypothesis that participants experienced cognitive conflict while reading the current experimental texts that in turn elicited emotional responses.

Path Analyses and Mediation Models

To test the mediation model depicted in Figure 2, we used Hayes and Preacher's (2013) MEDIATE SPSS macro, which is recommended with complex mediational models as it maintains higher levels of power while controlling for Type I errors (Preacher & Hayes, 2008). More specifically, we conducted path analyses to examine the predictive relations between epistemic beliefs and multiple levels of reading comprehension. We used two outcome measures to represent comprehension (surface level and textbase representations) for each of the three text documents. That is, the lexical and semantic similarities between participants' post-test

summaries and three experimental texts were determined with text-mining cosine and human coded values, which represented surface level and textbase mental representations.

Following a similar analytical procedure as Pekrun et al. (2009), we first calculated total effects models for each of the three texts, which express the sum of the direct and indirect effects of epistemic beliefs on similarity scores, to determine the predictive relations between beliefs and mental representations of the texts independent of mediational variables. Following this, we calculated the direct effects of epistemic beliefs predicting epistemic emotions, the direct effects of epistemic emotions on similarity scores, and the indirect effects of epistemic beliefs on similarity scores via epistemic emotions, to determine if emotions significantly mediated relations between beliefs and reading comprehension representations.

Total effects of epistemic beliefs on reading comprehension. For Text 1, the total effects model for epistemic beliefs and surface level similarity was significant, $F(4, 277) = 3.31$, $p < .05$, $R_a^2 = .032$, which showed that epistemic beliefs accounted for 3.2% of the variance associated with surface level similarity between summaries and Text 1. Complexity was a positive predictor, $\beta = .18$, $t = 3.03$, $p < .01$. For Text 2, the total effects model for epistemic beliefs and surface level similarity was also significant, $F(4, 277) = 3.14$, $p < .05$, $R_a^2 = .030$, which showed that epistemic beliefs accounted for 3.0% of variance associated with surface level similarity between summaries and Text 2. Complexity was a positive predictor, $\beta = .17$, $t = 2.83$, $p < .01$. For Text 3, the analysis of total effects of epistemic beliefs on surface level similarity was not significant. Analyses of total effects on textbase similarity for all three texts were not significant.

Emotions as mediators between epistemic beliefs and reading comprehension. To examine the direct and indirect predictive relations between epistemic beliefs, epistemic

emotions, and reading comprehension, parallel mediation analysis was conducted with MEDIATE (Hayes & Preacher, 2013). This allows the estimation of all direct predictive effects of four epistemic beliefs and seven epistemic emotions simultaneously on reading comprehension. The models were estimated separately for each of the two reading comprehension outcomes for each of the three texts, resulting in six analyses in total.

Text 1: anthropomorphic causes. The path model for Text 1 with standardized estimates is presented in Figure 4. For effects of beliefs on emotions experienced while reading Text 1, complexity was a negative predictor of surprise ($\beta = -.12$, $t = -2.07$, $p < .05$) and confusion ($\beta = -.19$, $t = -2.99$, $p < .01$). Uncertainty was a negative predictor of anxiety ($\beta = -.17$, $t = -2.35$, $p < .05$), frustration ($\beta = -.21$, $t = -3.00$, $p < .01$), and enjoyment ($\beta = -.13$, $t = -2.04$, $p < .05$). Justification by inquiry was a positive predictor of curiosity ($\beta = .17$, $t = 2.73$, $p < .01$), enjoyment ($\beta = .13$, $t = 2.29$, $p < .05$), and frustration ($\beta = .14$, $t = 2.15$, $p < .05$) and was a negative predictor of boredom ($\beta = -.13$, $t = -2.20$, $p < .05$). However, for Text 1, the analyses of indirect effects on surface level and textbase representations were not significant.

Text 2: natural causes. The path model for Text 2 with standardized estimates of direct and indirect effects is presented in Figure 4. For effects of beliefs on emotions experienced while reading Text 2, complexity was a positive predictor of frustration ($\beta = .14$, $t = 2.32$, $p < .05$). Uncertainty was again a negative predictor of frustration ($\beta = -.35$, $t = -5.24$, $p < .001$) and anxiety ($\beta = -.24$, $t = -3.24$, $p < .001$). Justification by inquiry was a positive predictor of surprise ($\beta = .18$, $t = 2.96$, $p < .01$), curiosity ($\beta = .14$, $t = 2.17$, $p < .05$), and marginally for enjoyment ($\beta = .12$, $t = 1.90$, $p = .059$), and a negative predictor of boredom ($\beta = -.14$, $t = -2.35$, $p < .05$). Source from active construction was a negative predictor of confusion ($\beta = -.15$, $t = -2.47$, $p < .05$).

For Text 2, the full mediational analysis of the direct and indirect effects of epistemic beliefs and emotions on surface level similarity was significant, $F(11, 270) = 2.00$, $p < .05$, $R_a^2 = .038$, which showed that epistemic beliefs and epistemic emotions together accounted for 3.8% of the variance associated with surface similarity between summaries and Text 2. With emotions entered into the mediational model, complexity retained a positive direct effect on Text 2 surface level similarity (β = .16, $t = 2.53$, $p < .05$). Surprise was positive predictor (β = .19, $t = 2.33$, $p < .05$) and confusion was nearly a significant negative predictor of Text 2 surface level similarity (β = -.12, $t = -1.80$, $p = .072$). Justification by inquiry on Text 2 surface level similarity was significantly mediated through surprise, with a point estimate of .004 and bias corrected bootstrapped confidence interval (95%) of .001 to .009. The indirect effect of source from active construction was nearly significantly mediated through confusion, with a point estimate of .002 and bias corrected bootstrapped confidence intervals (95%) of .000 to .005.

Likewise, the full mediational analysis of direct and indirect effects on Text 2 textbase similarity was also significant, $F(11, 270) = 2.15$, $p < .05$, $R_a^2 = .043$, which showed that epistemic beliefs and epistemic emotions together accounted for 4.3% of variance associated with textbase similarity between summaries and Text 2. With emotions entered into the mediational model, complexity had a direct positive effect on Text 2 textbase similarity (β = .14, $t = 2.29$, $p < .05$). Surprise (β = .19, $t = 2.35$, $p < .05$) and anxiety (β = .15, $t = 2.19$, $p < .05$) were positive predictors of Text 2 textbase similarity, whereas confusion (β = -.18, $t = -2.61$, $p < .01$) and enjoyment (β = -.19, $t = -2.48$, $p < .05$) were negative predictors. The indirect effects of uncertainty on Text 2 textbase similarity was significantly mediated through anxiety, with a point estimate of -.012 and bias corrected bootstrapped confidence intervals (95%) of -.030 to -.002. The indirect effect of source by active construction was significantly mediated through

confusion, with a point estimate of .009 and bias corrected bootstrapped confidence intervals (95%) of .002 to .023. The indirect effect of justification by inquiry was significantly mediated through surprise and enjoyment, with a point estimate of .015 and -.010, respectively, and bias corrected bootstrapped confidence intervals (95%) of .003 to .038 for surprise and -.030 to -.001 for enjoyment.

Text 3: negative consequences. The path model for Text 3 with standardized estimates of direct and indirect effects is presented in Figure 4. For effects of epistemic beliefs on epistemic emotions experienced while reading Text 3, complexity was again a negative predictor of surprise (β = -.15, t = -2.46, $p < .05$) and confusion (β = -.15, t = -2.46, $p < .05$), and uncertainty negatively predicted frustration (β = -.22, t = -3.13, $p < .01$). Justification by inquiry was a positive predictor of curiosity (β = .13, t = 2.14, $p < .05$) and enjoyment (β = .15, t = 2.40, $p < .05$).

The full mediational model of the direct and indirect effects of epistemic beliefs and emotions on Text 3 surface level similarity was significant, $F(11, 270) = 2.65$, $p < .01$, $R_a^2 = .059$, which showed that epistemic beliefs and epistemic emotions together accounted for 5.9% of variance associated with surface level similarity between summaries and Text 3. With emotions entered into the mediational model, curiosity was a positive predictor (β = .26, t = 2.81, $p < .01$) whereas enjoyment (β = -.18, t = -2.24, $p < .05$), and confusion (β = -.24, t = -3.51, $p < .001$) were again negative predictors of Text 3 surface level similarity. Mediational analysis of the indirect effects of complexity on Text 3 surface level similarity was significantly mediated through confusion, with a point estimate of .002 and bias corrected bootstrapped confidence intervals (95%) of .001 to .005. The indirect effects of justification by inquiry were significantly mediated through enjoyment, with a point estimate of -.002 and bias corrected bootstrapped

confidence intervals (95%) of -.006 to -.001, and through curiosity, with a point estimate of .003 and bias corrected bootstrapped confidence intervals (95%) of .001 to .008.

Discussion

The current study tested hypotheses that epistemic emotions mediate relations between epistemic beliefs and learning from multiple conflicting documents at a fine-grained level. Results from this study provide some support for our hypothesized relations, adding to our current theoretical models on epistemic beliefs, emotions, and reading comprehension and extending these models to the context of learning about a controversial topic. In particular, a belief in complex knowledge showed direct relations to indices of comprehension (Hypothesis 1). Epistemic beliefs also predicted epistemic emotions with consistency in relations observed across the three texts used in the current study (Hypothesis 2). Last, most epistemic emotions (i.e., surprise, curiosity, enjoyment, confusion, and anxiety) mediated relations between epistemic beliefs and multiple document reading comprehension (Hypothesis 3). Overall, the findings from this study are among the first to show that epistemic emotions mediate the relationship between epistemic beliefs and learning from multiple conflicting texts. Further, evidence of complex predictive relations between beliefs, emotions, and learning, their text-specific activation, and the use of multiple dependent variables to assess learning from reading, including cosine similarity from text-mining, represent additional unique theoretical and methodological contributions of the current study. We address each point in turn and conclude with a discussion of the limitations of the study and directions for future research.

Effects of Epistemic Beliefs when Reading Conflicting Texts

In the unmediated analyses, only belief in complex knowledge predicted the surface level representations for Text 1 and Text 2 but not for Text 3 or any textbase representation. These

findings are consistent with previous theoretical and empirical literature that describes small effects of beliefs on learning outcomes (Schraw, 2013). However, in predicting epistemic emotions, consistent relations between epistemic beliefs and emotions were observed across texts. Indeed, not only were all epistemic emotions predicted by at least one epistemic belief, but all emotions were predicted by the same epistemic belief across at least two of three measurement points, and three of seven emotions were predicted by the same epistemic belief across all three measurement times. The pattern of these results demonstrates stability in the predictive relationship between epistemic beliefs and emotions. Further, epistemic beliefs predicted emotions largely consistent with the hypotheses.

Specifically, with few exceptions, beliefs in complexity, uncertainty, justification by inquiry and source from active construction individually and negatively predicted surprise, confusion, anxiety, frustration, and boredom, and justification by inquiry positively predicted curiosity and enjoyment. Thus, we found support for our prediction that individuals who believed knowledge to be complex and uncertain and believed knowing required active personal construction were less likely to report being surprised and experienced fewer negative emotions when presented with multiple conflicting claims. Rather, individuals who anticipated that knowing required critical evaluation and corroboration were more likely to report experiencing positive emotions when reading controversial information. In sum, when individuals' epistemic beliefs were consistent with the complex epistemic nature of the learning task, positive emotions were experienced more intensely and negative emotions less intensely. These findings may be because epistemic beliefs create expectations about the nature of knowledge and knowing that, if violated by a contrasting presentation of knowledge, lead to a sudden loss of perceived control. Subsequently, we predict that any successive emotions experienced will be attributable in part to

perceptions of what it means to experience a sudden loss of control (e.g., as a challenge or as a threat) and perceptions of recovery, although these antecedents require direct empirical investigation.

