The Mediating Roles of Attitudes and Epistemic Beliefs in Knowledge Revision

James Aubrey Vivian

Department of Educational & Counselling Psychology

McGill University

June, 2018

A thesis submitted to McGill University

in partial fulfillment of the requirements of the degree of

Masters of Arts in Educational Psychology

© James Aubrey Vivian, 2018

Table of Contents

Abstract

The present study investigated the mediating roles of attitudes and epistemic beliefs in knowledge revision about genetically modified foods (GMFs). One hundred twenty undergraduate students participated. To measure misconceptions about GMFs, students first completed a prior knowledge test. Students then completed self-report inventories to measure their attitudes toward GMFs, as well as their topic-specific epistemic beliefs regarding knowledge and knowing about GMFs. Students were then randomly assigned to read a refutation or expository text about GMFs. Following reading, students completed a knowledge about GMFs post-test to measure knowledge revision. Results of a repeated measures ANOVA revealed participants who read a refutation text change significantly more misconceptions at post-test compared to participants who read an expository text. A stepwise linear regression revealed that beliefs in the complexity of GMFs knowledge significantly predicted attitudes toward GMFs. Path analyses revealed that attitudes towards GMFs significantly mediated the relationship between beliefs in the complexity of GMFs knowledge and post-test knowledge revision. A parallel mediation analysis revealed attitudes toward GMFs and beliefs about the complexity of GMF knowledge significantly mediated the relationship between prior (mis)conceptions and post-test knowledge revision. Theoretical and educational implications for understanding the roles of attitudes and epistemic beliefs in knowledge revision are discussed.

Keywords: attitudes; epistemic beliefs; knowledge revision; genetically modified foods

Resumé

La présente étude a pour but d'évaluer le rôle médiateur de l'attitude et des croyances épistémiques lors de la révision des croyances erronées au sujet des aliments génétiquement modifiés (GM). Cent vingt étudiants de premier cycle ont participé à cette étude. Les étudiants ont d'abord rempli un test de connaissances antérieures au sujet des aliments GM afin de mesurer leurs conceptions erronées à ce sujet et ont auto-rapporté leur attitude face aux aliments GM, ainsi que leurs croyances épistémiques par rapport aux connaissances sur les aliments GM. Un texte soit réfutatif, soit explicatif sur les aliments GM a ensuite été assigné aux étudiants de manière aléatoire. Après avoir lu le texte, les étudiants ont à nouveau complété le test de connaissances sur les aliments GM afin de mesurer la révision des conceptions erronés. Une ANOVA à mesures répétées a révélé que les étudiants qui ont lu le texte réfutatif ont révisé leurs conceptions erronées significativement plus que ceux qui ont lu le texte explicatif. De plus, une régression linéaire a révélé que de croire en la complexité des connaissances sur les aliments GM est un prédicteur significatif de l'attitude face aux aliments GM. Une analyse de pistes causales a révélé que l'attitude face aux aliments GM influence significativement la relation entre la croyance en la complexité des connaissances sur les aliments GM et la révision des conceptions erronées. Une analyse de variables médiatrices a révélé que l'attitude face aux aliments GM ainsi que la croyance en la complexité des connaissances sur les aliment GM influencent significativement la relation entre les connaissances antérieures et la révision des conceptions erronées. Les implications théoriques et éducatives sont abordées.

Mots-clés: révision des conceptions erronés; attitude; croyances épistémiques; aliments génétiquement modifiés

Acknowledgements

I dedicate this thesis to my dearest wife, Valerie, for her unconditional love and support. I could not have completed this work without your continual encouragement and unwavering belief in my ability to succeed. You are truly an inspiration.

You, me, the world!

I would also like to thank my thesis supervisor, Dr. Krista R. Muis, who provided ample space and freedom to enable me to pursue my research interests in the development of this thesis. Many thanks to you for your expert guidance and generous financial support. You have greatly contributed to my professional development, and I appreciate the many opportunities you made available during my time in the program.

Thank you, Krista!

To my fellow lab mates, thank you all for your support. It was a pleasure getting to know many of you. A special thanks to Marianne and Cara for their support, sharing their insights and expertise, and making me feel included and part of a team.

I would also like to thank my course instructors—Dr. Dubé, Dr. Lajoie, Dr. Konishi, Dr. Quintin, Dr. Muis, and Dr. Hoover—from whom I learned about the critical issues and challenges in educational psychology, including how to design empirical research and quantitatively analyze empirical data.

This study would not have been possible without grant support to Krista R. Muis from the Social Sciences and Humanities Research Council of Canada.

List of Figures

List of Tables

List of Appendices

CHAPTER 1

Introduction

A major global increase in the public's mistrust in science has become a particularly challenging problem for learning and education. Take, for example, the recent massive increase in measles outbreaks in North America and Europe (World Health Organization, 2018). This increase in the incidence of measles is a result of parents not vaccinating their children due to false beliefs that vaccines are unsafe, and more specifically, that the measles, mumps, and rubella vaccine (MMR) causes autism (Kata, 2012). This misconception about the vaccine-autism link can be traced back to Wakefield et al.'s (1998) fraudulent study published in the Lancet medical journal that proclaimed a link between the MMR vaccine and autism. Despite its retraction, including the substantial research evidence demonstrating no link between the MMR vaccine and autism, many parents continue to hold false beliefs and negative attitudes towards vaccinations, and consequently, have been increasingly refusing to vaccinate their children due to their misconceptions about vaccines.

Other things being equal, many individuals hold misconceptions about a variety of topics of global significance, including those about nuclear power, climate change, stem cell research, and genetically modified foods (GMFs). Indeed, due to a lack of knowledge, many individuals believe GMFs are unsafe for human consumption and, as a result, hold negative attitudes towards them (Thacker, Muis, Danielson, Sinatra, Pekrun, Winne, & Chevrier, 2017; Heddy, Danielson, Sinatra, & Graham, 2017). In addition to negative attitudes, individuals' epistemic beliefs (i.e., beliefs about the nature of knowledge and processes of knowing) may lead them to reject scientifically accurate information about GMFs if they believe their own knowledge or understanding to be just as valid as those of experts. Taken together, attitudes and epistemic

beliefs play a considerable role in terms of how individuals process, interpret, and evaluate various sources of knowledge and information related to a variety of topics of global significance.

Although some researchers have argued that attitudes and epistemic beliefs are orthogonally independent constructs (Fishbein & Icek, 1975; Schommer, 1994), others have proposed that they are inseparable (King & Kitchener, 1994; Rockeach, 1968). According to Rokeach (1968), an attitude is "an organization of several beliefs focused on a specific object (physical or social, concrete or abstract) or situation, predisposing one to respond in some preferential manner" (Rokeach, 1968, p. 16). In general, beliefs can be defined as personal understandings, convictions, or propositions about the world (phenomena or objects) that are held to be true regardless of veridicality (Richardson, 1996; Wogalter, DeJoy, & Laughery, 2005). Epistemic beliefs, more specifically, refer to personal theories (or individual doxastic assumptions) related to the nature of knowledge and knowing, which are described along the dimensions of structure of knowledge, certainty of knowledge, source of knowledge, and justification for knowing (Hofer & Pintrich, 1997). While attitudes predict the types of information individuals are likely to select and perceive, process and encode, epistemic beliefs play a role in how individuals interpret and evaluate knowledge. Taken together, beliefs can best be understood as the building blocks of attitudes (Dole & Sinatra, 1998; Wogalter, DeJoy, & Laughery, 2005).

The relationship between attitudes and epistemic beliefs have important implications for individual knowledge, learning and understanding (Burrell & Morgan, 1979; Dole & Sinatra, 1998; Hofer & Pintrich, 1997; Silverman, 2007; Sinatra & Seyranian, 2016). Individuals tend to seek out information that is congruent with their attitudes while ignoring attitude-incongruent

information (Maio & Haddock, 2010). Similarly, individuals are likely to interpret and evaluate discrepant knowledge claims within the context of their own personal systems of epistemic beliefs, and subsequently, to reject information that does not conform to their own understanding or topical knowledge. As such, systems of beliefs (and emergent attitudes) can reflect judgements of fact or processes of evaluation that may be derivative of conjecture (Rockeach, 1968). Consequently, individuals often hold misconceptions about important socio-scientific issues that are false from a scientific point of view (Sinatra & Seyranian, 2016).

Misconceptions represent inaccurate knowledge or understanding that departs from scientific knowledge (Heddy et al., 2017). Although scientifically inaccurate, misconceptions serve as explanations for individuals' understanding of scientific topics and issues (Sinatra, Brem, & Evans, 2008). According to Krause, Kelly, Corkins, Tasooji, and Purzer (2009), misconceptions are acquired during previous learning and can negatively impact new learning. Consequently, misconceptions can be counterproductive for learning and performance when individuals are unable to recognize and revise their misconceptions and discriminate between information based on evidence and information derived from opinion, including knowledge that has been contorted to meet social, political, and/or economic gains (i.e., misinformation; Ecker, Hogan, & Lewandowsky, 2017; Sinatra & Seyranian, 2016).

Revising misconceptions (i.e., conceptual change) entails not only the revision of previously acquired inaccurate knowledge, but also requires individuals' change their attitudes and underlying systems of epistemic beliefs. According to Sinatra and Seyranian (2016), changing conceptual knowledge from inaccurate to more accurate conceptions reciprocally leads to changes in attitudes from negative to more positive. Cho, Lankford, and Wescott (2011) note that changing epistemic beliefs inevitably leads to a revision of previously acquired

misconceptions (i.e., reconstruction of knowledge), thereby increasing the likelihood of conceptual change. Taking this into consideration, improved understanding of the roles of attitudes and epistemic beliefs in learning, knowledge acquisition, and knowledge revision may provide invaluable insights into the factors that function to facilitate or constrain conceptual change during knowledge revision. Indeed, delineating relationships between attitudes and epistemic beliefs in learning and knowledge revision could provide a more comprehensive framework for understanding how misconceptions are acquired and maintained, including why some misconceptions are so resistant to change.

Knowledge revision is a process of conceptually changing inaccurate knowledge, and thus, plays an integral role in how individuals' revise or update previously acquired but incorrect information (i.e., misconceptions; Kendeou, Walsh, Smith, & O'Brien, 2014; Sinatra & Seyranian, 2016). Changing misconceptions involves modifying the underlying knowledge structures (or systems of beliefs) and emergent attitudes that reinforce these errors in reasoning (Broughton, Sinatra, & Nussbaum, 2013; Kendeou et al., 2014). Revising knowledge requires conceptually reorganizing and reconfiguring one's epistemological assumptions and updating non-scientific knowledge (i.e., misconceptions) with the goal of acquiring a more evidence-based understanding of a topic (Sinatra & Seyranian, 2016). Additionally, knowledge revision involves modifying the emergent attitudes that bias information processing during knowledge acquisition and construction. Conceptually changing inaccurate knowledge therefore entails a process not only of reconfiguring underlying systems of beliefs, but also of modifying the emergent attitudes that reinforce individuals' misconceptions. Considering the importance of attitudes and epistemic beliefs in information processing and the interpretation and evaluation of knowledge, including

the roles these factors invariably play in the construction of knowledge, more research is needed to investigate how these factors facilitate or constrain knowledge revision.

Most research in the conceptual change literature focuses on various predictors of conceptual change, including the role of emotions (Broughton, Sinatra, & Nussbaum, 2013; Trevors, Kendeou, & Butterfuss, 2017a), epistemic beliefs (Franco, Muis, Kendeou, Ranellucci, Sampasivam, & Wang, 2012; Trevors, Kendeou, Bråten, & Braasch, 2017b; Stathopoulou & Vosniadou, 2007), and motivational constructs such as values and self-efficacy in facilitating or constraining the conceptual change process (Pintrich, Marx, & Boyle, 1993). Additionally, researchers have investigated the effects of conceptual change on subsequent attitudes and emotions (Heddy et al., 2017). One common thread in most conceptual change research is the use of refutation texts as rhetorical devices to foster knowledge revision. Refutation texts operate by directly confronting individuals' misconceptions about a topic and use causal explanations based on scientific evidence to refute the incorrect knowledge (Kendeou et al., 2014). According to Tippet (2010), decades of research in the conceptual change literature have shown the use of refutation texts to be a more effective strategy for fostering knowledge revision compared to the use of expository texts. Expository texts typically present the same information as refutation texts, but the former present information in a descriptive, matter-of-fact fashion similar to how information is organized in academic textbooks, whereas the latter presents information in an argumentative manner with the goal of targeting and changing individuals' misconceptions related to complex science topics. One key factor underlying the effectiveness of refutation texts is that they simultaneously activate individuals' epistemic beliefs and prior knowledge (i.e., misconceptions) alongside to-be-learned information, which generates cognitive conflict between previously acquired misconceptions and to-be-learned information. To reconcile the

conflict, individuals must reconfigure their previously acquired inaccurate knowledge and beliefs, which ultimately leads to the revision of knowledge and understanding (Tippet, 2010).

Despite the relative surplus of research that has investigated the directional and predictive roles of attitudes, emotions, beliefs, and motivation on conceptual change, including the role of refutation texts in facilitating knowledge revision, there have been no studies, to the best of my knowledge, that have directly investigated the potential mediating roles of attitudes and epistemic beliefs in knowledge revision in one coherent model. According to Hayes' (2013) mediation analyses allow researchers to move beyond questions that focus exclusively on 'whether' a group difference exists or 'if' a relationship between two factors is significantly different from zero. Instead, mediation analyses allow researchers to conduct investigations that seek to uncover 'how' the effects of an antecedent variable (say, prior misconceptions) on a consequent variable (say, post-test knowledge revision) can be partitioned into direct and indirect effects to uncover the underlying mechanisms (i.e., mediating factors) by which an antecedent variable transmits its effects on a consequent variable.