However, two belief dimensions predicted emotions in directions inconsistent with our predictions. First, a belief in justification of knowing by rules of inquiry and corroboration also positively predicted surprise and frustration across different texts. Perhaps the act of coordinating multiple conflicting sources is inherently frustrating when individuals are attempting to form a coherent understanding of the situations being described. Second, a belief in uncertain knowledge was unexpectedly found to negatively predict enjoyment while reading Text 1 (anthropomorphic causes). It may be possible that this account for the cause of climate change is already consistent with participants' prior views and the lack of cognitive incongruity and novelty diminished its perceived value or situational interest, yet more research is needed to substantiate these claims.

The Mediational Role of Epistemic Emotions

Importantly, the current study found evidence that epistemic emotions mediate relations between epistemic beliefs and multiple document comprehension, specifically the quality of surface level and textbase representations manifested in participants' summaries of texts. The current findings advance theoretical specifications for the relations between epistemic beliefs and emotions and extended these models to the context of learning about controversial knowledge. In particular, across texts, surprise and curiosity were found to positively predict, and confusion was found to negatively predict, the lexical and semantic similarity between participants' summaries and the original documents. These findings indicate that surprise and curiosity facilitated the construction of the surface and textbase mental representations whereas confusion

impeded their construction. These findings are consistent with our predictions and past research on the relations between surprise, curiosity, and confusion to learning. Previous research has found that surprise increases the salience of information, which is related to higher priority in cognitive processing and privileged status in memory (Bohn-Gettler & Rapp, 2014). Similarly, curiosity relates to increased intrinsic motivation and memory (Kang et al., 2009). Research on confusion showed complex relations to learning, demonstrating both positive and negative effects. Recently, confusion has been linked to beneficial learning outcomes by D'Mello et al. (2014). D'Mello and Graesser (2014) describe what they refer to as *optimal confusion*, where individuals experience and make attempts to resolve cognitive disequilibrium, which in turn stimulates deeper engagement (e.g., heightened attention, motivation, and problem-solving efforts) during learning and promotes more durable memory representations. However, in their empirical study, D'Mello et al. required participants to resolve the discrepancy-induced confusion, unlike the current study that allowed persistence of confusion to operate under the discretion of the participants, which may become maladaptive over time and thus accounting for the differences between beneficial and detrimental learning outcomes (D'Mello & Graesser, 2014). Indeed, Kobayashi (2015) found that instructing participants to resolve conflicting claims between texts led to greater comprehension and recall than general comprehension instructions.

However, there were several unanticipated results. In particular, across texts and mental representations, enjoyment was a negative predictor of multiple document comprehension whereas anxiety was a positive predictor of human coded semantic similarity for Text 2. These findings may be commensurate to Bohn-Gettler and Rapp (2011) and Daley et al.'s (2014) findings wherein the level of arousal of emotions was an important factor that facilitated coherence-building processes during reading comprehension and improved memory.

Specifically, Bohn-Gettler and Rapp found that both positive and negative emotion induction increased paraphrasing and decreased non-coherence-building processes compared to the relatively low arousal neutral induction. Daley et al. (2014) found that an increased level of affective arousal observed prior to reading, paired with its down-regulation during reading, predicted text recall at a higher rate than if anticipatory arousal was not observed. Similarly, enjoyment in this study may have been a relatively deactivating (i.e., lower physiological arousal) emotional state and anxiety a relatively activating (i.e., higher physiological arousal) state. Further, positive states have been previously linked to increases in elaborative and creative thinking, in contrast to negative emotions that have been linked to increases in analytical thinking (Fiedler & Beier, 2014). Thus, taken together, a relatively low arousal positive emotion may have lead participants in the current study to go beyond the content of the original documents to include dissimilar lexical and semantic content in their summaries. In contrast, if anxiety was experienced as a relatively high arousal negative state in the current study, this could lead participants to hew more closely to the original content while creating their summaries.

Unique Contributions of the Present Research

There are several unique theoretical and methodological contributions of the current study to understanding the effects of epistemic beliefs and emotions in the context of reading about controversial knowledge. First, mediational results from the study add to theoretical models of epistemic beliefs by demonstrating the existence of complex predictive relations between epistemic beliefs and learning outcomes. Specifically, it was observed that the epistemic belief in justification by inquiry dimension may have both positive and negative indirect effects on learning via different emotional paths. For instance, both curiosity and enjoyment were predicted by justification but had positive and negative impacts on comprehension, respectively.

These findings add to our theoretical understanding by revealing that the effects of epistemic beliefs on learning outcomes may not be straightforward and future research may need to refine measurement of beliefs and account for emotions as mediators to differentiate these effects. Second, we refine current theoretical understandings of emotions and reading comprehension through demonstrating that various emotions facilitate or impede the construction of mental representations during reading. Moreover, we extend these frameworks to include consideration of text-specific activation of emotions while reading about controversial knowledge. Further, the current findings point toward the arousal dimension of emotions and the complicated relationship between learning and confusion (cf. D'Mello et al., 2014) as worthy avenues of future inquiry.

Third, we used multiple methods and dependent variables to assess different levels of learning from multiple conflicting documents, which included the use of text-mining software. This provided us greater confidence in drawing conclusions from the data as we could assess how robust the relations were across methods and outcomes. In the future, researchers can build off the current findings in their efforts to evaluate and validate a rapid method to assess large corpora of open-ended texts for evidence of complex learning (see Crossley, Allen, Kyle, & McNamara, 2014, for a recent review).

Limitations and Conclusions

The conclusions of the current study are limited in several ways. First, we did not give participants a task that required them to form an integrated situations model or assess participants on their formation of this level of representation. We were therefore unable to assess the formation of the situations model. Although surface level and textbase representations are foundational to reading comprehension and learning, future research should include assessments of the situations model. Second, we did not include a measure of cognitive processes that may

yet still mediate relations between emotions and achievement (Pekrun, 2006; Pekrun & Perry, 2014). Likely, these include cognitive resources, motivation to learn, use of learning strategies, memory processes, and self-regulation of learning (Muis, 2007; Pekrun & Perry, 2014). We recommend that future research include process measures for these constructs, as can be evinced in eye-tracking, concurrent verbalizations, or hypermedia navigational patterns in computer log-files.

Paired with the current findings on the role of emotions, we see fruitful avenues for future inquiry and instructional practice for learning about controversial issues. Researchers can explore instructional methods to scaffold readers' mindfulness and regulation of the emotions experienced while reading as resources for epistemic access into the success of their learning activities (Brady, 2013; Elgin, 2010). For instance, awareness of feeling confused may signal readers to use of a new learning strategy or resources, or awareness of feeling relatively calm, deactivating emotions may prompt them to reconsider whether they have given enough careful and critical attention to what they have read.

Overall, the current findings have important theoretical implications for research on epistemic cognition. In particular, contending with multiple conflicting viewpoints can give rise to emotional reactions if individuals' epistemic beliefs are not aligned with complex, uncertain knowledge claims that can be adjudicated with corroboration and inquiry. Epistemic beliefs may serve as inputs into setting up expectations for learning new knowledge that, if violated, may represent a perceived sudden loss of control as an individual's planned course of action is upended by external events (e.g., conflict among experts). When misalignment between epistemic beliefs and the epistemic nature of learning tasks occur, negative emotions are likely to be generated. However, there was little consistency for positive or negative emotions to have

positive or negative effects, respectively, on measures of learning. Therefore, we surmise that these emotions differentially motivate the use of cognitive strategies. These conclusions may be further qualified by individual differences (e.g., control appraisals) and contextual features (e.g., topic and content of texts) that future research can explore.

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Table 7. *Descriptive and Correlational Statistics for Epistemic Beliefs, Epistemic Emotions, and Comprehension During Reading of Text 1.*

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Complexity [a]	6.82 (1.74)												
2. Uncertainty [a]	-.304**	6.29 (1.51)											
3. Justification: Inquiry [a]	.012	.313**	7.54 (1.17)										
4. Source: Active [a]	.226**	.041	.177**	5.93 (1.53)									
5. Surprise [b]	-.155**	.106	.011	-.030	2.17 (0.93)								
6. Curiosity [b]	.073	.008	.167**	.059	.353**	3.06 (0.99)							
7. Enjoyment [b]	.074	-.101	.100	.012	.199**	.537**	2.53 (0.96)						
8. Confusion [b]	-.217**	.057	-.059	-.143*	.391**	.116	-.040	1.88 (0.96)					
9. Anxiety [b]	.062	-.132*	.046	-.024	.129*	.203**	.119*	.236**	1.77 (0.93)				
10. Frustration [b]	.130*	-.166**	.087	.099	.037	.219**	.097	.282**	.514**	1.89 (1.03)			
11. Boredom [b]	-.107	-.010	-.151*	-.125*	-.143*	-.548**	-.381**	.210**	-.071	-.016	2.53 (1.08)		
12. Surface	.200**	-.025	.053	.105	.004	.104	.089	-.100	.031	.061	-.141*	0.25 (0.10)	
13. Textbase [c]	-.038	.057	-.065	-.003	.022	.017	.014	-.088	-.066	-.070	-.120*	.281**	0.44 (0.61)

Note. Means and standard deviation are on the diagonal. [a]1-10 Likert scale; [b]1-5 Likert scale [c] Square root transformation.
* $p < .05$. ** $p < .01$.

Table 8. *Descriptive and Correlational Statistics for Epistemic Beliefs, Epistemic Emotions, and Comprehension During Reading of Text 2.*

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Complexity [a]	6.82 (1.74)												
2. Uncertainty [a]	-.304**	6.29 (1.51)											
3. Justification: Inquiry [a]	.012	.313**	7.54 (1.17)										
4. Source: Active [a]	.226**	.041	.177**	5.93 (1.53)									
5. Surprise [b]	.078	-.036	.148*	-.061	2.70 (1.10)								
6. Curiosity [b]	.063	.076	.153*	.020	.545**	2.90 (1.06)							
7. Enjoyment [b]	.086	.076	.140*	.021	.419**	.604**	2.39 (0.95)						
8. Confusion [b]	.013	-.088	-.026	-.146*	.375**	.103	.006	2.38 (1.11)					
9. Anxiety [b]	.053	-.202**	-.040	-.027	.325**	.175**	.192**	.316**	1.59 (0.79)				
10. Frustration [b]	.244**	-.342**	-.018	.051	.190**	.034	-.043	.299**	.500**	1.93 (1.10)			
11. Boredom [b]	-.096	.049	-.135*	-.100	-.324**	-.479**	-.350**	.112	.012	.003	2.52 (1.12)		
12. Surface	.170**	.037	.033	.121*	.128*	.067	.058	-.065	.022	.058	-.099	0.29 (0.52)	
13. Textbase [c]	.109	.018	-.005	.038	.113	.077	-.019	-.089	.079	-.030	-.042	.199**	0.38 (0.13)

Note. Means and standard deviation are on the diagonal. [a]1-10 Likert scale; [b]1-5 Likert scale; [c] Square root transformation.
* $p < .05$. ** $p < .01$.

Table 9. *Descriptive and Correlational Statistics for Epistemic Beliefs, Epistemic Emotions, and Comprehension During Reading of Text 3.*

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Complexity [a]	6.82 (1.74)												
2. Uncertainty [a]	-.304**	6.29 (1.51)											
3. Justification: Inquiry [a]	.012	.313**	7.54 (1.17)										
4. Source: Active [a]	.226**	.041	.177**	5.93 (1.53)									
5. Surprise [b]	-.200**	.180**	.090	-.064	2.49 (1.08)								
6. Curiosity [b]	.082	.054	.157**	.102	.522**	3.20 (1.09)							
7. Enjoyment [b]	.040	.080	.168**	.041	.370**	.657**	2.69 (1.08)						
8. Confusion [b]	-.143*	.000	-.072	-.014	.291**	.060	-.054	1.66 (0.83)					
9. Anxiety [b]	.044	-.100	.040	.012	.120*	.209**	.066	.308**	1.94 (1.10)				
10. Frustration [b]	.128*	-.198**	.011	.061	.020	.170**	.055	.284**	.621**	1.76 (1.02)			
11. Boredom [b]	-.073	-.036	-.127*	-.104	-.278**	-.569**	-.478**	.147*	-.122*	.013	2.23 (1.15)		
12. Surface	.078	-.016	-.012	-.053	.008	.141*	.013	-.207**	.014	-.023	-.115	0.33 (0.57)	
13. Textbase [c]	.011	.001	-.028	-.112	.112	.127*	.085	-.099	-.054	.008	-.060	.336**	0.25 (0.10)

Note. Means and standard deviation are on the diagonal. [a]1-10 Likert scale; [b]1-5 Likert scale; [c] Square root transformation.
* $p < .05$. ** $p < .01$.