Explicating the mediating roles of attitudes and epistemic beliefs in learning and knowledge revision could provide invaluable insights into how and in what ways these factors facilitate or constrain conceptual change, particularly within the context of learning about controversial socioscientific topics. For example, GMFs are a provocative socioscientific topic that have an enormous impact on personal (food consumption), social (food labeling), economic (agricultural practices), and political (consumer protection laws) decision-making behaviors. Consequently, misconceptions regarding GMFs based on negative attitudes or limited epistemic understanding of knowledge related to the topic could lead to imprudent personal, social, economic, or political actions. In an age where public distrust in science has led to the

proliferation of misinformation and erroneous knowledge, it has become increasingly important to develop a working model of how attitudes and epistemic beliefs mediate conceptual change during knowledge revision to understand how these factors can be leveraged to enhance learning outcomes (i.e. reconstruction of knowledge or understanding) for individuals who hold inaccurate conceptions, negative attitudes, and false-beliefs related to complex scientific issues of global significance. The proposed study thus seeks to examine relations among attitudes, epistemic beliefs, and refutation texts with the aim of providing a descriptive and functional account of how attitudes and epistemic beliefs mediate the differential between prior learning and post-test knowledge revision. That said, developing a more comprehensive working theory of the processes at play during knowledge revision would otherwise be incomplete without considering the potential dynamic roles attitudes and epistemic beliefs in knowledge revision during conceptual change.

As such, the objective of the present study was to examine possible relations between prior knowledge, attitudes, epistemic beliefs, refutation texts, and knowledge revision in the context of learning about GMFs with the goal of uncovering the factors that function to facilitate or constrain conceptual change. Prior to delineating my research questions and hypotheses, I first present relevant theoretical and empirical work.

CHAPTER 2

Theoretical Frameworks

Conceptual Change

Conceptual change is a learning process that involves revising misconceptions or updating inaccurate knowledge (Kendeou et al., 2014). More specifically, conceptual change is a form of knowledge revision that entails reconfiguring erroneous knowledge structures, including modifying underlying systems of epistemic beliefs and emergent attitudes. Typically, the conceptual change (or revision) process is provoked when a state of cognitive conflict arises between misconceived prior knowledge and the learning of new, discrepant information (Chan, Burtis, & Bereiter, 1997). The ensuing dissonance between previously acquired incorrect knowledge and to-be-learned information typically results in attempts to reconstruct incorrect knowledge structures to reflect more accurate configurations of knowledge within the conceptual network (Chi, 2008; Lombardi, Nussbaum, & Sinatra, 2016). Conceptual change differs from other types of learning in that it does not entail merely adding or assimilating missing information to construct new knowledge structures, or accommodating new information to fill in the gaps of incomplete knowledge (Chi, 2008; Vosniadou, 1994). Rather, conceptual change as a form of knowledge revision involves attempts to reduce the cognitive disequilibrium that arises when incorrect prior knowledge comes into conflict with newly acquired, accurate conceptions of a topic (Chan et al., 1997; Chi, 2008). The result is a reconfiguration of knowledge within the conceptual network via the restructuring of existing knowledge structures, beliefs, and the modification of prevailing attitudes.

In terms of science learning, the notion of conceptual change implies that individuals have pre-existing misconceptions—inaccurate mental representations of a topic or issue—that

contradict scientific understanding of the topic (Lombardi et al., 2016). Science misconceptions are inaccurate prior conceptions regarding scientific topics that depart from widely accepted scientific knowledge or understanding (Sinatra et al. 2014). Such misconceptions are often quite enduring, resistant to change, and can have particularly deleterious effects on learning, decision-making behaviors, and the selection, perception, interpretation and evaluation of new information, even after previously acquired 'misinformation' has already been corrected (Ecker et al., 2017; Vosniadou, 1994). The relatively enduring quality of science misconceptions is often attributed to what has been referred to as the 'misinformation effect' (Ecker et al., 2017). Misinformation is the deliberate dissemination of false or inaccurate information with the intention to deceive or persuade others of the validity of an otherwise erroneous argument. Misinformation is commonly used to persuade others of one position or another related to various controversial topics or issues. For example, anti-vaccine advocates often use numerous tactics or strategies—such as skewing scientific data, shifting hypotheses, censoring information, or attacking the opposition—and common tropes—such as repeating social or political mottos and catch-phrases, or oversimplifying opponents' rebuttals—to convince others that vaccines are unsafe (Kata, 2012). According to Ecker et al. (2017), attempts to revise previously acquired misconceptions often fail to take hold because the fallacious content (i.e., misinformation) being refuted is too often repeated during the revision process. For example, simply explaining that vaccines do not cause autism essentially reiterates the very misconception that is being refuted. This repetition inexorably increases one's familiarity with the myth (Ecker, et al., 2017). The inadvertent rhetorical backfire characterized by the misinformation effect can thus be especially counterproductive to knowledge revision and new learning if individuals are unable to shift

activation away from previously acquired, inaccurate knowledge toward more accurate conceptions of a topic.

Research examining the processes involved in knowledge revision has shown that successful revision is not merely a product of refuting inaccurate knowledge (i.e., simply stating knowledge to be incorrect) (Ecker et al., 2017; Kendeou & O'Brien, 2014). In contrast, successful revision of inaccurate knowledge depends in large part on an interaction between both learner characteristics (i.e., prior knowledge, attitudes, beliefs, motivation) *and* message characteristics (i.e., comprehensibility, coherence, plausibility, and rhetorical structure) (Dole & Sinatra, 1998). For example, an individual with negative attitudes towards GMFs due to misconceptions and false-beliefs (i.e., learner characteristics) might be persuaded to revise their inaccurate conceptions if presented with a sufficiently persuasive counter message (i.e., a coherent and plausible knowledge claim). Conversely, an individual might fail to revise erroneous knowledge due to the strength of an existing conception, or their level of commitment to their existing knowledge despite being presented with a coherent and plausible counter message. That being the case, the likelihood that individuals will revise previously acquired, incorrect knowledge depends in large part on the interactions among various learner and message characteristics. The dynamic and interdependent relations among learner and message characteristics in knowledge revision have been efficiently delineated in Dole and Sinatra's (1998) Cognitive Reconstruction of Knowledge Model (CRKM), which is described next.

Cognitive Reconstruction of Knowledge Model (CRKM)

Dole and Sinatra's (1998) Cognitive Reconstruction of Knowledge Model (CRKM) was developed in response to a call by Pintrich, et al. (1993) to reconceptualize conceptual change models to account for 'hot' motivational and affective factors in addition to the 'cold' cognitive

(i.e., information processing) constructs commonly cited as factors involved in knowledge revision. In their model, Dole and Sinatra (1998) describe interactions between learner characteristics (i.e., existing knowledge, attitudes, beliefs, and motivation) and message characteristics (i.e., comprehensibility, plausibility, coherence, and rhetorical structure) in facilitating or constraining knowledge revision, as shown in Figure 1 below.

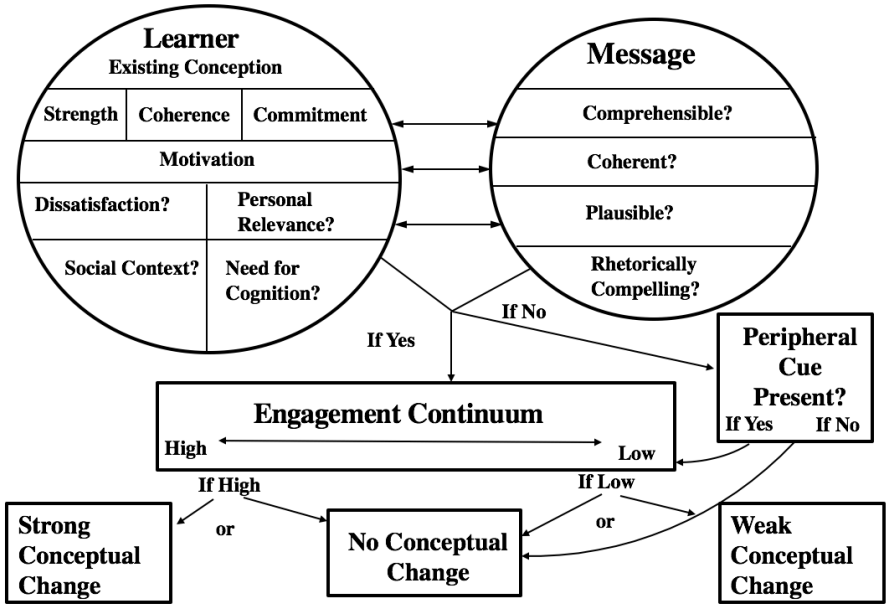

Figure 1. Dole and Sinatra's (1998) Cognitive Reconstruction of Knowledge Model (CRKM)[1].

According to Dole and Sinatra (1998), individuals differ in the quantity and quality of their prior knowledge (i.e., misconceptions), and this prior knowledge can interfere with learning and the interpretation and evaluation of new information (see also Krause et al., 2009; Sinatra, et al., 2008). The likelihood that individuals will change pre-existing (mis)conceptions depends in large part on the strength and coherence of previously acquired information (i.e., the richness and explanatory power of a conception), as well as an individual's commitment to their existing knowledge (i.e., an individual's attitudes and beliefs regarding the value of a conception). The

[1] Reprinted with permission from Taylor & Francis for use in a thesis or dissertation.

stronger and more conceptually coherent an individual's prior conception, as well as the degree of commitment an individual has toward previously acquired conceptions, the less likely knowledge revision (i.e., the reconstruction of knowledge) is to occur (Dole & Sinatra, 1998).

The probability that individuals will revise previously acquired, incorrect knowledge also depends on several motivational factors, including whether (1) an individual is dissatisfied with their existing knowledge (i.e., it is no longer useful for understanding new information or contexts), (2) a new conception is perceived as personally relevant (i.e., the individual has a personal stake in the outcome), (3) an individual is intrinsically motivated to change their existing conceptions—that is, an individual has a high need for cognition and is thus more likely to consider multiple perspectives and engage in high elaboration and cognitive processing of disparate knowledge claims—and, (4) an individual values the perspectives of their peers or instructors within the prevailing social context. In other words, the more an individual shares similar attitudes, beliefs, and values with his or her social group, the more likely he or she is to consider conflicting knowledge claims or points of view, and thus, to revise existing conceptions (Dole & Sinatra, 1998).

In terms of message characteristics, Dole and Sinatra (1998) highlight in their model several factors likely to affect whether an individual will revise their existing knowledge, including (1) the comprehensibility and plausibility of a message; that is, whether the message is conceptually palpable and individuals view the message as credible (source evaluations), (2) the coherence of the message and whether the message has explanatory power and effectively links back to larger conceptual structures (elaborative complexity), and (3) whether the message is rhetorically compelling; that is, whether the message's structure, sources of information, and

justification of arguments are sufficiently persuasive. Overall, a message that is elusive, ambiguous, incoherent, or disconnected will not likely facilitate knowledge revision.

According to Dole and Sinatra (1998), knowledge revision is an iterative process involving dynamic interactions between both learner characteristics and message characteristics. For example, a comprehensible and plausible message may be personally relevant for one individual but not another. Additionally, an individual may have a strong, coherent prior conception to which he or she is strongly committed despite a plausible and rhetorically compelling counter message. Further, an individual may be dissatisfied with a previously acquired conception but not find a new message sufficiently plausible or coherent to warrant replacement of the existing conception. Finally, a message may be considered rhetorically compelling, but perceived as implausible.

Depth of engagement with a message (or argument) is another critical factor predicting knowledge revision (Dole & Sinatra, 1998). An individual's depth of engagement is described along a continuum ranging from low cognitive engagement to high metacognitive engagement. High metacognitive engagement is required for knowledge revision to occur and involves deep processing of information, high elaboration of message content, and metacognitive reflection and strategy use. In contrast, low cognitive engagement is unlikely to result in knowledge revision and involves low-level processing of information, maintenance or rehearsal strategies, low elaboration of message content, and simple assimilation of new information without revision to existing conceptions. At the highest level of engagement, individuals are more likely to deeply process arguments and counterarguments and metacognitively reflect on the content of a message (i.e., evaluate knowledge claims), which facilitates greater likelihood of change in conceptions. At the lowest level of engagement, individuals are likely to process only that

information that is congruent with their prevailing attitudes or underlying epistemic beliefs (Dole & Sinatra, 1998). As previously noted, one method researchers have found to be effective in facilitating knowledge revision and promoting deeper engagement while processing a message is via the use of refutation texts, which are designed to directly confront misconceptions by presenting causal explanations using scientific evidence to refute inaccurate knowledge.

Refutation Texts

Refutation texts are rhetorical devices designed to target misconceptions and facilitate knowledge revision (Kendeou et al., 2014; Sinatra & Broughton, 2011). Numerous studies have shown refutation texts to be an effective method for changing misconceptions related to a variety controversial socio-scientific topics, including GMFs (Heddy et al., 2017; Heddy & Sinatra, 2013; Trevors et al., 2017a; Trevors, Muis, Pekrun, Sinatra, & Winne, 2016). Unlike expository texts that present information in a descriptive manner (similar to how information is presented in academic and educational textbooks), refutation texts integrate elements of argumentation to draw metacognitive awareness towards misconceptions or false-beliefs (Tippet, 2010). Essentially, refutation texts work by directly confronting individuals' misconceptions related to a topic and use causal explanations based on scientific evidence to refute incorrect knowledge (Kendeou et al., 2014). As previously noted, simply refuting misconceptions by restating the incorrect knowledge is not sufficient to prompt knowledge revision (Ecker et al., 2017). Therefore, to be effective, a refutation text must include the following three components. First, it must directly confront a misconception (i.e., draw metacognitive awareness toward inaccurate knowledge). Second, it must explicitly state the falseness of the misconception. Third, it must provide causal explanations based on empirical evidence to refute the misconception (Kendeou, Smith, & O'Brien, 2013; Kendeou et al., 2014). Causal explanations in refutations represent to-

be-learned information and are intended to create a rich tapestry of information to help reduce cognitive conflict and the activation of previously acquired, incorrect information to aid in the reconfiguration of inaccurate knowledge structures within the conceptual network (Kendeou et al., 2013, 2014). In other words, causal explanations help to reduce the reactivation of previously acquired but incorrect information by drawing increasing activation (i.e., metacognitive awareness) to correct information and decreasing activation of incorrect information (Kendeou et al., 2013, 2014). According to Tippet (2010), refutation texts are more likely to facilitate knowledge revision compared to expository texts because refutations provoke cognitive conflict via simultaneous activation of prior (mis)conceptions and to-be-learned knowledge concomitantly in working memory, and via the use of causal explanations, direct metacognitive awareness away from previously acquired inaccurate knowledge toward more accurate scientific conceptions of a topic, thereby prompting knowledge revision.