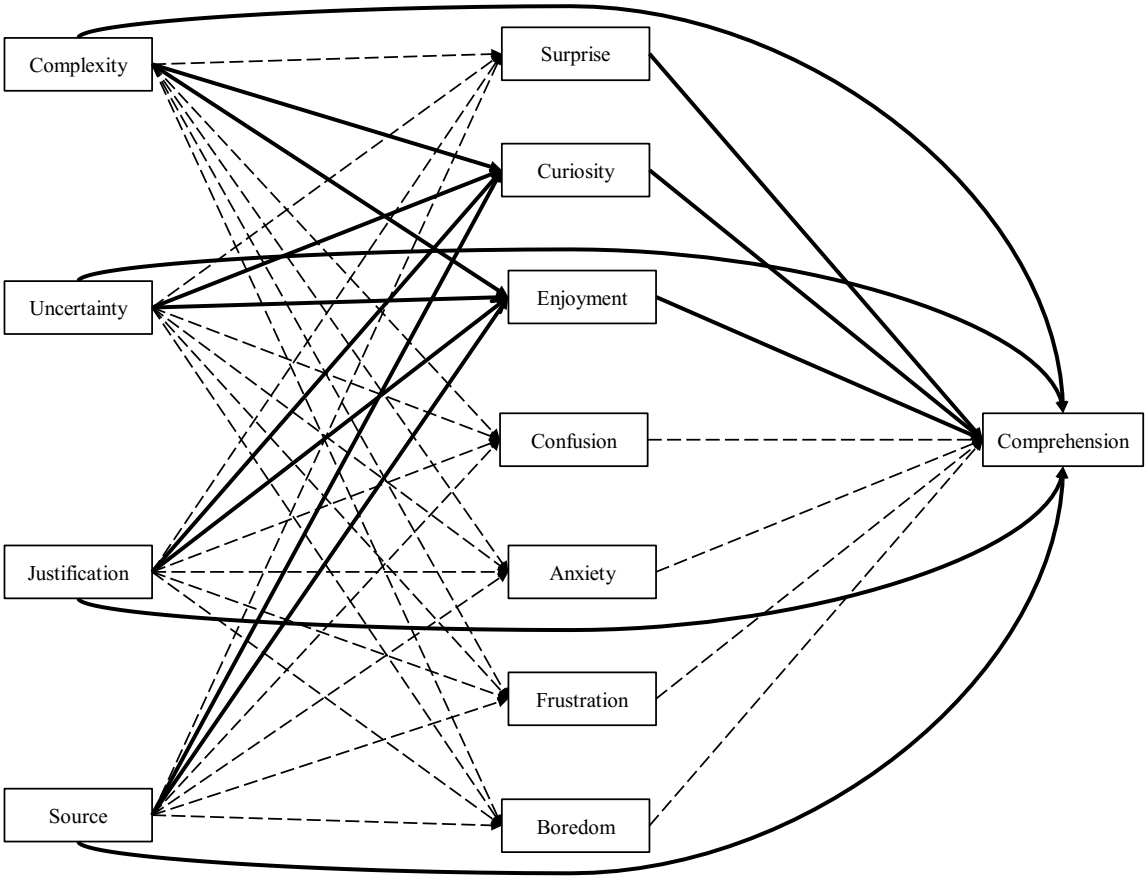

Figure 2. The proposed theoretical mediated relations between epistemic beliefs, epistemic emotions, and multiple document reading comprehension. Solid lines represent positive hypothesized relations and dashed lines represent negative hypothesized relations.

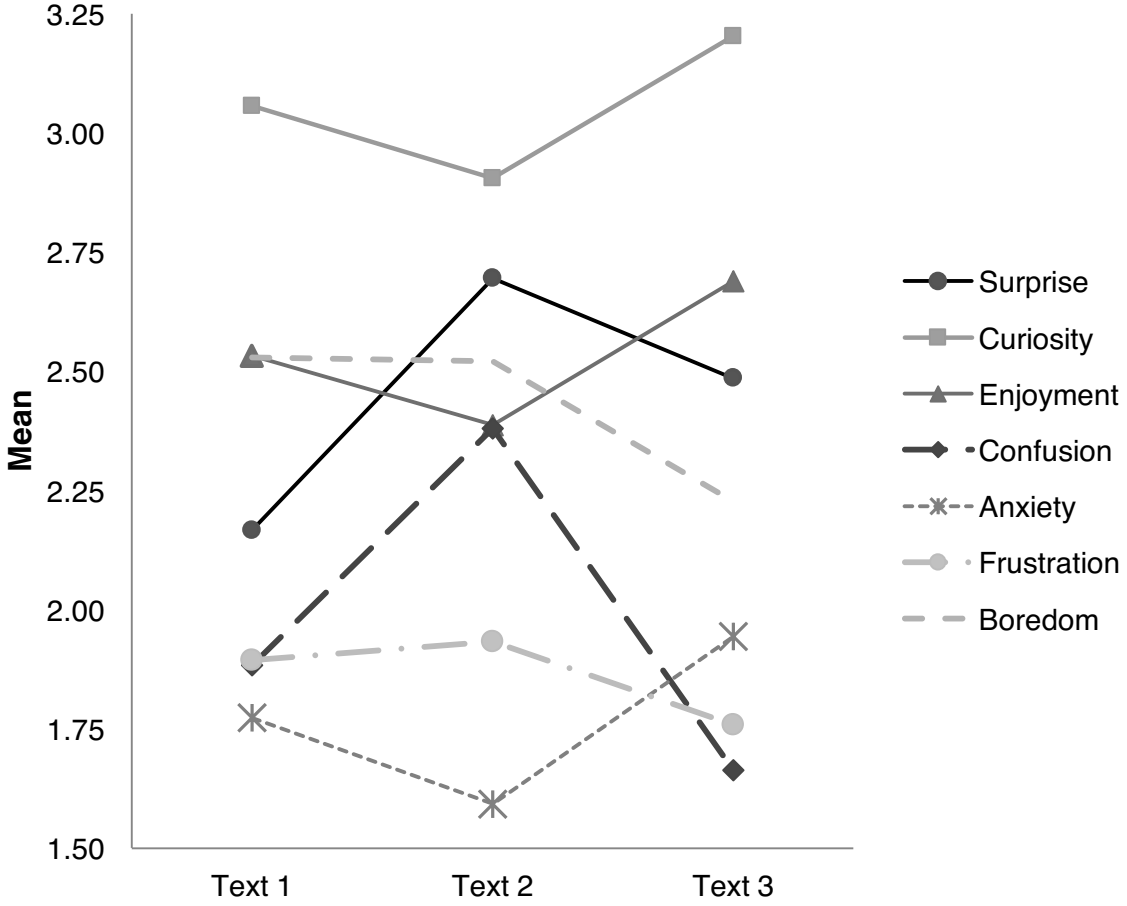

Figure 3. Evidence of treatment fidelity. Epistemic emotions reported across the three texts.

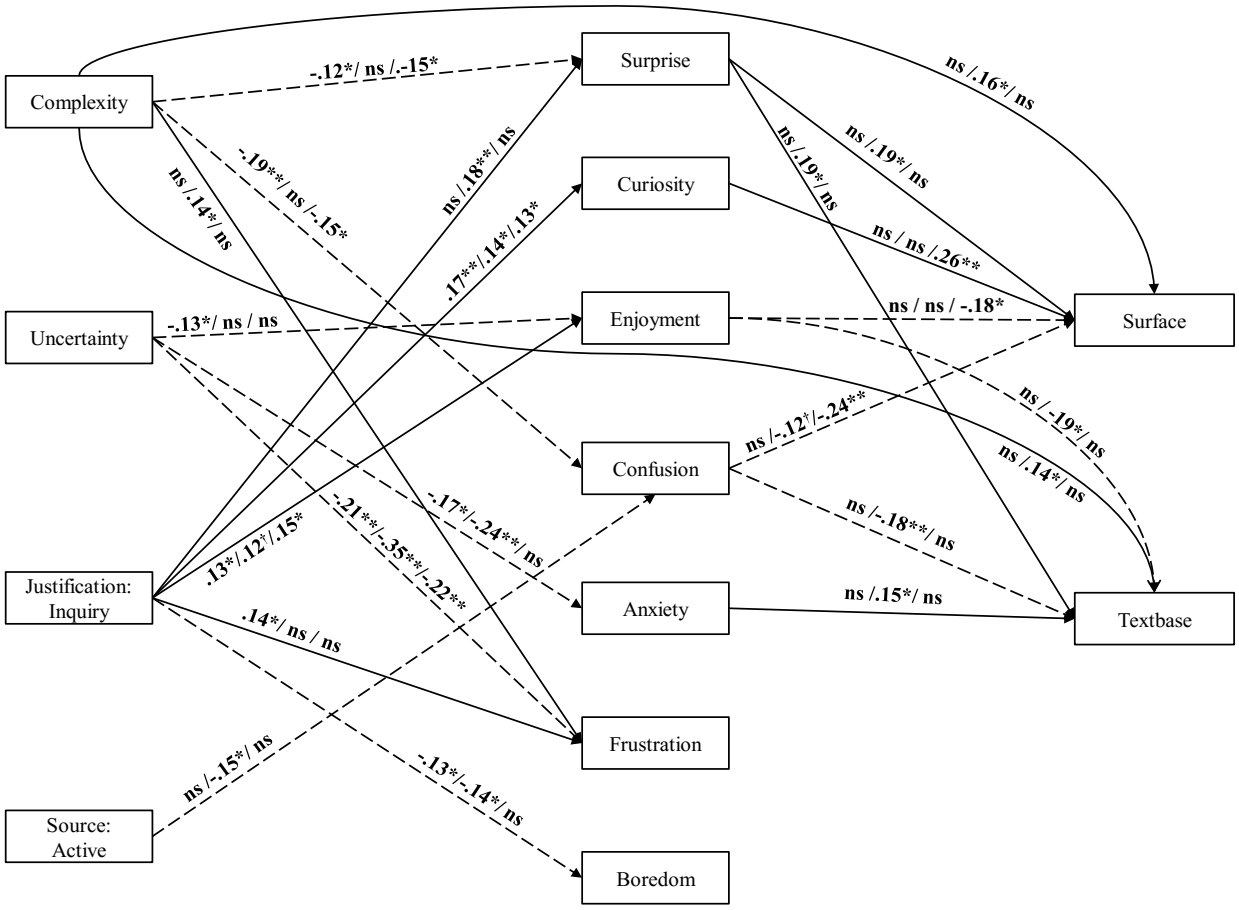

Figure 4. Summary of standardized effects for mediational analyses of epistemic beliefs, emotions, and comprehension while reading three conflicting texts. Standardized coefficients are separated by backslashes for each of the three texts.

† $p < .075$
* $p < .05$
** $p < .01$

Bridging Text

Chapter 4 reviewed literature that introduced the concept of epistemic emotions and presented an empirical study that showed its significance for learning about controversial knowledge. Specifically, the findings showed that epistemic emotions mediated the relations between epistemic cognition and learning from multiple conflicting documents in part by applying text-mining software and a mediational research paradigm. However, open questions remain surrounding epistemic emotions: Can epistemic emotions be predicted by educational constructs other than epistemic beliefs? What are the effects of epistemic emotions when the conflict is not between knowledge claims between various texts but between an individual and text? Chapter 5 addresses these questions to develop and test an integrated theoretical framework on the roles of identity and epistemic emotions during knowledge revision. Whereas Chapter 4 theorized how epistemic beliefs can serve as inputs into creating expectations for perceived control, an important antecedent to emotion generation, Chapter 5 focuses on how identity can shape perceptions of value and generate emotions when educational messages conflict with self-concept. In so doing, Chapter 5 addresses themes of the current dissertation related to the role of epistemic emotions within the context of controversial knowledge and the application of methodologies through development of a novel scale for self-concept and use of a mediational paradigm to tests its effects.