According to Kendeou et al. (2014), the structure of refutation texts must be standardized to be able to attribute knowledge revision to the refutations opposed to variation in the underlying text structure. For this reason, casual refutations should be written so that each sentence is interconnected and related to the original causal statement, which will create a coherent network of information (i.e., counter-arguments) to compete with incorrect knowledge while individuals are in the process of revising previously acquired but inaccurate conceptions (Kendeou et al., 2013, 2014). In terms of message characteristics, refutation texts should be comprehensible (easy to understand), coherent (provide an explanatory framework within which to refute incorrect knowledge), plausible (the messages conveyed must be probable), and rhetorically compelling (justification for arguments must be sufficiently persuasive) (Dole & Sinatra, 1998; Tippet, 2010). If the messages conveyed within refutation texts are opaque,

implausible, disconnected, or if the credibility of sources is considered unreliable, individuals are unlikely to revise inaccurate (mis)conceptions.

In addition to rhetorical structure and message characteristics, several learner characteristics are likely to impact the likelihood of conceptual change during knowledge revision in relation to refutation texts. For example, individuals with less commitment toward their exiting (mis)conceptions, who engage in more reflective elaboration of the content of messages instantiated in the texts, and who have more constructivist epistemic beliefs are more likely to experience conceptual change (Mason & Gava, 2007; Tippet, 2010). Indeed, learner characteristics such as individuals' attitudes and epistemic beliefs are likely to have an enormous impact on the probability that knowledge revision will occur.

Attitudes

Attitudes have a long theoretical and empirical research history within the social sciences (Fabrigar, Macdonald, & Wegener, 2005). Attitudes can be defined as positive or negative evaluations of objects, people, events, or ideas that lead people to respond with some degree of favor of disfavor (Eagly & Chaiken, 1993; Fishbein & Icek, 1975; Heddy et al., 2017). Despite the multitudes of theoretical and empirical research on attitudes in the social sciences literature, there has been a great deal of discrepancy concerning the structural properties of the attitude concept. Structural definitions of attitudes range from three component (hierarchical) models to single component (object-evaluation association) models (Ajzen, 1989; Kruglanski & Stroebe, 2005).

The well-known and often cited tripartite model of attitudes, displayed in Figure 2 below, is a hierarchical model that holds attitudes are comprised of three distinct yet inseparable components: cognition (including beliefs and related knowledge structures), affect (positive or

negative emotions), and conation (overt behavior or verbal responses) (Fabringer et al., 2005; Rosenburg & Hovland, 1960). One concern with the traditional tripartite model of attitudes, however, is that it presupposes congruity among attitudinally-relevant cognitions, emotions, and behaviors (Kruglanski & Stroebe, 2005). That said, correlations among these components are not always found in empirical studies (Richardson, 1996).

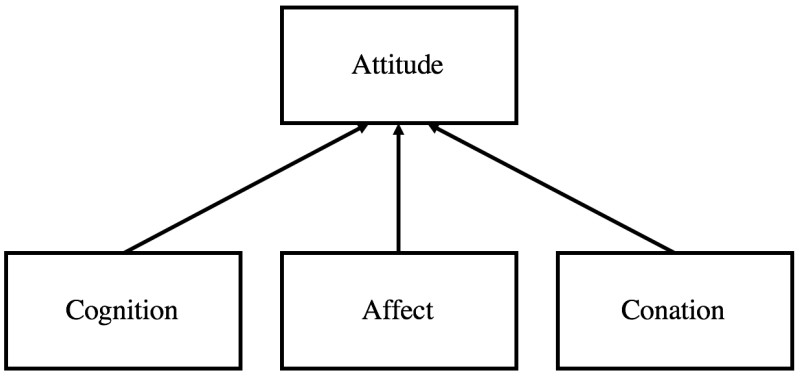

Figure 2. Tripartite model of attitudes.

As an alternative to the traditional three-component conception, many contemporary researchers postulate that attitudes are distinct entities existing separately from cognitive, affective, and conative factors, and more specifically, that attitudes serve an evaluative function in the appraisal of information derived from these distinct factors (Fabrigar, et al., 2005). In this way, attitudes can be more appropriately described in terms of simple object-evaluation associations (see Figure 3 below), which are typically embedded within larger semantic networks of associated knowledge structures. The view of attitudes as simple object-evaluation associations is supported by the mere fact that most measurement techniques for attitudes utilize Likert-type scales that require individuals to locate themselves on an "evaluative continuum vis-a-vis the attitude object" (Ajzen, 1989. p. 242; see also Likert, 1932). That said, few measures adequately distinguish between cognitive, affective, or conative evaluations of attitudinal

objects, which limits the descriptive power and reliability of these metrics in explaining domain-relevant properties of attitudes.

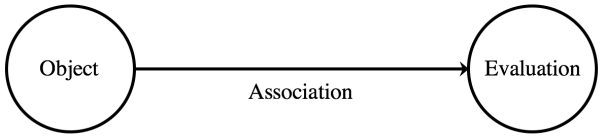

Figure 3. Simple object-evaluation association model of attitudes.

The structural view of attitudes as simple object-evaluation associations can be concisely described as follows: an attitudinal object (say, GMFs) represents one node within a semantic network, the evaluation of the object (say, beliefs about GMFs) represents the other node, and the link between the two nodes represents the relative strength of the association (Fabrigar, et al., 2005). For example, GMFs (the object of evaluation) could be evaluated based on a set of beliefs that GMFs are unsafe for human consumptions (attributes of the object), and the strength of these beliefs associated with the topic of GMFs could result in an overall negative attitudinal appraisal of GMFs.

According to Eagly and Chaiken (1993), simple object-evaluation associations are commonly embedded (or linked) to larger networks of associated knowledge structures (see also Fabrigar et al., 2005). For example, specific attributes associated with the representational nature of an object (e.g., cognitive or affective properties, or other objects) are also associated with local evaluations of these representational features in addition to the overall (global) appraisal of the attitudinal object. In this sense, the structure of an attitude includes both object-evaluation associations *and* related knowledge structures (i.e., specific attributes of the object) to which the simple nodal structure is linked within a larger semantic network. Thus, the structure of an attitude comprises not only object-evaluation associations, but also interconnected knowledge

structures (such as systems of epistemic beliefs), including the strength and pattern of the associative links between the attitude and related knowledge structures (Fabrigar et al., 2005). In other words, attitudes can be construed as simple object-evaluation associations that are shaped by both general (global) evaluations of a focal object and more specific (local) evaluations of an object's attributes (or interconnected knowledge structures) that situate the object within a larger semantic network. See Figure 4 below for example of an object-evaluation association regarding GMFs embedded within in a larger sematic network. In theory, any changes in knowledge (or conditions under which an object of knowledge is evaluated) at either the global or local level should lead to changes in the overall object-evaluation association (i.e., attitudes regarding the object of knowledge or knowing).

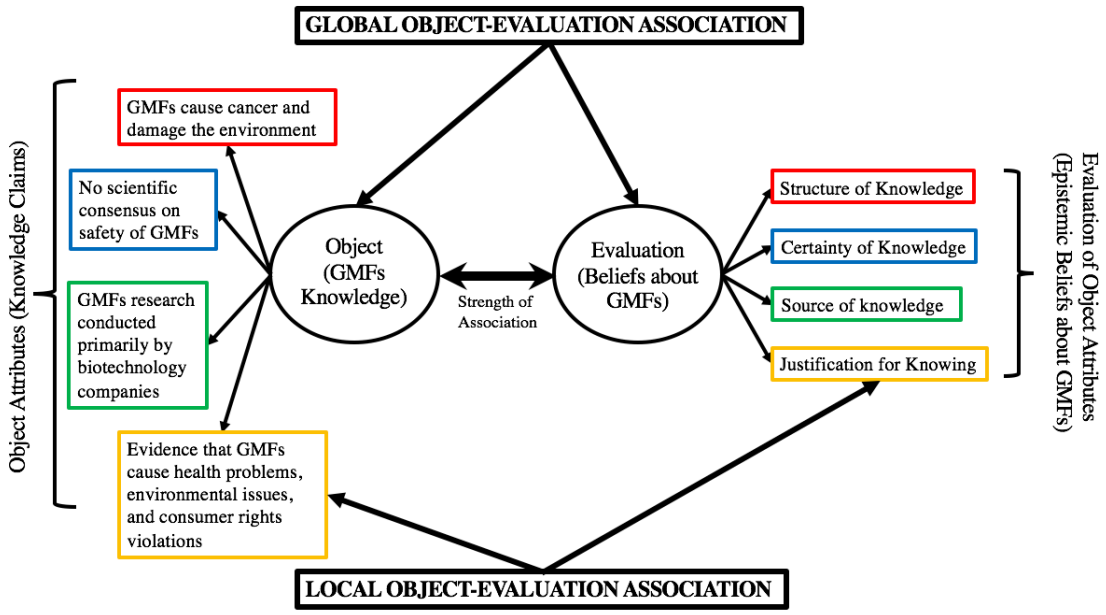

Figure 4. Object-evaluation association embedded in a semantic network.

According to Sinatra and Seyranian (2016), relations between attitudes and knowledge have important implications for learning and knowledge revision. In terms of the association between attitudes and conceptual knowledge (i.e., accurate knowledge versus misconceptions),

Sinatra and Seyranian (2016) developed a 2 x 2 matrix that describes the conditional relationship between attitudes, conceptual knowledge, and knowledge revision (see Figure 5 below). Based on this model, more accurate conceptual knowledge is related to more positive attitudes, whereas less accurate conceptual knowledge is related to more negative attitudes (Sinatra & Seyranian, 2016; see also Allum, Sturgis, Tabourazi, & Brunton-Smith, 2008). It is predicted that a shift from erroneous to correct knowledge (i.e., reconstruction of knowledge) entails a shift from negative to more positive attitudes (Sinatra & Seyranian, 2016). Indeed, a study by Heddy et al. (2017) found that individuals who experienced a change in knowledge from inaccurate to more accurate conceptions regarding GMFs experienced a concomitant shift from negative to more positive attitudes. It should be noted, however, that changing attitudes towards GMFs requires not only revising inaccurate knowledge about GMFs, but also reconfiguring the evaluations (i.e., beliefs) connected to the object (i.e., GMFs), including related knowledge structures (i.e., attributes of the object). To weaken the association between inaccurate conceptual knowledge regarding GMFs and an individual's underlying negative evaluations (which subsequently give rise to overall negative attitudinal appraisals of GMFs), it is necessary to change an individuals' underlying systems of beliefs in addition to their emergent attitudes.

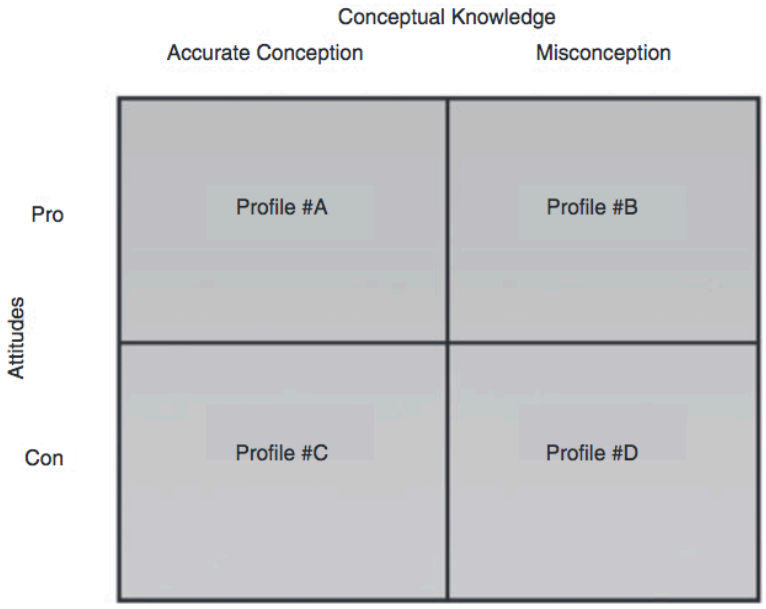

Figure 5. Hypothesized relationship between attitudes and conceptual knowledge[2].

Although numerous studies have found that facilitating knowledge revision (i.e., a shift from inaccurate to more accurate conceptions of a topic) additionally helps support a positive shift in attitudes related to complex socio-scientific topics (Broughton, et al., 2011; Heddy & Sinatra, 2013; Sinatra & Seyranian, 2016; Sinatra et al., 2014), the converse, that attitudes might also influence knowledge revision (and belief change), should also be considered while investigating factors that influence public knowledge and understanding of science (Allum et al., 2008; Sinatra et al., 2014). It should be noted that the relationship between knowledge revision and attitudinal change is topic-specific; that is, a change from inaccurate to accurate knowledge regarding the health risks of smoking, for example, does not imply that individuals will concomitantly experience a shift from negative to more positive attitudes toward smoking. In contrast, acquiring more accurate knowledge about the health risks of smoking tobacco should

[2] Reprinted with permission from Taylor & Francis for use in a thesis or dissertation.

appropriately reinforce more negative attitudes toward smoking. In the context of GMFs, however, more negative attitudes are commonly associated with inaccurate knowledge about the topic, so changing individuals' misconceptions should lead to more favorable attitudes. In other words, the difference between positive and negative attitudes should not be equated with notions of 'correct' versus 'incorrect' attitudes. Accordingly, individuals may have negative attitudes, though correct knowledge regarding smoking (i.e., smoking is harmful to one's health). Similarly, an individual may have negative attitudes, though incorrect knowledge about GMFs (i.e., GMFs are harmful to one's health and damage the environment). Therefore, the relationship between attitudinal and conceptual change is inevitably topic-specific and depends on the nature of the issue or subject.

Overall, individuals tend to hold negative attitudes toward science (and related socio-scientific topics) due to misinformation and misconceptions (Ecker, et al., 2017; Sinatra et al., 2014; Xiao & Sandoval, 2017), which impact how they cognitively process socio-scientific information (Sinatra et al., 2014). For this reason, negative attitudes towards science may serve to reinforce individuals' misconceptions as a function of the biased processing of scientific information. For example, evaluations related to the credibility of a scientific claim (attributes of the object) could be biased by pre-existing attitudes (and associated beliefs), and thus, individuals may ignore evidence that contradicts their own understanding or conceptions (Sinatra et al., 2014). Consequently, attitudes can interfere with new learning, including individuals' interpretations of information (i.e., perceptions of certainty or complexity), evaluations of source credibility, and judgements regarding the veracity of scientific information (Sinatra et al., 2014). In other words, attitudes are related to an individuals' epistemic beliefs, and research has shown

that this relationship predicts individuals' understanding, learning, achievement, and conceptual change (i.e., successful knowledge revision) (Stathopoulou & Vosniadou, 2007).

Epistemic Beliefs

According to Greene, Sandoval, and Bråten (2016), the term epistemic derives from the Greek '*episteme*,' which translates to '*knowledge or knowing*.' As an adjective, the term epistemic is used to describe objects in relation to knowledge or processes of knowing. Epistemic cognition, therefore, refers to individuals' thinking about knowledge, and includes processes that are inherently dynamic, change over time, and draw on individuals' schemas, cognitive resources, mental models, and epistemic beliefs, to name a few (Greene, Sandoval, & Bråten, 2016; Sinatra & Hofer, 2016). In contrast, epistemic beliefs concern individuals' personal theories or doxastic assumptions regarding the nature of knowledge and knowing, which are relatively stable over time (Hofer & Pintrich, 1997; Muis, 2007; Schommer, 1990; Sinatra & Hofer, 2016; Sinatra et al., 2014). Epistemic beliefs play a central role—either implicitly or explicitly—in how individuals reason about knowledge and knowing (Chinn, Buckland, Samarapungavan, 2011; Sinatra et al., 2014), evaluate and judge the veracity of information obtained from multiple sources instantiated on the Internet (Greene, Yu, & Copeland, 2014), and have been found to be predictive of both learning processes and achievement outcomes (Chinn et al., 2011; Hofer, 2000; Muis, 2004, 2007).

Based on the work of Hofer and Pintrich (1997), epistemic beliefs can be defined as personal theories related to beliefs about the structure of knowledge, certainty of knowledge, source of knowledge, and justification for knowing. While the first two dimensions (structure and certainty) concern beliefs about the properties of knowledge, the second two dimensions (source and justification) concern beliefs regarding processes of knowing. See Figure 6 below for

a structural model. Beliefs regarding the structure of knowledge concern whether knowledge is believed to be made up of discrete (simple) facts, or whether knowledge is multifaceted and composed of highly complex and interrelated concepts. For the certainty of knowledge, individuals may view knowledge as static and unchanging (steady state knowledge) or evolving and perpetually changing (entropic knowledge states). For the source of knowledge, individuals may believe knowledge is generated and disseminated via authority figures (externally generated), or personally constructed via reason and logic (internally generated). Finally, beliefs regarding the justification for knowing refer to whether individuals view knowledge as justified by expert authority, subjective experience, or via multiple sources of information (Hofer & Pintrich, 1997; Trevors et al., 2017b).

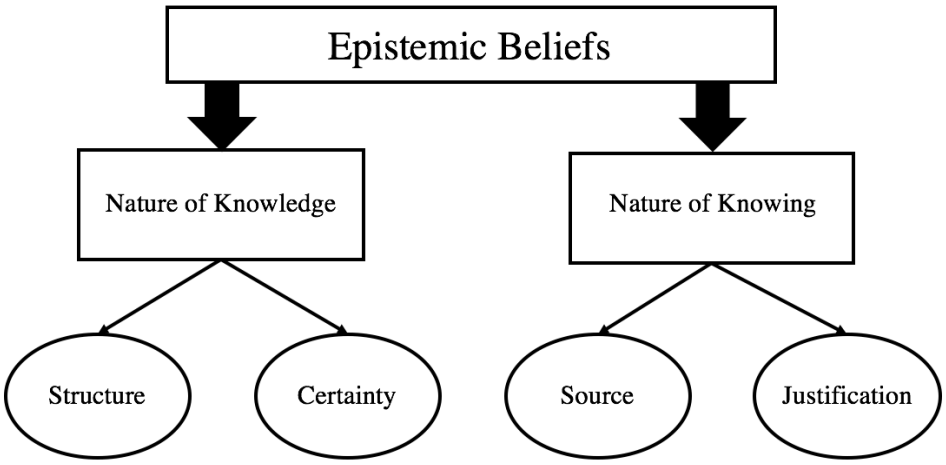

Figure 6. Structural model of epistemic beliefs.

Research has shown that more constructivist epistemic beliefs (i.e., knowledge is complex, highly interrelated, uncertain, derived and justified via multiple sources of information) are positively correlated with various facets of learning and achievement (Franco, et al, 2012; Stathopoulou & Vosniadou, 2007), including self-regulated learning (see Greene, Muis, & Pieschl, 2010; Muis, 2007; Muis, Chevrier & Singh, 2018), conceptual change (Mason & Gava,

2007; Mason, Gava, & Boldrin, 2008), emotions (Muis, Pekrun, Sinatra, Azevedo, Trevors, Meier, & Heddy, 2015; Pekrun, Vogl, Muis, & Sinatra, 2016), complex problem-solving (Muis, 2008), and digital literacy (Greene et al., 2014). In terms of knowledge revision, numerous studies have found that individuals who hold more constructivist epistemic beliefs change more misconceptions after reading refutation texts compared to individuals who hold less constructivist epistemic beliefs (i.e., knowledge is simple, certain, derived and justified via authority; see Franco, et al., 2012; Kendeou, Muis & Fulton, 2011; Mason & Gava, 2007; Mason et al., 2008; Murphy & Alexander, 2016; Trevors et al., 2017b).

Epistemic beliefs serve as a focal lens for understanding scientific topics and play an integral role in how individuals interpret and evaluate scientific knowledge, including discrepant knowledge claims (Sinatra et al. 2014). According to Stathopoulou and Vosniadou (2007), epistemic beliefs predict the ways in which individuals engage scientific inquiry, evaluate theories against evidence, interpret explanatory models of theoretical constructs, and develop understanding of complex science topics in relation to multiple, often discrepant sources of information. Considering the important role of epistemic beliefs in learning and understanding of scientific knowledge (Stathopoulou & Vosniadou, 2007), the role attitudes play in how individuals select, interpret, process and encode information (Maoi & Haddock, 2010), and the role of beliefs in object-evaluation associations (i.e., attitudes), more research is needed to examine potential direct and indirect effects of epistemic beliefs and attitudes in knowledge revision to gain a deeper understanding of how these factors function to facilitate or constrain conceptual change while learning about important socio-scientific topics. Additionally, more research is needed to delineate the structural and functional relationships between individuals'

underlying systems of epistemic beliefs and the emergent attitudes from which individuals appraise objects of knowledge and knowing.

Relationship Between Attitudes and Epistemic Beliefs

Traditional hierarchical accounts of attitudes hold cognition, affect, and conation to be first-order factors while an attitude (or the overall general evaluation of an object) is considered a second order factor (Ajzen, 1989). However, more contemporary accounts postulate attitudes as simple object-evaluation associations where cognition, affect, and conation serve as orthogonally distinct antecedents or consequences of attitudes (Ajzen, 1989). A common assumption in the research literature on attitudes is that cognitions (i.e., beliefs and related conceptual knowledge structures) and attitudes are functionally consistent with one another. For example, a belief that GMFs are harmful for human consumption (a negative, though inaccurate conception) typically elicits a negative attitude, and changes to false-beliefs (or misconceptions) can lead to a concomitant shift in the valence of attitudes (see Heddy et al., 2017 and Sinatra & Seyranian, 2016 for more information). According to Ajzen (1989), however, attitudes and beliefs are not merely consistent with one another; rather, attitudes systematically vary as a function of individuals' beliefs such that individuals' beliefs have a direct or causal effect on attitudes.

Although it is possible to infer attitudes form various types of belief statements, only beliefs that are salient in an individual's mind are presumed to have a direct impact on associated attitudes (Ajzen, 1989). Unlike beliefs, attitudes typically remain highly accessible and readily guide learning and decision-making behaviors (Ajzen & Fishbein, 2005). In other words, individuals do not necessarily have to consciously review their underlying systems of beliefs each time they engage in a learning activity or encounter knowledge for which an attitude has already been formed (Ajzen & Fishbein, 2005). For example, previously formed attitudes

regarding GMFs (the object of evaluation) are automatically activated during encounters with knowledge claims related to GMFs (attributes of the object), and these readily available object-evaluation associations mitigate the need for individuals to metacognitively process all attributes of an argument vis-a-vis their predominant underlying epistemic beliefs regarding GMFs each time they encounter a knowledge claim. Thus, attitudes may serve a heuristic function for learning by enabling individuals to quickly process topical knowledge and to make quick decisions regarding whether to accept or reject knowledge claims related to a focal topic.

Taken together, beliefs and attitudes reciprocally influence one another and play an integral role in learning and knowledge revision (Ajzen & Fishbein, 2005). Although individuals' beliefs might not necessarily be veridical (i.e., beliefs may be biased or inaccurate), once an individual has developed a system of beliefs, these beliefs provide the cognitive substrate from which congruent attitudes are cultivated in a more or less consistent fashion (Ajzen & Fishbein, 2005). Once an attitude is shaped, it can work backwards and influence the development of new systems of beliefs, or provoke a revision to incompatible systems. In other words, attitudes not only bias the selection and perception of new information, but through a process of reciprocal interaction, both influence and are influenced by the revision or formation of new systems of beliefs (Ajzen & Fishbein, 2005). Overall, the information processing qualities of attitudes and epistemic beliefs result in recurring and reciprocal processes during knowledge revision that create feedback loops to enable learners to metacognitively monitor, adapt, target and revise inaccurate knowledge structures during the conceptual change process. See Figure 7 below for a conceptual model of the iterative and reciprocal relationship between attitudes and epistemic beliefs.

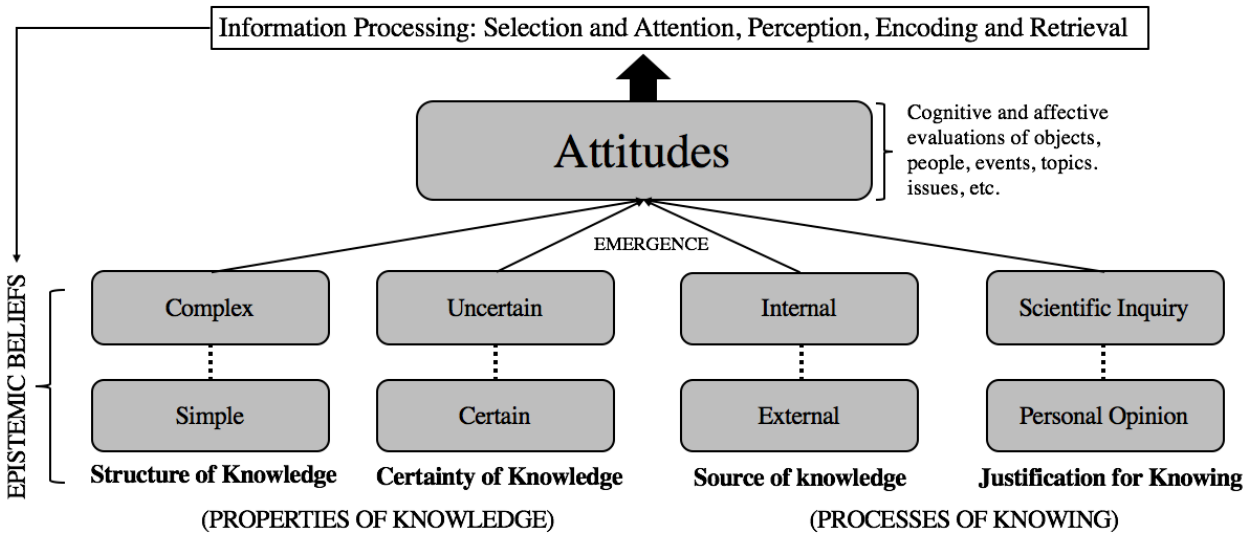

Figure 7. Conceptual model of the relationship between attitudes and epistemic beliefs.

Considering the dynamic and reciprocal relationship between attitudes and epistemic beliefs in processing, interpreting, and evaluating information, additional research is needed to examine the roles of attitudes and epistemic beliefs in learning and knowledge revision. Understanding relations between attitudes and epistemic beliefs in conceptual change would provide a functional understanding and explanatory framework within which to expound how and in what ways these factors operate to facilitate of constrain learning and knowledge revision while learning about complex socio-science topics. Such understanding could enable researchers and educators to develop educational interventions with the goal of equipping learners with the skills to more effectively recognize and revise their misconceptions while learning about complex and/or controversial science topics.

Genetically Modified Foods (GMFs)

Genetic modification refers to the process of altering the genetic make-up of a biological organism (Zhang, Wohlhueter, & Zhang, 2016). According to the World Health Organization (2014), genetically modified organisms (GMOs) refer to plants, animals, or microorganisms "in

which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination." GMOs in the form of genetically modified foods (GMFs) have become a particularly controversial topic among both food producers and consumers due to perceived potential biomedical risks or environmental side effects (Zhang, Wohlhueter, & Zhang, 2016). That said, countless empirical studies have reported increased health, economic, and environmental benefits associated with GMFs, including the enhanced nutritional value of genetically modified foods, increased agricultural outputs, and reduced human impact on the environment via more efficient methods of cultivation and husbandry (Zhang, Wohlhueter, & Zhang, 2016). Although the potential risks associated with GMFs are scientifically plausible, proclaimed issues related to allergenicity and selection of resistance (i.e., pest resistance), for example, are primarily speculative and unsupported. Although ignoring the risks would be otherwise unscientific, the preponderance of empirical evidence supports the immediate health and environmental benefits of producing and consuming GMFs (Zhang, Wohlhueter, & Zhang, 2016).