Chapter 5

Manuscript #3

Identity and Epistemic Emotion during Knowledge Revision: A Potential Account for the Backfire Effect

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Abstract

Recent research has shown that for some topics, refutational messages may backfire. The current offers one possible account for this backfire effect from an educational psychology perspective and examines the mediational role of epistemic emotions between self-concept and learning from refutational texts. Undergraduate students' (N = 120) responded to dietary self-concept and epistemic emotions questionnaires while reading an expository or refutational text on the topic of genetically modified foods. Knowledge of the topic was assessed after reading. Results showed an interaction effect on epistemic emotions between self-concept and text type; self-concept predicted negative epistemic emotions (i.e., confusion, anxiety, frustration) while reading a refutational text that subsequently negatively related to learning. Implications for educational design and future research are discussed.

Keywords: refutational text; knowledge revision; emotions; self-concept

Science knowledge is playing an increasingly bigger role in decision-making about issues of personal and global significance, such as climate change, evolution, vaccination, and genetically modified foods. However, many of these socio-scientific topics are embroiled in controversy, resulting in stalemate on urgent issues. Kahan (2015) captures this dilemma in his illumination of the paradox that confounds the field of science communication: "Never have human societies *known so much* about mitigating the dangers they face but *agreed so little* about what they collectively know" (italics in original; p. 1). Why this is the case and how it can be altered are the subject of intense scrutiny by researchers across multiple disciplines.

Sinatra, Kienhues, and Hofer (2014) surveyed the fields of educational, developmental, social, and cognitive psychology and identified several potential factors that undermine the public's understanding of science. Among these factors, Sinatra et al. highlight challenges posed by misconceptions, cognitive biases, and misalignment between individuals' epistemic cognition and epistemology of science. Sinatra et al. note that the mixed influence of these factors may explain how some misconceptions are generated and why they are resistant to interventions for knowledge revision (Trevors & Muis, 2014). However, beyond resistance, researchers and educators have shown that in some situations, attempts to revise erroneous knowledge are sometimes met with unintended and harmful consequences (Nyhan & Reifler, 2015a; Prasad et al., 2009).

In the following, we describe how and why efforts from the fields of political and communication sciences to correct misconceptions have "backfired" for some vital yet controversial socio-scientific issues. Next, we explain how theories from educational psychology – knowledge revision, identity, emotions, and discourse processes – can be fruitfully applied to help understand this effect and how to address it. We present empirical evidence that shows

potential links between these theories and draw upon an integrated theoretical framework to inform the hypotheses and design of the current study.

The Backfire Effect

One feature of motivated reasoning gaining increasing attention is what is known as the backfire effect[10] (Nyhan & Reifler, 2010). The backfire effect is the ironic strengthening of an original belief in misinformation that is the subject of an attempt of correction. It is the end result of a cognitive bias for some individuals to become more likely to believe information that is being refuted if that information has special personal relevance. For example, in one study, Prasad and colleagues (Prasad et al., 2009) found that participants who self-identified as Republican were more likely to believe a link between Iraq and the events of 9/11 *after* that information was refuted by researchers. The researchers concluded that individuals self-identifying as Republican were not only less predisposed to believe a refutation incongruent with their party's pre-war perspective but also doubled-down on the information that was refuted (i.e., intensified their original belief in the erroneous information as a consequence of the attempted correction). Other researchers have observed similar effects for a range of issues – including climate change (Hart & Nisbet, 2012); healthcare reform (Nyhan, Reifler, & Ubel, 2013); video game violence (Nauroth, Gollwitzer, Bender, & Rothmund, 2014, 2015); vaccinations (Nyhan & Reifler, 2015a; Nyhan, Reifler, Richey, & Freed, 2014); and even Lyme disease (Roh, McComas, Rickard, & Decker, 2015) – and have arrived at similar conclusions: attempts to argue for the inadequacy of incorrect knowledge in these areas results in some individuals more strongly adhering to that knowledge. Or as Gal and Rucker (2010) put more succinctly, if the backfire effect had a maxim it would be "when in doubt, shout!" (p. 1).

[10] Alternatively referred to as psychological reactance (e.g., Erceg-Hurn & Steed, 2011) or the boomerang effect (e.g., Byrne & Hart, 2009).

The common explanation for how the backfire effect occurs is that some individuals are more skeptical of the retraction (Garrett & Weeks, 2013) and expend effort to counter-argue it (Nauroth et al., 2014, 2015; Nyhan & Reifler, 2010; Prasad et al., 2009). In so doing, they activate more evidence that supports their original belief. The competing activation among various information and explanations is a core component of recent theorizing of whether attempts at knowledge revision of will succeed or fail (Kendeou, Smith, & O'Brien, 2013; Kendeou, Walsh, Smith, & O'Brien, 2014).

According to Kendeou and colleagues' Knowledge Revision Components (KReC) framework, once information becomes part of memory, it cannot be erased (Encoding Principle), and always has the potential to be reactivated and influence learning and memory. A passive process results in this reactivation of previously acquired information (Passive Activation Principle). A necessary condition for knowledge revision is the simultaneous activation of both prior knowledge and incoming information (Co-activation Principle) since co-activation allows for the integration of the correct and incorrect information into the same mental network (Integration Principle). Ideally, as the amount of correct information increases, for example with the addition of causal explanations, it begins to become prominent in the network. Activation is seen as a zero-sum situation; as such, as the correct information begins to dominate, it draws increasing amounts of activation to itself at the expense of the incorrect information (Competing Activation Principle). This competition is driven by the complexity of interconnected concepts in the network, including causal explanations, and largely determines whether knowledge revision will be successful or not (Kendeou, Smith, & O'Brien, 2013; Kendeou, Walsh, Smith, & O'Brien, 2014). Therefore, in the case of the backfire effect, individuals have intentionally and

strategically allocated attentional resources away from correct information and towards incorrect information to counter-argue the retraction (cf. Sinatra & Pintrich, 2003).

Researchers are still investigating the motivation underlying why some individuals counter-argue retractions. However, contemporary researchers view the backfire effect as a defensive action against threats to one's self-identity (Kahan, Peters, Dawson, & Slovic, 2013). Specifically, across studies, the backfire effect is observed for individuals who adhere to a particular ideological worldview that is consistent with or sympathetic to the belief targeted by a refutation (Nyhan & Reifler, 2010). These strongly held ideological beliefs are believed to be integral to one's sense of self (i.e., identity or self-concept; Eccles, 2009). To accept the argument of a refutation means to reject some valued aspect of self-concept. Thus, it is speculated that refutations are perceived as identity-threatening and trigger ego-protective responses that motivate individuals to restore a sense of self-worth (Nyhan & Reifler, 2015b), which includes undermining and counter-arguing the refutation and reinforcing the original belief. For example, Nauroth and colleagues have shown that individuals who strongly self-identify as "gamers" (compared to weaker self-identification) will more likely negatively criticize research reports on the negative effects of video games, discredit scientists responsible for such reports, and experience more anger (Nauroth et al., 2014, 2015).

Bolstering this claim is evidence that self-affirmation techniques – which ask participants to remember a time when they acted in accordance with personally important values (Steele, 1988) – when administered prior to refutation resulted in an attenuation of motivated reasoning (Cohen, Aronson, & Steele, 2000) and the backfire effect (Nyhan & Reifler, 2015b). Nyhan and Reifler (2015b) reasoned that the effectiveness of self-affirmation interventions is due to their effect of bolstering participants' sense of self-worth and security of their self-identity. This has

the result rendering the threat posed by a refutation appear relatively minor to these individuals, which may lead them to give it a more favorable review. The researchers hypothesized that "rejection of uncomfortable facts is a form of defensive processing that serves to protect one's self-identity; when self-identity is buttressed, people may be less likely to respond defensively" (Nyhan & Reifler, 2015b).

However, what is still unclear are the psychological mechanisms that account for this phenomenon. To this end, we draw upon theories from educational psychology to illuminate cognitive and affective processes and future research directions. In particular, we turn to conceptual change theory as a mean to provide a framework with which to understand the mechanisms that account for these findings.

Self-Concept and Threat Appraisals in Knowledge Revision

Many scholars have long contended that strongly held beliefs and worldviews are resistant to conceptual change (Chi, 2008; Dole & Sinatra, 1998; Sinatra & Pintrich, 2003) Moreover, Gregoire (2003) has proposed that some misconceptions may be integrated with self-concept, such that efforts at knowledge revision may be appraised as threats. According to Gregoire, if the topic of a message implicates knowledge that is core to one's identity then the integrity of identity is at stake. Then the message may be seen as threatening to one's self-concept, leading to experiencing anxiety and adopting a goal to avoid the threatening message rather than seeing the message as a challenge and approaching it as an opportunity for growth. Thus, similar to the backfire effect, if counter-attitudinal advocacy involves individuals' core beliefs about themselves, a detrimental impact on learning is expected in part due to the negative emotions evoked.

Self-Concept and Emotions in Reading and Knowledge Revision

To understand the function of emotions during knowledge revision, we draw upon the control-value theory of achievement emotions (Pekrun, 2006; Pekrun & Perry, 2014). As Pekrun (2006) contends, control and value appraisals of achievement situations jointly predict emotions. Relevant to the current study, appraisals of value refer to perceived intrinsic (e.g., interest) or extrinsic (e.g., utility) value of an activity or outcome (Pekrun & Perry, 2014). Emotions are predicted to affect learning indirectly, mediated through various psychological mechanisms that include cognitive resources, memory processes, use of learning strategies, motivation, and self-regulation of learning (Pekrun, 2006; Pekrun, Elliot, & Maier, 2009; Pekrun & Perry, 2014). Pekrun further delineates emotions along physiological arousal (i.e., activating or deactivating) and valence (i.e., positive/pleasant or negative/unpleasant) dimensions. This theoretical organization renders four groups of emotions, including positive activating emotions (enjoyment, hope, pride), negative activating (anger, anxiety, shame), positive deactivating (relaxation, contentment, relief), and negative deactivating (boredom, hopelessness, disappointment).

Related to identity, to the extent that situations present the opportunity to confirm or disconfirm salient aspects of actual or ideal self-concept, they will have higher attainment value (Eccles & Wigfield, 2002). According to Eccles (2009), individuals engage in activities, behaviours, and tasks to validate their identities. As a result, individuals will not be motivated to engage in activities inconsistent with their self-image and personal and social identities (Eccles, 2009; Nauroth et al., 2014, 2015) such as accepting information that undermines valued or salient aspects of identity. Thus, situations perceived as aversive to attaining identity-related needs, such as maintaining identity integrity, ought to have negative value that can lead to experiencing negative emotions (Pekrun & Perry, 2014). In sum, the conflict between self-concept and new concepts presented by educational refutations creates a complex learning

situation that implicates individuals' appraisals of value and thus their emotions pertaining to revising what they think they know.

In such situations when personal and external knowledge are in conflict, emotions are presumably more active and relevant since the potential for cognitive incongruity may be higher and thus may activate emotions focused on the epistemic nature of the task (Muis et al., 2015). Epistemic emotions are produced from cognitive qualities of knowledge tasks and knowledge-generating activities (Pekrun & Linnenbrink-Garcia, 2014; Pekrun & Stephens, 2012) and may include surprise, curiosity, enjoyment, confusion, anxiety, frustration, or boredom. Philosophers of epistemology contend that such emotions can provide insights into phenomena by directing perceived salience and attention (Brady, 2013; Elgin, 2008; Morton, 2010).