Perhaps the primary driving force behind the anti-GMO movement centers on the complexity of the science behind genetic modification and the difficulty the scientific community faces in trying to explain to the public the processes involved. The relative complexity and lack of transparency regarding genetic modification, teamed with the public's growing distrust in science due to fake news, appeals to emotions and personal beliefs, and the systematic dissemination of misinformation related to the topic make GMFs a worthwhile subject for situating an investigation into the roles of attitudes and epistemic beliefs during conceptual change. Indeed, given the provocative nature of the topic, GMFs provide a useful subject for investigating the factors involved in knowledge revision, including how individuals'

attitudes and beliefs related to GMFs impact the likelihood they will revise their misconceptions while learning from refutation texts.

The Current Study

Attitudes and epistemic beliefs are predictive of how individuals process, interpret, evaluate, and learn scientific information, and thus, play a significant role in knowledge revision. Results from a study by Fulmer (2014), for example, found that students' attitudes toward science predicted their epistemic beliefs pertaining to the uncertainty of scientific knowledge and their subsequent evaluations of sources of scientific knowledge. Conversely, a study by Kapucu and Bahçivan (2015) found that students' epistemic beliefs about science positively correlated with their attitudes towards learning physics. In other words, students who hold more constructivist epistemic beliefs regarding science knowledge also tend to self-report more positive attitudes towards science (and vice versa). Having said that, additional studies are needed to examine the exact nature of the relationships between individuals' attitudes and epistemic beliefs in the context of learning activities designed to change misconceptions related to important, complex socio-scientific topics. Although previous studies have revealed the predictive and directional roles of attitudes and epistemic beliefs in conceptual change (Broughton et al., 2013; Franco et al., 2012), as well as the effects of conceptual change on subsequent attitudes and knowledge (Heddy et al., 2017), there has been no research to date, to the best of my knowledge, that has directly investigated how and in what ways attitudes and epistemic beliefs function to facilitate or constrain knowledge revision while learning about complex science topics from refutation or expository texts.

Given the important roles of attitudes and epistemic beliefs in learning, knowledge acquisition, and knowledge revision, more research is needed to fill the gap in understanding

regarding the functional roles of these factors in learning and conceptual change. Such understanding would enable researchers and educators to more efficiently target and change individuals' misconceptions related to important socioscientific topics. Examining potential relations between attitudes and epistemic beliefs in knowledge revision can provide invaluable insights into how these factors impact socio-scientific reasoning and public understanding of science, particularly in terms of whether individuals with more constructivist epistemic beliefs and positive attitudes toward science engage in more successful knowledge revision. Thenceforth, the current study explores the potential mediating roles of attitudes and epistemic beliefs on the relationship between prior (mis)conceptions and post-test knowledge revision while learning about GMFs.

More specifically, the current study aims to (1) provide additional evidence for the effectiveness of refutation texts in facilitating knowledge revision, (2) provide empirical support for the hypothesized relationships between attitudes and epistemic beliefs in knowledge revision and the processing of scientific information, (3) uncover the mediating roles of attitudes on the relationship between epistemic beliefs and post-test knowledge revision, (4) provide evidence for the interceding effects of attitudes and epistemic beliefs on the relationship between prior (mis)conceptions and posttest knowledge revision (i.e. conceptual change), and (5) to delineate the potential moderating role of text type (i.e., refutation versus expository) on the mediated relationship between prior (mis)conceptions and post-test knowledge revision via individuals attitudes and epistemic beliefs regarding GMFs.

Although empirical research has explored the mediating effects of knowledge building (i.e. conceptual processing strategies) on the relationship between cognitive conflict and conceptual change (Chan et al., 1997), the interceding effects of attitudes on the relationship

between epistemic beliefs and academic motivation (Şahan, 2017), the mediating role of emotional change on the relationship between attitudinal change and conceptual change (Heddy et al., 2017), and the mediating role of emotions on the relationship between self-concept and post-test knowledge revision and attitudes (Trevors et al., 2016), there have been no empirical studies, to the best of my knowledge, that have explicitly investigated the potential mediating roles of attitudes and epistemic beliefs in knowledge revision in one coherent model. Additionally, there have been no studies, as far as I am aware, that have investigated the potential moderating effects of refutation texts on the mediated relationship between prior misconceptions and post-test knowledge revision via individuals' attitudes and epistemic beliefs regarding GMFs. Taking this into consideration, it is clear that additional research is needed to investigate how and in what ways attitudes, epistemic beliefs, and refutation texts impact learning to gain a more comprehensive understanding of the roles of these factors in knowledge revision during conceptual change related to complex science topics.

Based on theoretical and empirical considerations, the following research questions were addressed: RQ1: Is there a difference in learning outcomes (i.e. knowledge revision) between individuals who read a refutation text about GMFs versus individuals who read an expository text about GMFs? RQ2a: Is there are relationship between epistemic beliefs about GMFs and attitudes towards GMFs; that is, do epistemic beliefs regarding GMFs predict individuals' attitudes towards GMFs? RQ2b: Do attitudes towards GMFs mediate relations between epistemic beliefs about GMFs and post-test knowledge revision? RQ3: Do attitudes toward GMFs and epistemic beliefs about GMFs mediate the relationship between prior (mis)conceptions and post-test knowledge revision? RQ4: Does type of text (expository versus

refutation) moderate the mediated relationship between prior (mis)conceptions about GMFs and post-test knowledge revision via individuals attitudes and epistemic beliefs regrading GMFs?

While RQ1 is aimed at establishing 'whether' group differences in post-test knowledge revision vary as a function of text condition (i.e. refutation versus expository text), RQ2a is aimed at establishing 'if' epistemic beliefs regarding GMFs significantly predict individuals' attitudes towards GMFs. It should be noted that RQ1 is additionally intended to establish treatment fidelity for the experimental texts as a reliable intervention for facilitating conceptual change during knowledge revision. The remaining research questions described above pertain to questions of 'how' and 'for whom' attitudes, epistemic beliefs, and refutation texts impact knowledge revision (see Hayes, 2017). For example, RQ2b and RQ3 are aimed at understanding 'how' and in what ways epistemic beliefs exert their effect on post-test knowledge revision via individuals' attitudes, as well as 'how' and in what ways prior knowledge (i.e. misconceptions) exerts its effect on post-test knowledge revision via individuals' attitudes and epistemic beliefs regarding GMFs. Finally, RQ4 is aimed at understanding under what conditions (i.e., for whom) prior knowledge exerts its effect on post-test knowledge revision via the mediating effects of attitudes and epistemic beliefs. In other words, RQ4 is intended to delineate the conditional boundaries by which prior knowledge exerts its effect on post-test knowledge revision via participants' attitudes and epistemic beliefs regarding GMFs. Overall, the research questions described above are organized in such a way that they enable replication of results via the reiterative testing of increasingly complex, inclusive models to uncover how, for whom, and in what ways attitudes, epistemic beliefs, and refutation texts facilitate or constrain knowledge revision.

In relation to the research questions described above, the following hypotheses were derived: (H1) Participants who read a refutation text will experience greater change in misconceptions at posttest compared to participants who read an expository text. In reference to the conceptual model detailed in Figure 7 above, it was hypothesized that there would be a statistically detectable relationship between participants' attitudes towards GMFs and their epistemic beliefs about GMFs such that individuals' epistemic beliefs regarding GMFs will be positively correlated with their attitudes toward GMFs (H2a). Additionally, it was hypothesized (H2b) that attitudes towards GMFs (as an emergent property of epistemic beliefs) would mediate the relationship between participants' epistemic beliefs about GMFs and their post-test knowledge revision (see Figure 8 below for the hypothesized model).

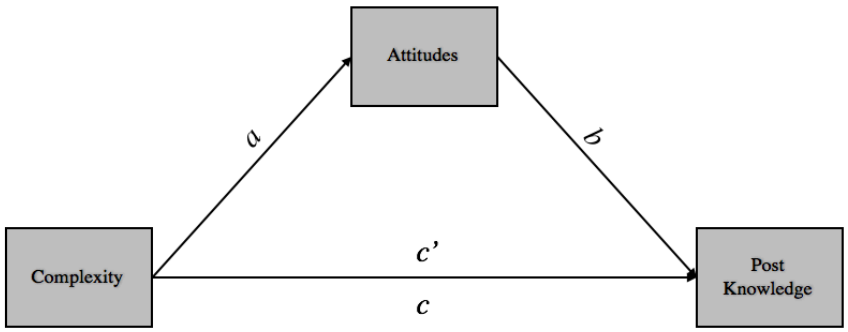

Figure 8. Hypothesized Mediation Model for H2b.

It was also hypothesized (H3) that the effect of prior knowledge (i.e. misconceptions) on post-test knowledge revision would be mediated by individuals' attitudes and epistemic beliefs regarding GMFs such that participants with less constructivist EBs and more negative attitudes toward GMFs would experience less change in misconceptions at post-test compared to participants with more constructivist epistemic beliefs and more positive attitudes toward GMFs. See Figure 9 below for the hypothesized model. It should be noted that for the sake of brevity, a

parallel mediation model was computed that included both attitudes and epistemic beliefs in lieu of running (and testing) separate analyses (models) for each factor.

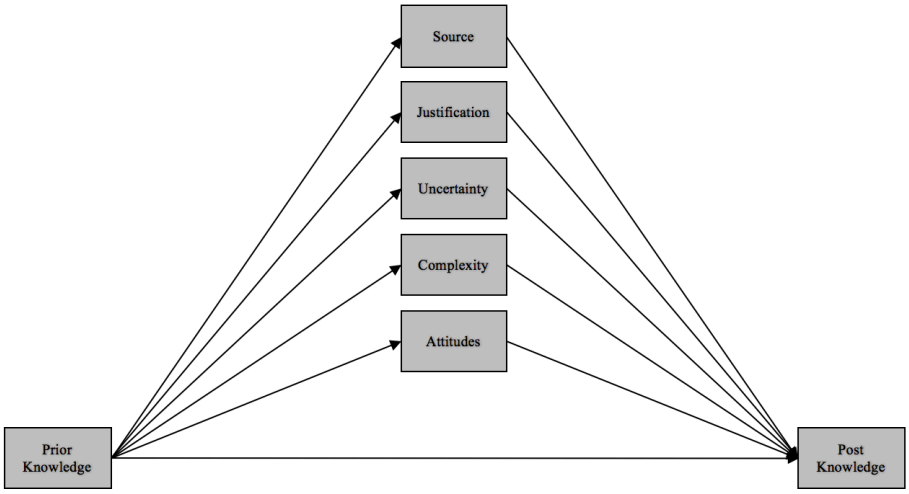

Figure 9. Hypothesized parallel mediation model for H3.

Finally, it was hypothesized (H4) that the mediation of attitudes and epistemic beliefs on the relationship between prior knowledge and post-test knowledge revision would be moderated by text condition such that participants with more positive attitudes toward GMFs and more constructivist epistemic beliefs about GMFs who read a refutation text would experience greater knowledge revision from pre-test to post-test compared to participants who read an expository text. See Figure 10 below for the hypothesized model.

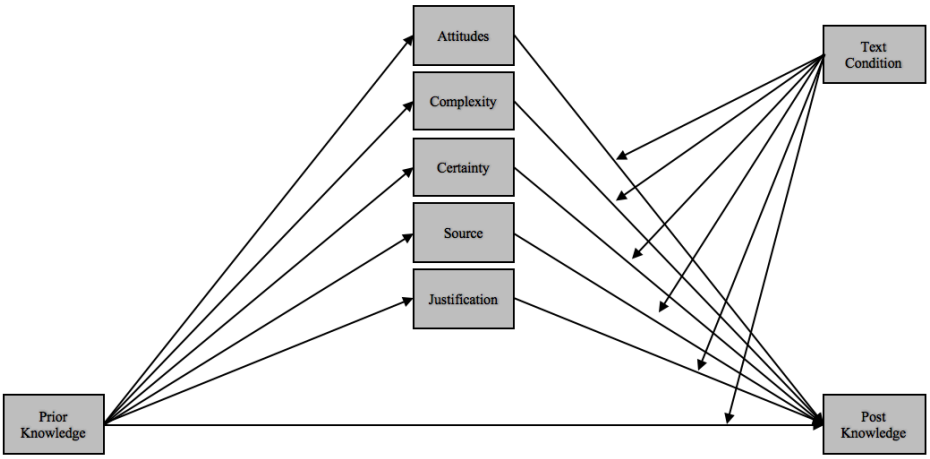

Figure 10. Hypothesized Moderated Mediation Model for H4.

CHAPTER 3

Methods

Participants

One hundred twenty undergraduate students participated in the study (n = 32 males) with a mean age of 21.29 years (SD = 3.83). Nineteen were in their first year of university, 24 were in their second year, 37 were in their third year, and 40 were in their fourth year. Students were drawn from an eclectic range of majors, including biology, biochemistry, chemistry, engineering, computer science, political science, environmental science, arts, psychology, economics, theology, English, geography, finance, and history. Participants were recruited from a public university using an online advertisement posted to the university's classifieds.

Materials

Demographics Survey. A brief demographics survey was administered to capture participants' basic background information, including gender, age, degree major/minor, cumulative GPA, first and second languages spoken and written, political affiliation, etc. Please see Appendix A for the full questionnaire.

Prior Knowledge Test. The prior knowledge measure included a 10-item multiple-choice test about genetically modified foods (taken from Heddy et al., 2017). The items assessed participants' prior knowledge related to GMFs. Participants were required to select the correct answer from a multiple-choice list of four possible answer choices. Example items include: "Methods that are NOT used in producing genetically modified foods include which of the following…?" "Genetically modifying foods occur through…" and "Processes used by scientists to modify the genetic makeup of plants and animals include which of the following?" One point was awarded for each correct answer, and zero points were awarded for each incorrect

answer. Participants' scores were summed, and an overall average prior knowledge score was calculated. Based on an acceptable reliability coefficient threshold of .70 (see Nunnally, 1978), the reliability index for the prior knowledge measure was relatively low (Cronbach's $\alpha = .60$). Although low, this level of reliability is expected when participants' level of prior knowledge is also low, or when the topic being tested is sufficiently complex, as is the case with knowledge pertaining to the topic of GMFs. The prior knowledge test can be found in Appendix B.

Attitudes Toward GMFs. The attitudes measure included four Likert-type items (adapted from Heddy et al., 2017) and was used to assess attitudes toward GMFs. An example item included, "I approve of genetically modified foods." Participants self-reported their attitudes toward GMFs on a scale ranging from "1 = strongly disagree" to "5 = strongly agree". The attitudes measure showed very good reliability (Cronbach's $\alpha = .92$) and thus provided a useful measure to assess participants' attitudes toward GMFs. That said, the attitudes measure provided only a general assessment of individuals attitudes toward the topic of GMFs and did not measure more specific attributes of attitudes, including cognitive, affective, and behavioral aspects of individuals' attitudes. A copy of the attitudes towards GMFs questionnaire can be found in Appendix C.

Topic Specific Epistemic Beliefs Questionnaire. A modified version of the Topic Specific Beliefs Questionnaire (TSEBQ; Strømsø, Bråten, & Samuelstuen, 2008) was be used to assess participants' epistemic beliefs related to GMFs. In contrast to other measures that assess epistemic beliefs in a domain-specific context (i.e. Buehl, Alexander, & Murphy, 2002; Hofer, 2000), the TSEBQ measures epistemic beliefs on a topic-specific level within a domain (Strømsø et al., 2008). The TSEBQ includes 24 items organized along four belief dimensions, including certainty of knowledge (6-items), complexity of knowledge (6-items), source of knowledge (5-

items), and justification for knowing (7-items). Participants rated each item on a 10-point Likert scale ranging from "1 = strongly disagree" to "10= strongly agree". Psychometric analyses of the TSEBQ revealed low to moderate reliability estimates for each factor, including certainty (Cronbach's $\alpha = 0.68$), complexity (Cronbach's $\alpha = 0.48$), source (Cronbach's $\alpha = 0.62$), and justification (Cronbach's $\alpha = 0.71$). Although modest, the low to moderated reliability estimates on the TSEBQ scales could reflect the relative diversity of participants' epistemic beliefs related to knowledge and knowing about GMFs, which is generally considered a complex scientific topic. Although reliability estimates were quite modest, the TSEBQ nonetheless provides a useful measure for assessing participants' epistemic beliefs related to the topic of GMFs. The TSEBQ can be found in Appendix D.

Experimental Texts. The experimental texts presented information regarding GMFs and included one expository and one refutation text (Heddy et al., 2017). Both texts were comparatively equivalent in length (617 vs. 624 words, respectively). In terms of ease of readability, each text obtained Flesch-Kincaid ease of reading scores of 42.1 and 42.2, respectively (Flesch, 1948). Both the refutation and expository texts included the same information, but the refutation text presented information by directly identifying a common misconception and refuting it using three empirically validated (causal) explanations. The refutation text presented participants with a total of four refutations that targeted common misconceptions related to GMFs. The expository text presented the same information as the refutation text, but information was represented in a matter-of-fact, descriptive fashion without the refutational content. Please see Appendices E and F for copies of the refutation and expository texts, respectively.

Post-knowledge Test. To assess post-test learning (i.e., knowledge revision), participants completed the same prior knowledge test. Psychometric reliability for the post-test measure was modest (Cronbach's $\alpha = .71$). Despite modest reliability, the post-test measure nevertheless met a minimum acceptable reliability coefficient threshold (Nunnally, 1978), and therefore served as a suitable metric for assessing participants' post-test knowledge revision. The post-knowledge measure can be found in Appendix G.

Procedure

A pretest-posttest experimental design was used to assess potential mediating and moderating effects of attitudes, epistemic beliefs, and refutation texts on post-test knowledge revision while learning about genetically modified foods (GMFs). The entire study was conducted on a computer using Survey Monkey© to administer the pre- and post-knowledge tests, capture self-report data, present the experimental texts, and collect participants' demographic information. To begin, participants provided informed consent and subsequently received instructions on how to complete the study. Next, participants completed the prior knowledge test about GMFs, the attitudes toward GMFs survey, and an adapted version of the TSEBQ (Strømsø et al., 2008). Following this, participants were randomly assigned to a refutation ($n = 62$) or expository ($n = 58$) text condition. After reading the text, participants completed the same prior knowledge test about GMFs to gain a measure of knowledge revision. Finally, participants completed a brief demographics survey to obtain basic background information related to their age, gender, nationality, languages spoken and written, undergraduate major/minor, grade-point averages (GPA), and general political affiliation. At the end of the session, participants were thanked for their participation and compensated $10 for their time.

CHAPTER 4

Results

Preliminary Analysis

There were no missing values in the data set. Each continuous variable was inspected for skewness and kurtosis. Based on Tabachnick and Fidell's (2013) recommendations, acceptable ranges of ±3 for skewness and ±8 for kurtosis were used to investigate the relative normality of the distributions for each continuous variable of interest. Analyses revealed that only the distribution for the GMFs knowledge post-test was negatively skewed (-4.88). Given the post-test measure included a true 0-value (answers were tabulated as being either correct or incorrect), no transformation was applied to normalize the distribution. In terms of kurtosis, no issues were observed in the data set. Descriptive statistics for all variables can be found in Table 1 below.

Table 1

Descriptive Statistics for all Variables

	Mean	*SD*	*Skewness*	*Kurtosis*
prior knowledge	.44	.20	2.30	.32
post-test knowledge	.77	.20	-4.88	3.08
attitudes	4.48	1.37	-2.09	.06
complexity of knowledge	4.12	.70	.42	-0.68
uncertainty of knowledge	4.71	.82	-1.13	.71
source of knowledge	4.17	.86	.40	-.13
justification for knowing	5.36	.70	-1.56	-.47

Note. Prior knowledge and post-test knowledge are reported as proportions.

To inspect for univariate outliers, each continuous variable was converted to a standard *z*-score with a mean of 0 and a standard deviation of 1. Based on recommendations by Hair, Black, Babin, and Anderson (2010), *z*-scores exceeding a critical threshold of ±2.5 were considered univariate outliers. Inspection of the data set revealed univariate outliers for the following variables: attitudes ($n = 3$, $z = -2.53$), uncertainty of knowledge ($n = 2$, $z = -2.69$), complexity of knowledge ($n = 1$, $z = -2.55$), and the post-test measure ($n = 3$, $z = -3.29$). In lieu of deletion,

however, all cases were kept based on recommendations by Cohen, Cohen, West, and Aiken (2003) who suggest that if the values for the univariate outliers are not very extreme, and equate to less that 2% of *n*, then they should be included in subsequent data analyses.

To inspect for multivariate outliers, Mahalanobis distances were calculated using SPSS. Based on recommendations from Myers, Gamest, and Guarino (2017), inspection of Mahalanobis distances were based on a χ^2 distribution with 7 degrees of freedom and a critical cutoff of 24.32 ($\alpha = .001$). Results revealed no issues regarding multivariate outliers in the data set. Finally, examination of Pearson correlations revealed no issues related to multicollinearity among variables of interest in the data set based on an inspection of a bivariate correlation matrix using a recommended critical cut-off point of .70 (Meyers et al., 2017). See Table 2 below.

Table 2

Correlations Among All Variables (N = 120)

Variables	1	2	3	4	5	6	7
1. Attitudes	—	.215*	.131	.076	.138	.380**	.389**
2. Structure of Knowledge	.215*	—	-.005	.506**	.341**	.427**	.358**
3. Certainty of Knowledge	.131	-.005	—	.011	.247**	.097	.155
4. Source of Knowledge	.076	.506**	.011	—	.350**	.351**	.108
5. Justification for Knowing	.138	.341**	.247**	.350**	—	.344**	.248**
6. Prior Knowledge	.380**	.427**	.097	.351**	.344**	—	.391**
7. Post-test Knowledge	.389**	.358**	.155	.108	.248**	.391**	—

*p < .05. **p < .01. Two-tailed.

Repeated Measures Analysis of Variance (ANOVA)

To address the first research question (RQ1), a repeated-measures ANOVA was conducted to assess whether there were any significant group differences in pretest and post-test learning outcomes between participants who read a refutation text versus participants who read

an expository text. Time was used as a within-subjects factor (2 levels, pretest and post-test) and text condition (refutation and expository) as the between-subjects factor. Results revealed a significant main effect of Time, Wilk's Lambda = .279, $F(1,118) = 304.74$, $p < .001$, $\eta^2 = .72$. Additionally, results revealed a significant Time by condition interaction (see Figure 11 below), indicating that participants in the refutation text condition changed significantly more of their misconceptions at post-test compared to participants in the expository text condition, Wilks' Lambda = .850, $F(1,118) = 20.76$, $p < .001$, $\eta^2 = .15$ (see Table 3 below). Specifically, post hoc analyses revealed a significant difference ($M = .17$, $SD = .04$) in post-test knowledge revision between participants who read a refutation text versus participants who read an expository text, $t(118) = 4.56$, $p < .001$.

Table 3

Summary of a One-Way Repeated-Measures ANOVA (N=120)

Sources	Sum of Squares	*df*	Mean Square	*F*	*p*	Partial η^2
Time	6.578	1	6.578	304.741	.000*	.721
Time*Condition	.448	1	.448	20.755	.000*	.150
Error (Time)	2.547	118	.022			

*$p < .001$ (two-tailed).

Overall, results revealed that 15% of the variance in post-test knowledge revision could be accounted for by text condition such that participants in the refutation text condition changed significantly more of their misconceptions related to GMFs at post-test compared to participants in the expository text condition. Findings support H1 and provide additional support for the effectiveness of refutation texts in facilitating knowledge revision (Heddy et al., 2017; Heddy & Sinatra, 2013; Trevors et al., 2016, 2017a; Kendeou et al., 2014).

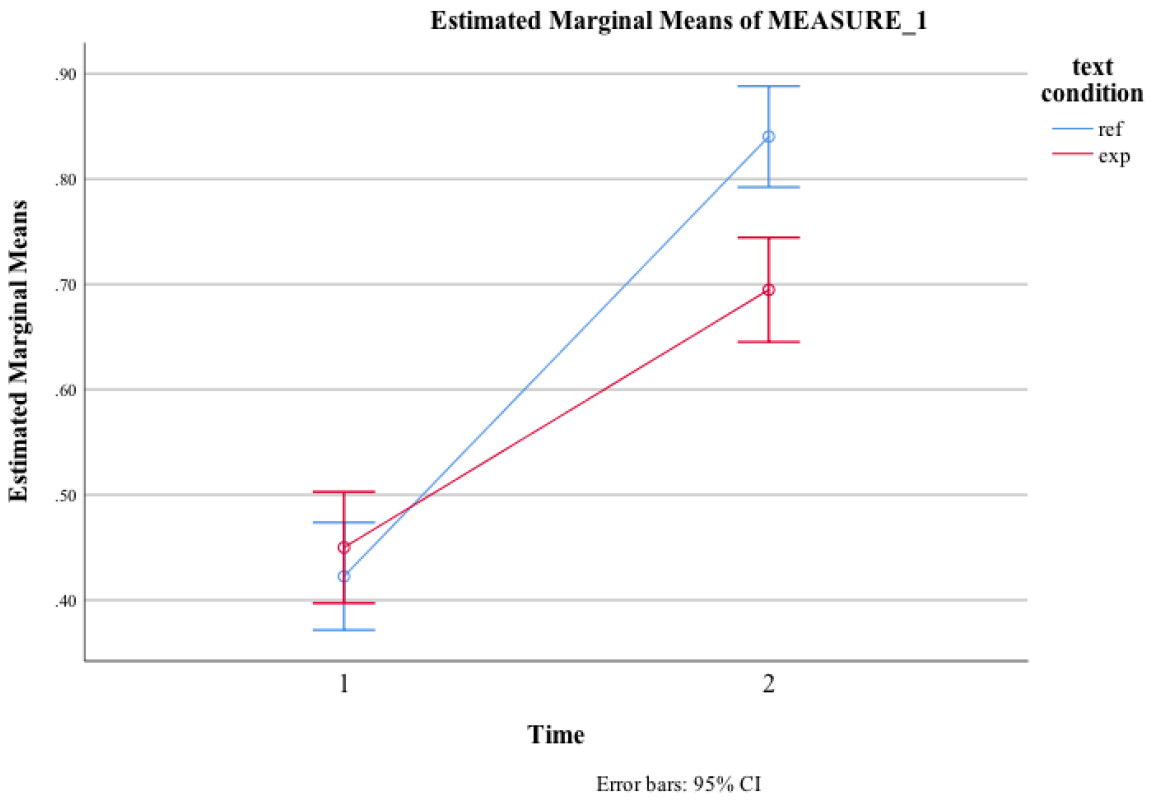

Figure 11. Effect of text condition on post-test learning.

Regression Analysis

To address RQ2a, a multiple linear regression was conducted to investigate whether participants' epistemic beliefs regarding the structure, certainty, source, and justification of knowledge and knowing related to GMFs predicted their attitudes towards GMFs. Results revealed a significant model, $F(1, 119) = 5.75$, $p = .018$, $R^2 = .215$, indicating that 22% of the variance in attitudes toward GMFs could be accounted for by participants' epistemic beliefs regarding GMFs. See Table 4 and Figure 12 below.

Table 4

Analysis of Variance for Multiple Linear Regression (N = 120)[a]

Sources	Sum of Squares	*df*	Mean Square	*F*	*p*
Regression	10.413	1	10.413	5.745	.018[b]
Residual	213.887	118	1.813		
Total	224.300	119			

a. Dependent Variable: Attitudes
b. Predictors: (Constant), Complexity of Knowledge

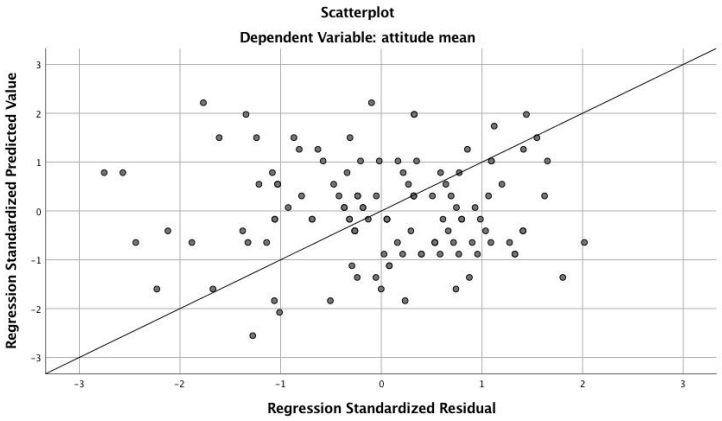

Figure 12. Scatterplot for Multiple Linear Regression, H2a.