Recent empirical evidence shows that epistemic emotions are active (D'Mello & Graesser, 2012, 2014) and influential during learning, affecting intrinsic motivation (Kang et al., 2009), type of strategies used (Muis et al., 2015), and learning outcomes (D'Mello, Lehmann, Pekrun, & Graesser, 2014). In their comprehensive review, Fiedler and Beier (2014) note that negative emotions may facilitate conscientiousness, avoidance of surface level errors, selective attention on task-relevant stimuli, and detailed representations, whereas positive emotions facilitate constructive inferences, creative problem-solving, and higher-order organization and integration of complex stimuli. In the context of reading comprehension, Bohn-Gettler and Rapp (2011) found that participants who received a positive emotion induction engaged in a greater proportion of coherence building text-based inferences and paraphrases than those who received a negative or neutral induction, respectively (see Bohn-Gettler and Rapp (2014) for an extensive review). Further, positive emotions more than negative emotions promote additional reading processing time, comprehension (Scrimin & Mason, 2015), and attitude change during

knowledge revision (Broughton, Sinatra, & Nussbaum, 2013) whereas negative emotions mediate the relations between identity-threatening science communication and negative evaluation of scientific findings (Nauroth et al., 2014).

Current Study

Central to the current study is the contention that the backfire effect may be attributable to the negative processing consequences of negative emotions that occur when there is a conflict between self-concept and refutational messages. More specifically, if an educational message refutes information that is integral to a salient or valuable aspect of self-concept, individuals may appraise this learning situation as threatening to their attainment value that leads to experiencing negative emotions, which in turn negatively affect learning. Thus, based on theoretical and empirical considerations we present the following hypotheses:

Hypothesis 1: We expect to replicate the backfire effect, wherein lower learning scores will be observed for individuals reading a refutation message that conflicts with some salient aspect of their self-concept (Kendeou et al., 2013; Kendeou et al., 2014; Nyhan & Reifler, 2010, 2015b; Nyhan et al., 2014; Nyhan et al., 2013);

Hypothesis 2: Self-concept will predict negative emotions while reading a refutational text (Eccles, 2009; Eccles & Wigfield, 2002; Gregoire, 2003; Nauroth et al., 2014; Pekrun, 2006; Pekrun et al., 2009; Pekrun & Perry, 2014);

Hypothesis 3: Negative emotions will mediate the relation between self-concept and learning from a refutational text (Bohn-Gettler & Rapp, 2011, 2014; Muis et al., 2015) (see Figure 5).

In sum, we hypothesized the relationship between self-concept and learning is mediated by negative emotions, which in turn are moderated by the experimental condition. To test these hypotheses, we randomly assigned participants to receive an expository text on genetically modified organisms (GMOs) or a refutational text on the same topic, which identified common misconceptions about GMOs, refuted them, and offered a scientifically-accepted explanation (Tippett, 2010).

Method

Participants

One hundred twenty (*N*=120) undergraduates were recruited to participate from a large public university in North America; 88 were female (73.3%), 32 were male, with an overall mean age of 21.3 years (*SD*=3.9 years), and a mean self-reported GPA of 3.38 (*SD*=.43).

Materials

Dietary Self-Concept. All participants were asked to complete a self-report questionnaire assessing their dietary self-concept (Appendix C). Sixteen Likert-type items were developed for the current study to assess dietary self-concept, of which 10 items were retained for subsequent analysis (e.g., "I take pride in eating healthy") after factor and reliability analyses showed high loadings and very good reliability ($\alpha = .86$) (described in the Results section). Higher scores represent greater perception of the self as concerned with conscientiousness, purity, and health with respect to diet.

Prior Knowledge Test. A 10-item, multiple-choice test of prior knowledge about GMOs was developed for the current study. The content of the questions assessed participants' prior

knowledge of the information that was the subject of the refutations. This measure scored poor reliability (α = .60).

Attitudes towards GMOs. Five Likert-type items adopted from Heddy, Sinatra, & Danielson (2014) were used to assess attitudes towards GMOs ("I approve of genetically modified foods"), which showed good reliability (α = .80).

Texts. Two texts adopted from Heddy et al. (2014) that presented information on GMOs were used in this study, one expository and one refutational. Both texts were roughly equivalent in length (617 versus 624 words, respectively) and Flesch-Kincaid Reading Ease (42.1 versus 42.2, respectively). The refutational text presented the same informational content as the expository text but within a refutational format that explicitly identifies a common misconception, refutes it, and presents the scientifically valid explanation (Appendix D). Four refutations were presented that targeted common misconceptions on the use of hormones and cloning in relation to genetically modified foods, and misconceptions on whether genetic modification can be a naturally occurring process that may be performed by farmers and gardeners (versus a product of contemporary scientific research only performed in laboratories by scientists).

Epistemic Emotions Scales. Twenty-one Likert-type items assessed how strongly participants felt various emotions experienced while reading using the Epistemic Emotions Scales (Muis et al., 2015; Pekrun & Meier, 2011). Each item consisted of a single adjective (e.g., "Frustrated") that measured three categories of epistemic emotions: surprise (e.g., "Astonished), positive emotions (e.g., "Curious") and negative emotions ("Anxious"). These three subscales showed very good reliability (α's = .83, .83, .89, respectively) and were used for subsequent analysis.

Learning Outcomes. To measure learning, participants completed the multiple-choice pre-test again, which showed acceptable reliability at retest ($\alpha = .70$), and were asked to write a brief argumentative essay for or against GMOs.

Procedure

All participants provided informed consent and were informed that they would be completing a post-test at the end of the session. Next, all participants completed the dietary self-concept measure, prior knowledge test, and attitude assessment in the same fixed order. Then, participants were randomly assigned to one of two experimental conditions; participants were randomly assigned to read an expository text ($n = 58$) or a refutational text ($n = 62$). Immediately following reading, all participants were asked to report on their emotions experienced during reading and then to complete the knowledge test and brief argumentative essay task. Demographics were collected at the end of the study and participants were compensated $10 for their time.

Results

Preliminary Analyses

We examined each variable for skewness and kurtosis. Emotion subscales were positively skewed. Following Tabachnick and Fidell (2013), we conducted a square-root transformation on these variables to normalize each distribution. All other variables were within a normal range (absolute values were less than 3). Descriptive and correlational statistics for all variables by condition are presented in Table 10 (refutation) and Table 11 (expository).

An exploratory factor analysis of the 16 items of the self-concept scale was performed on the current data using IBM SPSS. A set of uncorrelated components in the measure was identified using a principal components analysis with varimax rotation. The mean Kaiser-Meyer-

Olkin measure of sampling adequacy was .81, indicating the data were suitable to principal components analysis. Similarly, the Bartlett's test of sphericity was significant ($\chi^2 = 557.54$, $df = 120$, $p < .001$). The analysis revealed five factors whose eigenvalues were ≥ 1, accounting for 62.1% of the total variance in the measure. However, inspection of the scree plot indicated that there should be one factor to be retained. In addition, six items revealed an item-factor loading score of less than 0.50. Thus, we deleted these items from the measure and set the number of factors to extract at one in SPSS and re-ran the analysis with the remaining 10 items (Appendix C). The factor solution revealed the one interpretable factor accounting for 44.4% of the total variance in the measure. The average of these 10 items was used in subsequent the analysis.

Moderated Mediation Path Analysis

To test the moderated mediation model depicted in Figure 5, we used Hayes and Preacher's (2014) PROCESS SPSS macro, which is recommended with complex mediational models as it maintains higher levels of power while controlling for Type I errors (Preacher & Hayes, 2008).

Following a similar analytical strategy as Pekrun et al. (2009), we first calculated the total effects model, which expresses the sum of the direct and indirect effects of self-concept on learning scores to determine the predictive relations between self-concept and of the texts independent of the effects of mediational variables. Following this, we calculated the direct effects of self-concept predicting epistemic emotions, the direct effects of epistemic emotions on learning, and the indirect effects of self-concept on learning via epistemic emotions, to determine if emotions significantly mediated relations between self-concept and learning. At each step, we calculated whether these predictive paths were moderated by the experimental condition (i.e.,

expository vs. refutation text) and controlled for the effects of prior knowledge and attitudes towards GMOs.

Total effects of self-concept on learning. The total effects model with covariates for self-concept on learning was significant, $F(3, 116) = 10.99$, $p < .001$, $R^2 = .221$, which showed that the model accounted for 22.1% of the variance associated with learning. Prior knowledge ($\beta = .28$, $t = 3.09$, $p < .01$) and Positive Attitudes towards GMOs ($\beta = .30$, $t = 3.13$, $p < .01$) were positive predictors of learning. However, Self-Concept was not a significant predictor ($p > .5$), which does not support Hypothesis 1 that predicted a direct negative relationship between self-concept and learning.

Emotions as mediators between self-concept and learning. To examine the direct and indirect predictive relations between self-concept, epistemic emotions, and learning, parallel moderated mediation analysis was conducted with PROCESS (Hayes & Preacher, 2014). This allows the estimation of all direct predictive effects of self-concept and three categories of epistemic emotions simultaneously on learning moderated by text condition.

Self-Concept, Text Condition (dichotomized), and the interaction term Self-Concept × Text Condition were entered into a model that predicted surprise along with Prior Knowledge and Positive Attitude covariates. The model predicting surprise was significant, $F(5, 114) = 5.64$, $p < .001$, $R^2 = .198$, which showed that the model accounted for 19.8% of the variance associated with surprise. Only Prior Knowledge was a significant negative predictor, $\beta = -.41$, $t = -4.39$, $p < .001$, indicating that those with more knowledge about GMOs prior to reading the texts reported less surprise during reading.

The model predicting positive emotions was not significant, $F(5, 114) = 1.27$, $p > .25$. However, the model predicting negative emotions was significant, $F(5, 114) = 5.08$, $p < .001$, R^2

= .182, which showed that the model accounted for 18.2% of the variance associated with negative emotions. Positive Attitudes towards GMOs was a significant negative predictor, β = -.32, t = -3.26, p < .01, such that those with more favorable attitudes towards GMOs reported less negative emotions during reading. Self-Concept was a significant positive predictor of negative emotions, β = .28, t = 2.46, p < .05, such that those scoring higher on the self-concept measure reported greater negative emotions during reading. The interaction Self-Concept × Text Condition was also a significant predictor, β = -.44, t = -2.53, p < .05, such that those scoring higher on the self-concept measure reported the highest negative emotions while reading the refutational text. This interaction is plotted with mean reported anxiety in Figure 6, which was typical of the pattern for negative emotions. These findings support Hypothesis 2 where self-concept predicted negative emotions within a refutational context.

Finally, to test the last hypothesis that negative emotions mediate the relations between self-concept and learning while reading a refutational text, we calculated the full moderated mediation analysis. Results showed that when Self-Concept, Text Condition, Self-Concept × Text Condition interaction were entered into the model predicting learning with Surprise, Positive Emotions, Negative Emotions and Prior Knowledge and Positive Attitudes covariates, the overall model was significant, $F(11, 108) = 7.39$, $p < .001$, $R^2 = .429$, which showed that the model accounted for 42.9% of the variance associated with learning. The two covariates remained significant positive predictors of learning (Prior Knowledge: β = .31, t = 3.27, p < .01; Positive Attitudes: β = .26, t = 2.84, p < .01). Text Condition was a significant predictor of learning, β = -.78, t = -5.30, p < .001, indicating that those in the refutation condition scored higher on the post-test after controlling for the effects of prior knowledge and attitudes. Negative Emotions was a significant negative predictor of learning, β = -.33, t = -2.94, p < .01. Further, the

interaction term Negative Emotions × Text Condition was also a significant predictor of learning, $\beta = -.44$, $t = -2.62$, $p = .01$, indicating that negative emotions reported while reading the refutational text negatively predicted post-test learning. A summary of all significant standardized effects is depicted in Figure 7.

A test of the moderated mediation paths showed that self-concept had negative indirect effects on learning that were significantly mediated by negative emotions only for those individuals within the refutational condition but not the expository condition, with a standardized point estimate of -.09 and bias corrected bootstrapped confidence intervals (95%) of -.22 to -.02. No other emotion was a significant mediator.