Inspection of the regression coefficients (see Table 5 below) revealed that only beliefs regarding the complexity of GMFs knowledge significantly predicted participants' attitudes toward GMFs. More specifically, for every one-unit increase in participants' beliefs regarding the complexity of GMFs knowledge, there was a .423 increase in participants' attitudes toward GMFs such that the more participants viewed GMFs knowledge as highly complex and made up of interrelated concepts, the more positive were their self-reported attitudes toward GMFs. These findings provide partial support for H2a that participants' epistemic beliefs regarding GMFs would predict their attitudes toward GMFs.

Table 5

Test Results of Multiple Linear Regression Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. error	Beta		
1 (Constant)	2.732	.737		3.705	.000
Complexity of Knowledge	.423	.177	.215	2.397	.018

a. Dependent Variable: Attitudes

Mediation Analysis 1

To address RQ2b, a mediation analysis was conducted using Preacher and Hayes' (2014) PROCESS macro for SPSS to test whether participants' attitudes toward GMFs would mediate relations between their epistemic beliefs about GMFs and post-test knowledge revision. The regression (*c*-path) of beliefs regarding the complexity of GMFs knowledge on post-test knowledge revision, excluding the mediator (i.e., attitudes towards GMFs), was statistically significant, $\beta = .29$, $t(118) = 3.46$, $p < .001$. The regression of beliefs regarding the complexity of GMFs knowledge on the mediator (*a*-path) was also statistically significant, $\beta = .22$, $t(118) = 2.40$, $p = .02$. The combination of beliefs regarding the complexity of GMFs knowledge and the mediator produced an overall significant model, $F(2,117) = 17.47$, $p < .001$, $R^2 = .23$, wherein 23% of the variance in post-test knowledge revision was accounted for by both the predictor and mediator variables. Further analyses revealed that attitudes ($\beta = .33$, $t(117) = 3.94$, $p < .001$) was a significant predictor of post-test knowledge revision (*b*-path) while controlling for beliefs regarding the complexity of GMFs knowledge. Overall, analyses revealed that attitudes towards GMFs mediated the relationship between beliefs regarding the complexity of GMFs knowledge and post-test knowledge revision, (*effect* = .07, with 95% bootstrap *CIs* from .004 to .163). Despite the rather small beta-coefficient and marginally significant CIs, attitudes toward GMFs nonetheless significantly mediated the relationship between beliefs regarding the complexity of

GMFs knowledge and post-test knowledge revision, thereby confirming H2b that participants' attitudes towards GMFs (as an object-evaluation association) would mediate relations between their epistemic beliefs about GMFs and post-test knowledge revision. See Figure 13 below for the final model.

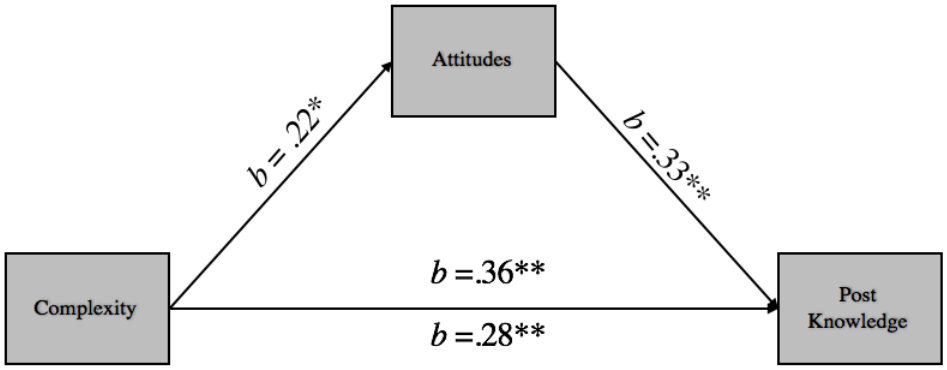

Figure 13. Final mediation model for H2b.
Note. All values represent standardized coefficients.
** p < .001
* p < .05

Notwithstanding these findings, separate mediation analyses were also conducted using each additional dimension of epistemic beliefs about GMFs (i.e., certainty, source, and justification) as predictors, attitudes towards GMFs as a mediator variable, and post-test knowledge revision as a criterion variable. Results of these analyses revealed no other statistically detectable mediations of attitudes towards GMFs on the relationship between participants' epistemic beliefs regarding GMFs on post-test knowledge revision. In short, the findings reported here revealed a significant mediation of attitudes on the relationship between beliefs in the complexity of GMFs knowledge and post-test knowledge revision. Additionally, these results reveal beliefs in the complexity of GMFs knowledge to be a significant positive predictor of participants' attitudes towards GMFs, thereby providing additional support for H2a

described above. Finally, these results provide additional support for the conceptual model regarding the relationship between attitudes and epistemic beliefs as shown in Figure 7 above.

Mediation Analysis 2

To address the research question (RQ3) whether attitudes and epistemic beliefs mediate the relationship between prior knowledge (i.e., misconceptions) and post-test knowledge revision, Preacher and Hayes' (2014) PROCESS macro for SPSS was used to evaluate the hypothesized model. It should be noted that for the sake of brevity a single parallel mediation model was tested in lieu of running separate analyses to examine potential interceding effects of attitudes and epistemic beliefs regarding GMFs on the relationship between prior knowledge and post-test knowledge revision.

Results of the analysis revealed that the regression of prior knowledge on post-test knowledge revision (*c*-path), excluding the mediators (i.e., attitudes and epistemic beliefs), was significant, $\beta = .39$, $t(118) = 4.61$, $p < .001$. Additionally, the regressions of prior knowledge on the mediators were significant (*a*-path), with the exception of prior knowledge on beliefs about certainty of knowledge, $\beta = .10$, $t(118) = 1.06$, $p = .29$. That is, prior knowledge significantly predicted attitudes ($\beta = .38$, $t(118) = 4.47$, $p < .001$), complexity of knowledge ($\beta = .43$, $t(118) = 5.13$, $p < .001$), source of knowledge ($\beta = .35$, $t(118) = 4.07$, $p < .001$), and justification for knowing ($\beta = .34$, $t(118) = 3.98$, $p < .001$). The combination of prior knowledge and the mediators produced an overall significant model, $F(6,113) = 7.54$, $p < .001$, $R^2 = .29$, wherein 29% of the variance in knowledge revision was accounted for by both the predictor and mediator variables. Further analyses (*b*-path) revealed that only attitudes ($\beta = .24$, $t(113) = 2.81$, $p = .006$) and beliefs in the complexity of GMFs knowledge ($\beta = .27$, $t(113) = 2.69$, $p = .008$) were significant predictors of knowledge revision while controlling for prior knowledge, whereas

uncertainty, source, and justification were not. Final analyses (*c'*-path) revealed a statistically detectable mediation in the model for attitudes (*effect* = .09, with 95% bootstrap *CIs* from .07 to .35) and complexity of knowledge (*effect* = .11, with 95% bootstrap *CIs* from .04 to .21), whereas uncertainty, source, and justification were not significant mediators in the model. Overall, attitudes toward GMFs and beliefs about the complexity of GMFs knowledge significantly mediated the relationship between prior (mis)conceptions about GMFs and post-test knowledge revision. See Figure 14 below for the final model. The findings reported here provide partial support for H3 indicating that attitudes and epistemic beliefs regarding GMFs mediate the effect of prior knowledge (i.e., misconceptions) and post-test knowledge revision.

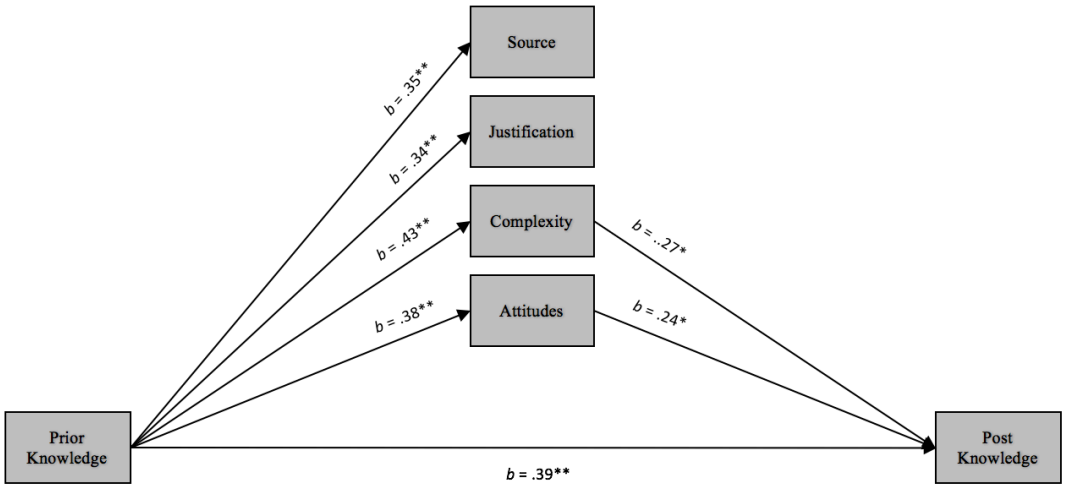

Figure 14. Final mediation model for H3.
Note. All values represent standardized coefficients
** p < .001
* p < .01

Moderated Mediation Analyses

To address RQ4, a moderated mediation analysis was conducted using Preacher and Hayes' (2014) PROCESS macro for SPSS to examine whether type of text (refutation versus expository) moderated the mediated relationship of prior knowledge on post-test knowledge

revision via participants' attitudes and epistemic beliefs regarding GMFs. Results revealed a significant regression of prior knowledge on post-test knowledge revision (β = .23, t(107) = 2.49, p = .014). Results also revealed significant regressions of prior knowledge on attitudes towards GMFs (β = .38, t(118) = 4.47, p < .001), beliefs in the complexity of GMFs knowledge (β = .43, t(118) = 5.13, p < .001), beliefs regarding the source of GMFs knowledge (β = .35, t(118) = 4.07, p < .001), and beliefs regarding the justification of GMFs knowledge (β = .34, t(118) = 3.98, p < .001), but the regression of prior knowledge on beliefs regarding the certainty of GMFs knowledge was not statistically significant (β = .10, t(118) = 1.06, p = .29). Further analyses revealed there were no statistically significant regressions of attitudes towards GMFs (p = .10), beliefs in the complexity of GMFs knowledge (p = .23), beliefs in the certainty of GMFs knowledge (p = .84), beliefs regarding the sources of GMFs knowledge (p = .52), and beliefs regarding the justification of GMFs knowledge (p = .33) on post-test knowledge revision.

Results revealed significant conditional indirect effects of attitudes towards GMFs (*effect* = .12, with 95% bootstrap *CIs* from .02 to .27) and beliefs in the complexity of GMFs knowledge (*effect* = .11, with 95% bootstrap *CIs* from .02 to .20) on post-test knowledge revision for participants in the refutation text condition. However, given there were no statistically detectable interaction effects of text condition on prior knowledge or the mediators, nor any significant indices of moderated mediation, text condition was not found to be a significant moderator in the model. That said, there was a statistically detectable conditional direct effect of prior knowledge on post-test knowledge for participants in the expository text condition (*effect* = .35, with 95% bootstrap *CIs* from .09 to .61), indicating that participants with low prior knowledge who read an expository text changed significantly less misconceptions at post-test compared to participants who read a refutation text. Overall, results revealed that text condition did not significantly

moderate the mediated relationship between prior knowledge and post-test knowledge revision via participants' attitudes and epistemic beliefs regarding GMFs. Although there were statistically detectable conditional indirect effects of attitudes and epistemic beliefs regarding the complexity of GMFs knowledge on post-test knowledge revision for participants in the refutation text condition, there were no significant interaction effects or indices of moderated mediation, thereby revealing a statistically null moderated mediation model. See Figure 15 below for the final model.

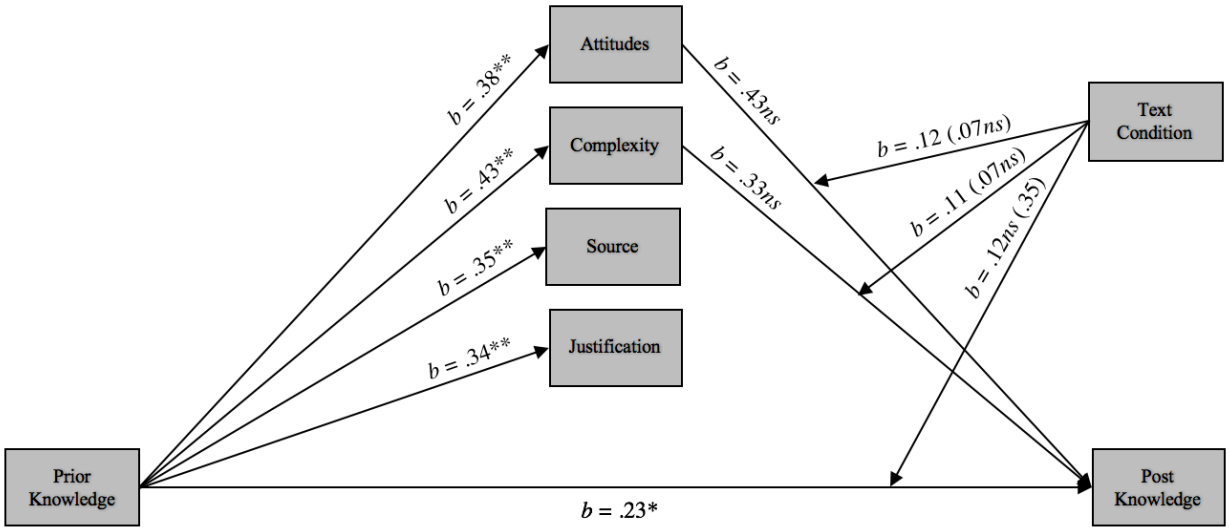

Figure 15. Final Moderated Mediation Model for H4
Note. Values on left of moderations reflect standardized coefficients for the refutation condition. Values on right reflect standardized coefficients for the expository condition.
** p < .001
* p < .05

Summary of Results

Results of a repeated measures ANOVA confirmed the first hypothesis (H1) that participants who read a refutation text would change significantly more misconceptions at post-test compared to participants who read an expository text. Participants who were presented with a refutation text experienced greater learning gains in terms of knowledge revision at post-test

compared to participants who read an expository text. These results provide additional evidence for findings from other empirical studies regarding the effectiveness of refutation texts as useful rhetorical devices for facilitating knowledge revision (Heddy et al., 2017; Kendeou et al. 2013, 2014; Tippet, 2010; Trevors et al., 2016).