Discussion

The current study investigated the roles of self-concept and emotions while learning from refutational messages. We contended that these constructs might offer one potential explanation for the backfire effect that researchers observe during some instances of knowledge revision. By and large, the current findings support this contention. That is, results from this study support our hypothesized relations and extend current theoretical models on knowledge revision by specifying and testing the effects of self-concept and epistemic emotions on memory for information about a controversial topic. Specifically, although self-concept did not directly negatively predict memory for text (Hypothesis 1), self-concept did predict negative emotions and importantly, interacted with the refutation text condition to predict negative epistemic emotions (Hypothesis 2). Last, negative emotions mediated the relation between self-concept and fundamental aspect of learning. Crucial to the current study was the finding that this mediational path was moderate by text condition, such that this relationship was only significant when individuals read a refutational text and not when they read an expository text (Hypothesis 3).

Overall, the findings are among the first to show that conflicts between refutational messages and salient and valued aspects of self-concept negatively affect a fundamental aspect of knowledge revision wherein emotions may act as one mechanism and therefore advance our understanding on these socially relevant learning processes. We address each point in turn and conclude with a discussion of the limitations of the study and directions for future research.

Effects of Self-Concept in Controversial Knowledge Revision

The current findings largely support our predictions of the relations between self-concept and epistemic emotions during knowledge revision of a controversial topic. We obtained evidence that self-concept predicted negative epistemic emotions, including confusion, anxiety, and frustration. More specifically, individuals who reported that high degree of conscientiousness and valued achieving some ideal of dietary purity (e.g., strongly agreeing to "I seek out organic food when I shop for groceries") experienced more negative epistemic emotions. Importantly, this effect was more pronounced in the refutation condition compared to the condition without the refutation structure, where we predicted that the refutation would implicate aspects of individuals' self-concept (Gregoire, 2003). Accepting the premise of refutations could be seen as undermining attaining identity-related needs, such as maintaining identity integrity, and therefore the message may be appraised as threatening (Eccles, 2009; Eccles & Wigfield, 2002; Gregoire, 2003). We contend that the formation of threat appraisals is analogous to perceiving a situation to have negative attainment value, which, according to Pekrun (2006; Pekrun & Perry, 2014), is one theoretical antecedent to experiencing negative emotions. These findings represent unique theoretical and methodological contributions to understanding the roles, measurement, and mediational effects of self-concept during knowledge revision.

However, we did not find evidence of a negative relation between self-concept and learning that would have been an unequivocal indication that we replicated the backfire effect in the current study. Despite this, Zhao, Lynch, and Chen (2010) contend that a significant effect between an independent and dependent variable is not relevant to establishing mediation. According to Zhao et al. (2010), if the direct and indirect paths in mediation analysis have opposite signs (i.e., positive and negative coefficients) then a situation that they refer to as competitive mediation may occur wherein the total relations between predictor and predicted variable can be close to zero and no statistically significant relation detected. In the current study, the indirect path was significantly negative ($\beta = -.09$). Due to sampling error it is plausible that the coefficient between self-concept and learning may have had a small positive value, which would attenuate the total effects model. In the current study this path did have a non-significant positive coefficient of $\beta = .04$ ($p = .66$). Therefore, despite the theoretical and methodological contributions of this paper, there is room for future research. Following the recommendation of Zhao et al., we present a focused discussion on these effects in the Future Directions section.

In sum, individuals' self-concept scores did not provide a reliable indication of their subsequent learning scores in the current study. However, individuals who reported that dietary purity was a salient and valued component of their self-concept did report the highest negative emotions during reading, which did provide a reliable indicator of learning. Importantly, this effect was more pronounced in the refutation condition. We turn to the effects of epistemic emotions within this experimental condition next.

Epistemic Emotions as Mechanisms in Knowledge Revision

Prominently, the current study found evidence that epistemic emotions mediate relations between self-concept and learning. The current findings advance theoretical models for role of emotions in knowledge revision, including their antecedents and consequences, and extend these models to the context of learning about knowledge that conflict with self-identity. In particular, negative emotions negatively predict post-test learning scores after controlling for the effects of prior knowledge and positive attitudes. This finding indicates that negative emotions may have impeded recall of information central to the refutational message or promoted avoidance in processing its content. Furthermore, results from the moderated mediation analysis showed that this significant path was only present within the refutational condition. These findings are consistent with our hypotheses and past research on the effects of negative emotions on the more general cases of learning and reading comprehension and on the specific case of processing identity-threatening messages. Previous research has shown that negative emotions (compared to positive emotions) were less likely to result in coherence-building inferences during reading (Bohn-Gettler & Rapp, 2011), less likely to result in integration of unexpected information (Pinheiro et al., 2013), and more likely to result in poorer memory for texts (Ellis, Moore, Varner, Ottaway, & Becker, 1997; Ellis, Ottaway, Varner, Becker, & Moore, 1997; Ellis, Seibert, & Varner, 1995; Ellis, Varner, Becker, & Ottaway, 1995). Relatedly, in the context of knowledge revision paradigms, the findings of the current study are consistent with previous research that has shown that negative emotions were less likely to result in change in attitudes about a science phenomenon (Broughton et al., 2013) and more likely to result in a critical evaluation of science communication messages (Nauroth et al., 2014).

However, it should be noted that a number of the aforementioned studies experimentally induced affect and it was therefore incidental to the semantic content of the task, whereas a

contribution of the current study was to examine the effects of naturally occurring emotions integral to the semantic content. The distinction is meaningful since experimental induction of some dimensions of emotions, like arousal, is likely to be irrelevant to the task and may lead to variable performance whereas integral arousal can sometimes be adaptive for performance (Bennion, Ford, Murray, & Kensinger, 2013). In general, though, not enough research has examined the effects of emotions on reading comprehension and text-based knowledge revision (Bohn-Gettler & Rapp, 2014). Often, research in this area has examined incidental emotions, word-level processes, norm-referenced emotional stimuli, and inferences about narrative characters' emotions. In contrast, future research should examine the effects integral emotions experienced during reading on naturalistic passage-level comprehension processes. Furthermore, emotions focused on the epistemic nature of the task – which, in the current study, was a conflict over what is known to be true – may have different effects than other emotional stimuli and inductions used in previous research. For instance, a given experimental stimulus for negative emotions like the word "bomb" or an induced sadness state likely result in dissimilar effects on memory and comprehension processes than negative epistemic emotions, which may account for the avoidance intention described by (Gregoire, 2003) as underlying failure of knowledge revision.

Indeed, theoretical contributions of the current study include developing and testing an integrated framework that may account for why some attempts at knowledge revision fail and backfire. Nyhan and colleagues (Nyhan & Reifler, 2010, 2015a; Nyhan et al., 2014; Nyhan et al., 2013) note that the backfire effect is due to motivated reasoning where individuals marshal cognitive resources to arrive at a predetermined outcome. In the case of the backfire effect, researchers speculate that this outcome is an identity-protective action in response to threatening

refutational messages, which results in greater skepticism and counter-arguing refutations (Nauroth et al., 2014, 2015). Notably, Kendeou et al., (2013, 2014) describe that this competitive activation among information is a core determinant of the success or failure of knowledge revision.

One potential account for this motivated reasoning is Pekrun and Perry's (2014) assertion that negative activating emotions like the ones observed in the current study display complex relations to motivated performance. For example, in some instances anxiety and confusion can undermine motivation whereas in other instances these emotions can prompt motivation to avoid failure (D'Mello, Lehman, Pekrun, & Graesser, 2014; Pekrun & Perry, 2014). Currently, we contend that negative epistemic emotions may account for motivated reasoning to avoid processing and learning identity-threatening knowledge. The findings from the current study provide support for this contention by demonstrating how negative epistemic emotions mediate the relation between identity and a fundamental learning process.

Limitations and Future Directions

The conclusions of the current study are limited in several ways. First, we did not observe a relation between self-concept and learning, which would have been clear evidence of the backfire effect. However, our dependent variable in this study was memory for important text information fundamental to learning, whereas studies on the backfire effect often assessed higher-order learning directly. Thus, this effect may be observable on measures that assessed attitude preference. However, the current post-test assessing memory nonetheless represents an important fundamental learning process affected indirectly by self-concept.

Second, we did not include a measure of cognitive processes that yet may still mediate relations between emotions and achievement (Pekrun, 2006; Pekrun & Perry, 2014). These likely

include the strategic use of learning strategies and self-regulation of learning (Muis, 2007; Muis et al., 2015) as well as potentially more automatic processing (Kendeou et al., 2013). We recommend that future research include process measures for these constructs, evinced in eye-tracking, concurrent verbalizations, or reading times. Likewise, the self-report measurement of emotion can be complemented by and triangulated with additional physiological measures, such as analysis of electrocardiograms or facial expressions (Daley, Willet, & Fischer, 2014; D'Mello et al., 2014)

Another future direction would be to see how the refutation messages are conceptually framed in different ways that activate salient and valued aspects of other self-concepts that are more amendable to processing the message. For instance, if educational messages about GMOs are framed only as natural versus unnatural food then self-conceptions of valuing dietary purity activate and increase the likelihood of the message backfiring. However, if the debate prefaced with information on using innovation to feed the world's hungriest, this could activate self-conceptions related to entrepreneurship, generosity, or compassion, potentially turning down the temperature on the rest of the message's content. We could then perhaps see more agreement on what we collectively believe is known.

Conclusion

Overall, the current findings have important theoretical implications for research on knowledge revision. In particular, refutations that conflict with salient aspects of self-concept can give rise to emotional reactions. Self-concept may serve as input into setting up perceptions of attainment value for learning new knowledge. If self-concept is perceived to be threatened, then negative emotions may be generated that negatively affect measures of learning, either through avoiding processing the message, undermining its arguments, or activating prior knowledge that

conflicts with it. We therefore surmise that emotional experiences differentially motivate the use of these cognitive processes that future research can explore.

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Table 10.
Descriptive and Correlational Statistics for Control Variables, Self-Concept, and Epistemic Emotions During Reading of Refutational Text.

	1	2	3	4	5	6	7
1. Prior knowledge [a]	.42 (.20)						
2. Positive attitude [b]	.45**	3.58 (1.16)					
3. Self-concept [b]	-.14	-.38**	4.28 (.98)				
4. Surprise [c]	-.34**	-.25	.21	2.35 (.97)			
5. Positive emotions [c]	.01	-.15	.31*	.65**	1.62 (.20)		
6. Negative emotions [c]	-.09	-.41**	.39**	.38**	.23	1.20 (.22)	
7. Post-test knowledge [a]	.41**	.50**	-.05	-.22	.06	-.41**	.84 (.19)

Note. Means and standard deviation are on the diagonal. [a]proportion correct; [b]1-7 Likert scale; [c]1-5 Likert scale.
* $p < .05$. ** $p < .01$.

Table 11.
Descriptive and Correlational Statistics for Control Variables, Self-Concept, and Epistemic Emotions During Reading of Expository Text.

	1	2	3	4	5	6	7
1. Prior knowledge [a]	.45 (.21)						
2. Positive attitude [b]	.32*	3.58 (1.03)					
3. Self-concept [c]	.20	-.25	4.20 (1.12)				
4. Surprise [d]	-.46**	.022	-.14	2.12 (.81)			
5. Positive emotions [d]	-.06	.06	-.07	.59**	1.59 (.21)		
6. Negative emotions [d]	-.23	-.30	-.07	.37**	.28*	1.19 (.19)	
7. Post-test knowledge [a]	.48**	.34**	-.03	-.17	.03	-.08	.70 (.20)

Note. Means and standard deviation are on the diagonal. [a]proportion correct; [b]1-7 Likert scale; [c]1-5 Likert scale.
* $p < .05$. ** $p < .01$.

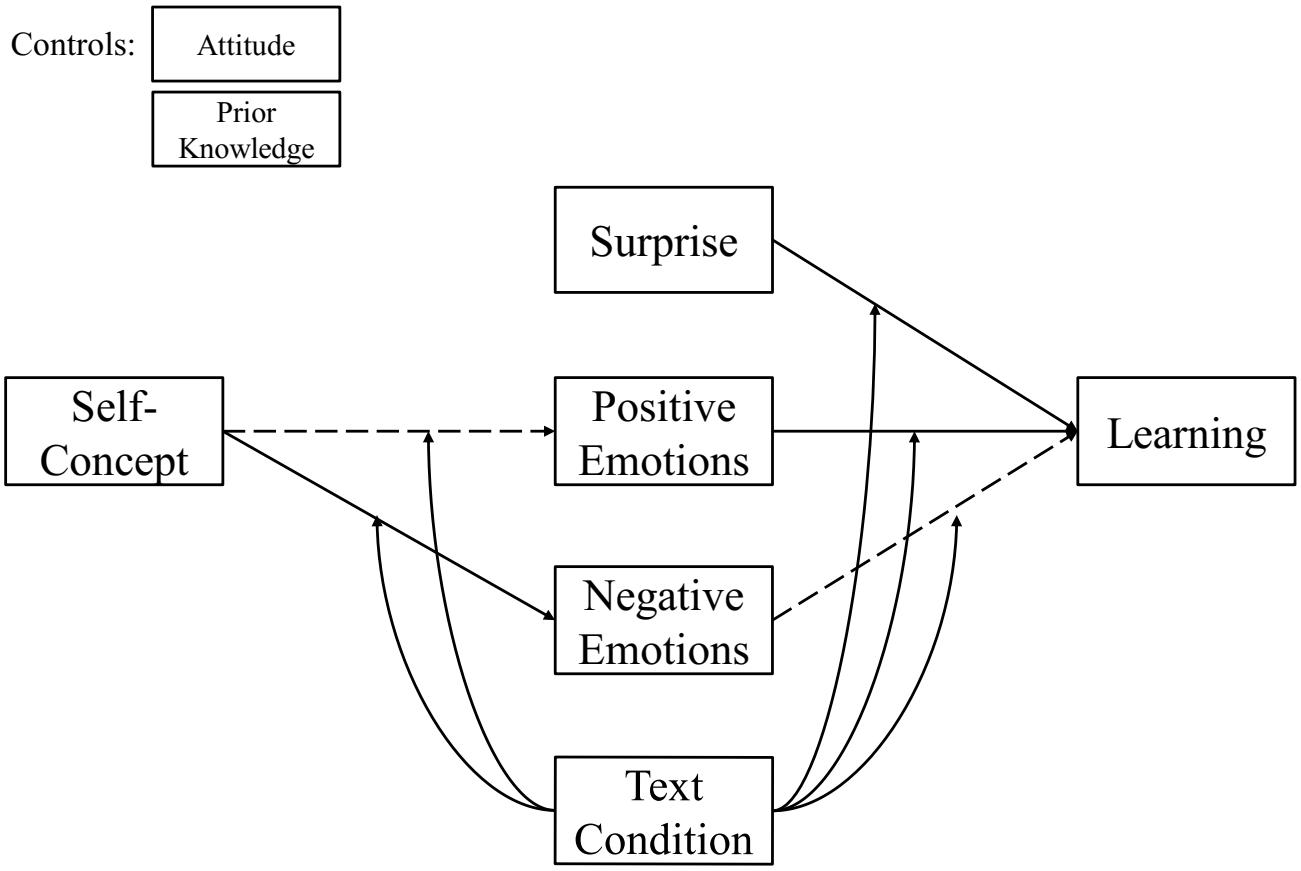

Figure 5. Hypothetical moderated mediation relations between self-concept, epistemic emotions, and post-test learning while reading. Solid lines represent positive predictive relations whereas dashed lines represent negative predictive relations.

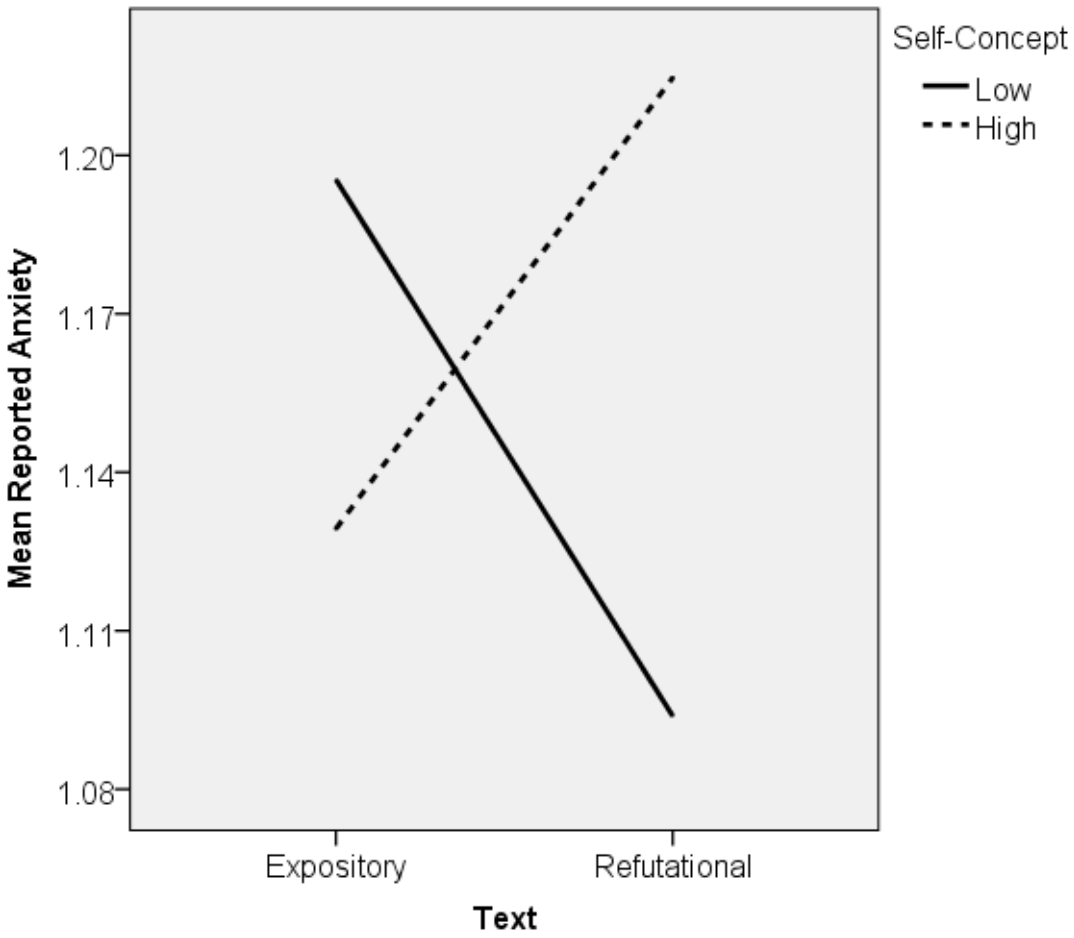

Figure 6. Plotted interaction between text condition and high and low self-concept groups on mean reported anxiety while reading. This pattern was typical for all negative activating emotions (i.e., confusion, anxiety, and frustration).

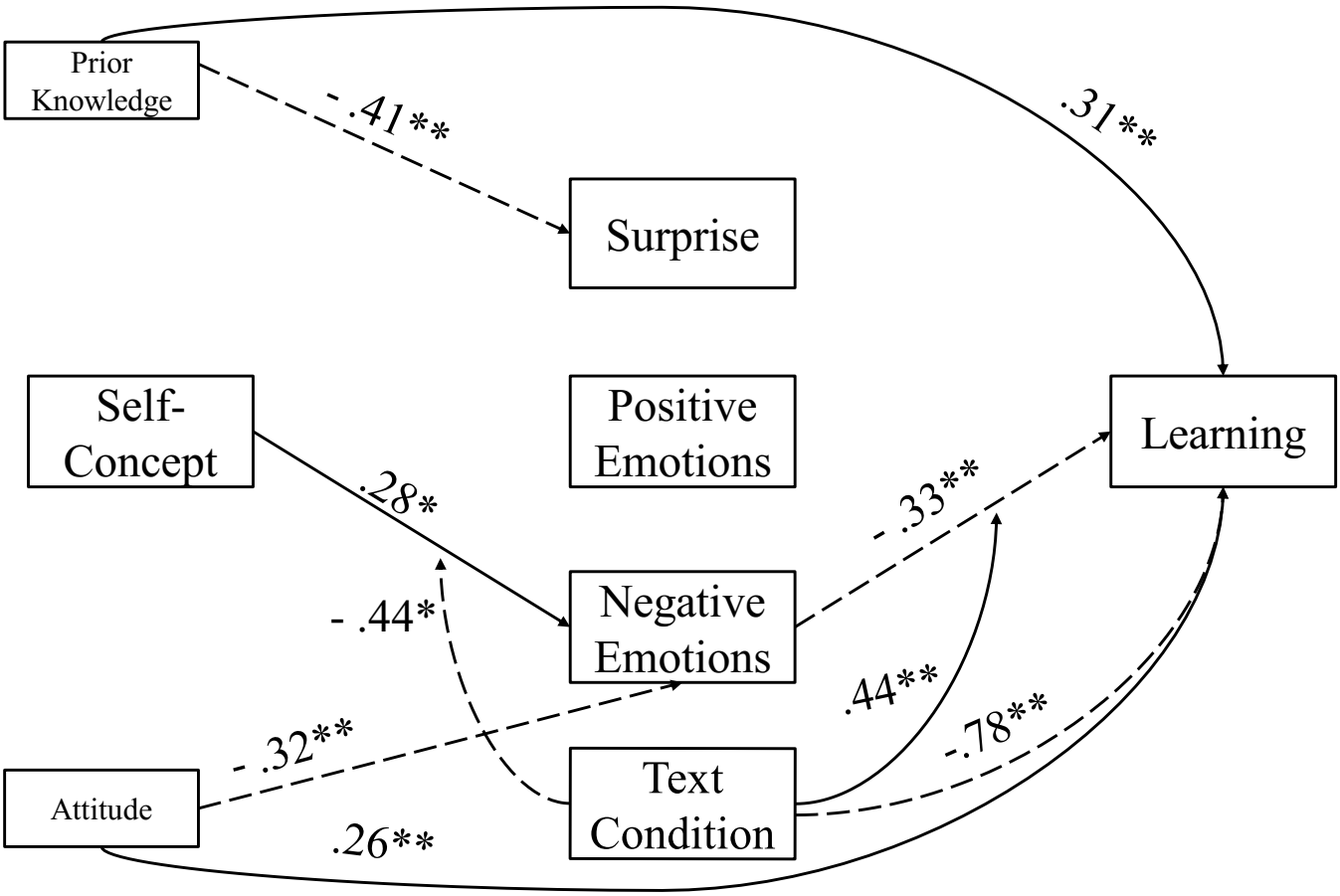

Figure 7. Summary of standardized effects for moderated mediation path analysis of self-concept, emotions, and learning while reading. Solid lines represent positive predictive relations whereas dashed lines represent negative predictive relations.

* $p < .05$

** $p < .01$

Appendix C
Dietary Self-Concept Measure

(NB: Items marked with * were retained after factor analysis)

1) * I take pride in eating healthy.
2) * I have a personal diet that I consistently adhere to.
3) * I keep up to date on news about diet trends.
4) My body is sensitive (but not allergic) to some foods.
5) I regularly partake in recreational activities that introduce toxins into my body.
6) * I am very aware of the nutritional value of the foods I eat.
7) * I seek out organic foods when I shop for groceries.
8) I worry whether my food was cooked or prepared properly.
9) I am careful to wash my store bought produce every time before eating.
10) * I pay close attention to health labels on foods such as "all natural" or "antioxidant."
11) * I like to shop at farmers' markets because how my food is grown or raised is very important to me.
12) * I avoid activities or substances that may introduce toxins into my body.
13) * It upsets me if I am unable to choose foods that fit with my dietary preferences.
14) * I often think about the lasting effects of the foods I eat.
15) I believe the practices of cleansing or detoxing have important nutritional and/or health benefits.
16) I make sure I am aware of all the potential side effects of any medications I take.

Appendix D
Example Refutation Segment (1 of 4)

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.

Chapter 6

Final Discussion

Research on epistemic cognition has burgeoned in recent years and has illuminated new epistemic structures (Chinn, Buckland, & Samarapungavan, 2011; Elby & Hammer, 2010; Greene, Torney-Purta, & Azevedo, 2010; Muis & Duffy, 2013; Muis, Bendixen, & Haerle, 2006; Stahl & Bromme, 2007), integrated existing perspectives into older research traditions (Barzilai & Zohar, 2014; Bråten, Britt, Strømsø, & Rouet, 2011; Muis, 2007; Muis et al., 2015), and uncovered multiple relations to meaningful educational outcomes (Barzilai & Eshet-Alkalai, 2015; Bromme & Goldman, 2014; Lee, Chiu, Liang, & Tsai, 2014; Mason, Pluchino, & Ariasi, 2014; see Greene, Sandoval, & Bråten, 2016, for an extensive review).

However, the measurement of epistemic cognition has been notoriously difficult. Such challenges include attaining strong indicators of reliability, construct and predictive validity. As concluded in Chapter 2, these issues may originate in how epistemic cognition has been conceptualized and its alignment with the methodological choices of researchers. Furthermore, these issues likely have stymied advancement of theories and impact on educational practice.

In the current dissertation I adopted new conceptualizations, research designs, data sources, and analytical techniques with the intent to address some of these issues. The findings from the present studies include new ways of investigating the specific relations of epistemic cognition to important cognitive, metacognitive, emotional, and learning variables. Therefore, the conclusions drawn from this dissertation contribute meaningfully to advancing our knowledge on theoretical and methodological issues and may add important information with regard to how to develop educational interventions.

Specifically, in this dissertation I have made several key conclusions. First, on the basis of a comprehensive literature review, I have illuminated consensus positions among leading theorists about the components of epistemic cognition and related mediating constructs that are

likely active in a given learning context and how their effects can be measured. Second, on the basis of a multi-study, mixed method design where I triangulated data from eye tracking, computer log files, and qualitative interviews, I concluded specific relations exist between epistemic cognition and self-regulated learning while processing discrepancies in science multimedia and also highlighted epistemic self-efficacy as a potentially valuable construct for further inquiry. Third, with the use of mediational analysis and text-mining techniques, I concluded further evidence to the growing support for the role of epistemic emotions as mediators between epistemic cognition and learning (Muis et al., 2015) and have extended this relation to specific facets of reading comprehension in scientific texts. Fourth and finally, I have concluded that epistemic emotions are likewise active mediators between self-concept and learning for controversial science knowledge. Taken together, across the current studies, epistemic cognition and related constructs are shown to relate to important cognitive, metacognitive, and emotional variables in addition to educational outcomes on understanding controversial science knowledge.

In concentrating on these research issues I have attempted to add to, refine, and extend our theoretical knowledge about epistemic cognition along three themes that have connected the chapters of this dissertation: (1) controversial science knowledge; (2) new research methodologies; and (3) epistemic emotions. First, across all empirical chapters, I have sought to extend theories of epistemic cognition to consideration of science knowledge in controversy at multiple levels of granularity (i.e., knowledge discrepancies within a source, discrepancies between sources, and discrepancies between individuals and sources). Second, across chapters I have shown how the measurement of epistemic cognition can be refined to examine process-level data and relations to specific facets of other constructs. Third and relatedly, an important

aspect of this objective has been to add to theories on the role of potential constructs that mediate the relations between epistemic cognition and controversial science learning; to this end the current chapters add to the growing support for the mediating role of epistemic emotions as a relevant educational psychology variable.

In the following sections, I will first address potential limitations and then I will discuss future directions for research in this area. Then I will end with a discussion of practical implications of epistemic cognition in understanding controversial science knowledge.

Limitations of the Present Dissertation

The conclusions drawn from the current dissertation are potentially limited in several ways. First, the use of contrived discrepancies within a single source and between multiple sources may not fully capture the range of psychological responses possible in more authentic settings. More specifically, the discrepancies encountered in real-world settings may not be as obvious or proximal to one another as was the case in the current research. Therefore, individuals may engage in different types or intensities of epistemic or learning processing in more authentic settings. Nevertheless, the findings from these empirical studies do reveal individuals' psychological responses to the nature of the current discrepancies, and how these responses relate to their epistemic cognition, which I have attempted to present with fine-grained and contextualized analysis. In so doing, I sought to respond to calls to adopt a "double-track" approach to the study of individuals' epistemic cognition and the epistemic context in which it is active (Bromme, Pieschl, & Stahl, 2010). Relations observed in the current studies are therefore likely to be representative of ecologically valid processing of some forms of controversial knowledge used in the current dissertation and may provide insights into habitual patterns or response tendencies to other forms of controversies.

Second, the experimental science content individuals were presented in the current research may differ from the content that would typically be relevant in their lives. Therefore, individuals' type and intensity of motivation to process experimental content likely differs from the studying they engage in from day-to-day (or the night before an exam). This difference in motivation likely has different implications for the strength of the relations between epistemic cognition and learning variables. Moreover, relations between epistemic cognition and motivation remained largely unexplored in the current dissertation save for a discussion on epistemic self-efficacy at the end of Chapter 3. Thus, deeper integration between epistemic cognitive and motivation research traditions represent worthy and likely fruitful avenues for future work.

Last, data on the relations between emotions, cognitive processes, and achievement was not collected in Chapters 4 and 5. As Pekrun (2006) notes, emotions are predicted to affect learning achievement indirectly, mediated through various psychological mechanisms that include cognitive resources (e.g., attention and working memory), use of learning strategies, memory processes, motivation to learn, and self-regulation of learning. Therefore, questions remain on the cognitive mechanisms that mediate epistemic emotions and learning (cf. Muis et al., 2015). However, conclusions from Chapter 3 show the specific relations between epistemic cognition and some types of cognitive and metacognitive processes that may present a promising starting point for this future research.

Future Directions

At this point, the discussion of the limitations of the present research has already indicated areas in need of future research. However, two avenues of future research are worthy of a fuller discussion. Specifically, questions remain on the role of cognitive mechanisms and the

long-term relations between epistemic cognition and learning across the lifespan. Future research can productively build off the findings from the current dissertation by examining these questions.

Cognitive mechanisms. The development of sound interventions to promote better learning outcomes will depend on what we know about learning processes. That is why it is crucial that researchers examine the cognitive mechanisms that account for the relations between epistemic cognition and learning outcomes beyond the emotional mediators collected in the current studies. A growing body of empirical work has indeed begun to investigate cognitive and metacognitive processes related to epistemic cognition (Barzilai & Eshet-Alkalai, 2015; Hsu, Tsai, Hou, & Tsai, 2014; Muis et al., 2015; Pieschl, Stallmann, & Bromme, 2014). This is especially important in online learning environments that depict complex or controversial knowledge where epistemic cognition is likely to be most active and relevant, as seen in Internet-based searches for health-related information (Kammerer, Amann, & Gerjets, 2015). As shown in Chapter 3, cognitive and metacognitive processes related to epistemic cognition can be inferred from eye tracking and computer log files. Future work can extend this line of research by examining the relations between epistemic cognition and cognitive variables evinced in think-aloud protocols or classroom discourse, hypermedia navigational patterns in online environments, and eye tracking on epistemically-relevant areas of interest (such as source information). Such empirical investigations into the cognitive mechanisms related to epistemic cognition can serve as the foundation for interventions; these possibilities are discussed more in length in the section on practical implications of research on epistemic cognition.

Relations between epistemic cognition and learning across the lifespan. With respect to the long-term effects of epistemic cognition on lifelong learning, little is known. The current

studies were conducted in single laboratory sessions, none lasting more than three hours. Therefore, the present data do not allow for strong inferences of the role of epistemic cognition over the course of the lifespan. Relations between epistemic cognitive and learning processes in specific, short-term learning situations may not inform researchers of the long-term relations between epistemic cognition and a myriad of other important occurrences in individuals' lives: the habitual patterns and topics of discourse with family and friends; entertainment and media individuals consume; educational achievements they pursue; career pursuits and professional training; significant purchases or investments (e.g., cars, mortgages, retirement plans); health-related decision-making (for themselves and loved ones); voting behaviors; and in general, how they inform themselves in a present-day knowledge society in order to make important decisions in the face of uncertainty and risk. Further, the relations between epistemic cognition and how individuals respond to each of these issues likely drastically changes from adolescence to early, middle and late adulthood. Cross-sectional and developmental studies could then also begin to address the limitations associated with one-point-in-time correlational designs. Thus, there are many worthy research questions remaining for the role of epistemic cognition across the lifespan. Such empirical research and the findings from the current dissertation can add important information for the design of educational interventions and messages for controversial topics.

Practical Implications of Epistemic Cognition for Learning about Controversial Science Knowledge

Through the identification of specific and significant cognitive, metacognitive, and emotional variables that relate to epistemic cognition, the current dissertation reveals several mechanisms on which educators can focus their attention. Although interventions to change epistemic cognition sometimes show mixed and counter-productive results (Kienhues, Bromme,

& Stahl, 2008) and that it is likely a long-term development (Muis & Duffy, 2013), interventions can be designed to promote adaptive epistemic cognitive processes in specific contexts.

A computer-based learning environment could present scientific content of personal relevance and a problem for a learner to solve. This system could also relay an animated pedagogical agent that would administer a pre-assessment for maladaptive epistemic cognition, such as beliefs in simple, structured, certain, and objective science knowledge. The agent could then interact with the learner to bring explicit attention to the maladaptive beliefs about science knowledge, make an argument for their limited productivity in this problem-solving context, and describe the constructivist beliefs about the nature of science knowledge (i.e., complex, unstructured, uncertain, and subjective) with supporting evidence (Kendeou, Braasch, & Bråten, 2015). To complement the epistemic belief refutation, during the problem-solving phase, the agent could prompt and scaffold learning strategies related to constructivist epistemic cognition (e.g., critical evaluation of content, corroboration of multiple sources, down-regulation of negative emotions) that are aligned with the adaptive epistemic cognition advocated earlier by the agent. The sequence of refutation of maladaptive beliefs about knowledge could be repeated at several points for different dimensions of epistemic cognition when the system detects persistent maladaptive strategy-use (e.g., shallow acceptance of content, use of a single source of knowledge, persistent confusion). The combination of epistemic belief refutation with constructivist strategy scaffolding is the type of comprehensive belief change model that has yet to be put into practice but one that is advocated by leading scholars (Sinatra & Chinn, 2012). Such computer-based learning environments could also continuously and non-invasively collect multiple streams of observational data that could be mapped onto theories of epistemic cognition (Greene, Muis, & Pieschl, 2010). In sum, educational interventions could target a comprehensive

array of specific cognitive, metacognitive, and emotional processes shown in the current dissertation to be related to epistemic cognition with the intent of promoting more constructivist and adaptive learning.

Conclusion

Epistemic cognition has been shown to be an active factor in learning. As individuals encounter more complex issues, such as reconciling diverse perspectives on health treatment options, climate change policies, or the teaching of evolution in schools, possessing a constructivist epistemic cognitive stance will gain increasing relevance in a knowledge-based society. However, as theories and assumptions about epistemic cognition have proliferated, methodological strategies have remained relatively homogenous and stagnant, which has only recently begun to change.

The current dissertation adds to this growing empirical trend. Overall, my objectives for the chapters presented in this dissertation were to review various theoretical assumptions about the underlying structure of epistemic cognition, the alignment between assumptions and methodological choices by researchers, and to empirically investigate fine-grained and contextualized data sources of the relations between epistemic cognition and related cognitive, metacognitive, and emotional mechanisms within the context of learning about controversial science knowledge. In addressing these issues I hope to have illuminated points of concern and paths forward to continue our advancement of knowledge on epistemic cognition and its relations to learning controversial but important knowledge.

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