To test whether epistemic beliefs about GMFs predicted participants' attitudes toward GMFs (H2a), a stepwise linear regression was conducted. Findings revealed that only beliefs regarding the complexity of GMFs knowledge significantly predicted attitudes toward GMFs, whereas beliefs regarding the certainty, source, and justification of GMFs knowledge did not. These results suggest that the more individuals believed GMFs knowledge to be complex (i.e., made up of highly interrelated concepts and knowledge structures), the more positive were their attitudes towards to GMFs. In other words, participants in the present study with more highly differentiated beliefs regarding the complexity of GMFs knowledge also self-reported more favorable attitudes towards GMFs. These results support empirical findings from other studies in the literature that have shown epistemic beliefs regarding scientific knowledge to predict individuals' attitudes towards science (Kapucu and Bahçivan, 2015)

To further investigate possible relationships between attitudes and epistemic beliefs (H2b), and more specifically, to test whether attitudes mediated relations between participants' epistemic beliefs (evaluations of GMFs knowledge) and post-test knowledge revision regarding GMFs (the object of evaluation), a mediation analysis was conducted using Preacher and Hayes' (2014) PROCESS macro for SPSS. Findings revealed a statistically detectable mediation of attitudes towards GMFs on the relationship between beliefs in the complexity of GMFs knowledge and post-test knowledge revision. These results suggest that participants' attitudes (object-evaluation associations) mediate between the evaluative function of participants'

epistemic beliefs regarding GMFs and subsequent knowledge revision. Although there were no statistically detectable mediations of attitudes towards GMFs on the relationship between participants' epistemic beliefs regarding the certainty, source, and justification of GMFs knowledge and post-test knowledge revision, these findings (along with the results from the regression analysis noted above) provide partial support for the conceptual relationship between attitudes and epistemic beliefs outlined in Figure 7 above.

To test the hypothesis (H3) whether attitudes towards GMFs and epistemic beliefs regarding GMFs knowledge would mediate relations between prior knowledge (i.e., misconceptions) and post-test knowledge revision, an additional mediation analysis was conducted using Preacher and Hayes' (2014) PROCESS macro for SPSS. As previously noted, a parallel mediation model was conducted including both attitudes and epistemic beliefs regarding GMFs in lieu of running separate analyses to test potential mediating roles of each of these factors independently. Overall, findings showed that only attitudes toward GMFs and beliefs regarding the complexity of GMFs knowledge significantly mediated relations between prior (mis)conceptions and post-test knowledge revision. These results suggest that participants with more positive attitudes and more highly differentiated epistemic beliefs regarding the complexity of GMFs knowledge experienced greater learning gains in terms of knowledge revision at post-test compared to individuals with negative attitudes and less constructivist epistemic beliefs regarding the complexity of GMFs knowledge. In other words, participants with negative attitudes towards GMFs who viewed GMFs knowledge in terms of simple facts, isolated concepts, or who simply lacked a more differentiated understanding of the science behind GMFs knowledge revised less misconceptions at post-test.

Finally, a moderated mediation analysis was conducted using Preacher and Hayes' (2014) PROCESS macro for SPSS to investigate whether type of text (i.e., refutation versus expository) moderated the mediated relationship of prior knowledge on post-test knowledge revision via participants' attitudes towards GMFs and their epistemic beliefs about GMFs knowledge (H4). Results revealed that type of text was not a significant moderator in the model, and although the previous mediation analyses (H3) revealed a statistically detectable mediation of attitudes and epistemic beliefs regarding the complexity of GMFs knowledge on the relationship between prior knowledge and post-test knowledge revision, these effects disappeared with the introduction of the moderator (i.e., text-type) into the model. Although results revealed significant conditional indirect effects of prior knowledge on post-test knowledge revision via attitudes towards GMFs and beliefs about the complexity of GMFs knowledge for participants in the refutation text condition, the lack of significant interaction effects and indices of moderated mediation indicated that text-type was not a significant moderator in the model. In other words, text-type did not significantly moderate the mediated relationship between prior knowledge and post-test learning via participants' attitudes and epistemic beliefs regarding GMFs. As such, these results did not provide support for H4. That said, there was a statistically significant conditional direct effect of prior knowledge on post-test knowledge revision for participants in the expository text condition, which suggested that participants with low prior knowledge regarding GMFs who read an expository text changed less misconceptions at post-test compared to participants who read a refutation text. This finding adds credence to the results from the repeated measures ANOVA described above where it was found that participants with low prior knowledge who read a refutation text changed significantly more misconceptions at post-test compared to participants who read an expository text. As such, this finding provides additional

support for the effectiveness of refutation texts compared to expository texts in facilitating knowledge revision (Tippet, 2010). The practical significance and educational implications of these and previously described results are discussed next.

CHAPTER 5

Discussion

The purpose of this research was to advance knowledge about the roles of attitudes and epistemic beliefs in knowledge revision, and to provide additional support for the effectiveness of refutation texts in facilitating conceptual change. The results of this study have important theoretical implications for conceptual change research, particularly in terms of understanding factors related to how individuals interpret, evaluate, and make sense of important personal, social-political, economic, and scientific issues. Results also have practical implications for the design and development of educational interventions aimed at equipping learners with the skills to recognize and revise their misconceptions while learning about complex science topics.

Refutation Texts and Knowledge Revision

To test whether participants who read a refutation text would revise significantly more of their misconceptions at post-test compared to participants who read an expository text (H1), a repeated-measures ANOVA was conducted. Results confirmed H1 and provided additional support for findings from previous studies that have shown refutation texts to be effective rhetorical devices for facilitating knowledge revision (Heddy et al., 2017; Heddy & Sinatra, 2013; Kendeou et al., 2014; Trevors et al., 2016, 2017b).

According to Kendeou et al. (2013, 2014), refutation texts are effective in facilitating knowledge revision because they directly target misconceptions and present a rich network of causal explanations based on scientific evidence to refute inaccurate knowledge. These causal explanations compete with previously-acquired misconceptions and begin to dominate the conceptual network by reducing activation of previously-acquired misinformation, thus facilitating a change in knowledge within a conceptual network. Although the structure of the

texts was not systematically varied in this study (i.e., using pro-refutations versus con-refutations or pro- versus con-expository texts), the results nonetheless provide support for the use of refutation texts as an effective strategy for facilitating conceptual change during knowledge revision (Heddy et al., 2017; Heddy & Sinatra, 2013; Trevors et al., 2016, 2017a).

The effectiveness of refutation texts in supporting knowledge revision depends on both the unique structural qualities of the texts and the characteristics of the messages they convey. Recall Dole and Sinatra (1998) described in their Cognitive Reconstruction of Knowledge Model (CRKM) that only messages that are comprehensible, plausible, coherent, and rhetorically compelling are likely to facilitate knowledge revision. In terms of refutation texts, the messages conveyed are designed to be conceptually palpable, to provide an explanatory framework that essentially links back to larger conceptual structures, and are designed to be rhetorically compelling; that is, the rhetorical structure of the texts—including information sources and justification of arguments—are purposefully designed and organized to be iterative and to create an interconnected chain of sufficiently persuasive counter arguments to compete with previously acquired misconceptions to facilitate knowledge revision. Overall, the carefully designed structure of refutation texts and the characteristics of the messages they convey make them effective tools for facilitating knowledge revision during conceptual change.

Although refutation texts provide an effective strategy for facilitating knowledge revision, learner characteristics such as attitudes and epistemic beliefs also play an important role in determining the likelihood individuals will revise previously acquired, inaccurate knowledge (Dole & Sinatra, 1998). Indeed, attitudes and epistemic beliefs play a central role in information processing and underlie how individuals interpret and evaluate knowledge and information instantiated in a wide variety of sources, including refutation texts. Taken together, message

characteristics (i.e., comprehensibility, plausibility, coherence, and rhetorical structure) and learner characteristics (i.e., existing knowledge, attitudes, epistemic beliefs), including the reciprocal and dynamic interactions between them, should be considered concomitantly while evaluating the factors involved in knowledge revision.

Relationships Between Attitudes and Epistemic Beliefs About GMFs

To address H2a, a regression analysis was conducted to test for potential relationships between epistemic beliefs about GMFs and attitudes towards GMFs. Results revealed that participants' beliefs in the complexity of GMFs knowledge significantly predicted their attitudes toward GMFs such that the more participants believed knowledge related to GMFs to be highly complex and differentiated, the more positive were their self-reported attitudes towards GMFs. In other words, participants who self-reported more positive attitudes toward GMFs also expressed more constructivist epistemic beliefs regarding the complexity of GMFs knowledge.

According to Alum et al. (2008), the more scientifically literate an individual, the more likely they are to express positive attitudes towards science learning and education (see also Hayes & Tariq, 2000). Similarly, individuals who are more scientifically literate are also likely to have more constructivist epistemic beliefs, which has been shown to correspond with more positive attitudes towards science (Fulmer, 2014; Kapucu & Bahçivan, 2015). Beliefs that GMFs knowledge is complex (i.e. multifaceted, highly differentiated, comprised of a variety of interrelated concepts and knowledge structures) presumably mitigates the impact of the cognitive conflict that arises during knowledge revision when individuals encounter discrepant and contradictory knowledge claims. More constructivist epistemic beliefs towards science may foster greater openness to diverse and discrepant sources of knowledge, and in turn, facilitate

more positive attitudinal appraisals regarding objects of scientific knowledge (and associated attributes) via an appreciation that scientific knowledge is sufficiently complex.

Although there was a significant positive regression of beliefs in the complexity of GMFs knowledge on participants' attitudes towards GMFs, there were no other statistically detectable relationships between participants' attitudes towards GMFs and their beliefs in the certainty, source, or justification of GMFs knowledge. These results were somewhat surprising considering findings from other studies have found significant relations between individuals' attitudes toward science and their beliefs in the uncertainty of scientific knowledge, as well as their beliefs in the justification of scientific knowledge via authority (i.e., source evaluations) (Fulmer, 2014). Perhaps the lack of significant findings for the other dimensions of epistemic beliefs reflect the academic nature of the experimental texts used in this study (i.e., the texts were empirically sourced, justified, and structured using causal arguments). The fact that complexity had a statistically detectable effect on knowledge revision may reflect the relative complexity of the topic, and/or perhaps a majority of participants' beliefs regarding the complexity of GMFs knowledge were based on less scientific sources of information (i.e., self-authored content on the Web), and thus, were sufficiently challenged by the empirical and structural characteristics of the experimental texts used in the study. Whatever the case, the results reported here nonetheless provide additional empirical support for the relationships between attitudes and epistemic beliefs in knowledge revision, and highlight the need for more research to explore the exact nature of the relationships between individuals' attitudes and epistemic beliefs during learning and knowledge revision.

To address H2b, a mediation analysis was conducted using Preacher and Hayes' (2014) PROCESS macro for SPSS to determine whether attitudes mediate relations between

participants' epistemic beliefs about GMFs and their post-test knowledge revision. Overall, results revealed a statistically detectable regression of beliefs in the complexity of GMFs knowledge on post-test knowledge revision via participants' attitudes toward GMFs such that participants who reported more constructivist epistemic beliefs regarding the complexity of GMFs knowledge also self-reported more positive attitudes towards GMFs, and in turn, experienced greater learning gains in terms of knowledge revision at post-test.

These results are somewhat unique in the conceptual change literature given that this is the first study, to the best of my knowledge, that has investigated the direct and indirect effects of attitudes and epistemic beliefs in knowledge revision in one coherent model. While most studies in the conceptual change literature have focused on the predictive roles of epistemic beliefs (Franco et al., 2012; Trevors et al., 2017b; Stathopoulou & Vosniadou, 2007), emotions (Broughton et al., 2013; Trevors, et al, 2017a) and motivation (Pintrich et al., 1993) in conceptual change, as well as the role conceptual change on subsequent attitudes and emotions (Heddy et al., 2017), including the effectiveness of refutation texts in facilitating knowledge revision related to complex science topics (Heddy et al., 2017; Heddy & Sinatra, 2013; Trevors et al., 2016, 2017a), the results reported here provide evidence for the functional roles of attitudes and epistemic beliefs as critical factors involved in information processing during knowledge revision. Overall, the present findings substantially add to existing conceptual change literature by moving beyond questions of whether or if significant differences or relationships exist between attitudes and epistemic beliefs in knowledge revision, and instead, provide a descriptive account regarding how and in what ways attitudes and epistemic beliefs function to facilitate knowledge revision during conceptual change.

In summary, the results of the present study provide support for both theory (Ajzen, 1989; Ajzen & Fishbein, 2005; Eagly & Chaiken, 1993; Fabrigar, et al., 2005) and empirical findings (Fulmer, 2014; Silverman, 2007; Xiao & Sandoval, 2017) that have postulated and subsequently demonstrated measureable relationships between individuals' attitudes and epistemic beliefs during knowledge revision and conceptual change. Overall, findings from the present study highlight the need to build a more comprehensive understanding of the structural and functional relationships between attitudes and epistemic beliefs in learning and knowledge revision so that interventions can be designed to help learners effectively target and change their misconceptions (i.e., inaccurate knowledge), attitudes (object-evaluation associations), and epistemic beliefs (individual doxastic assumptions) to more accurately process, interpret, and evaluate knowledge and information pertaining to important, complex socio-scientific topics that have a global impact on personal, social, and economic decision-making behaviours.

The Mediating Roles of Attitudes and Epistemic Beliefs in Knowledge Revision

To address H3, a mediation analysis was conducted using Preacher and Hayes' (2014) PROCESS macro for SPSS to test whether attitudes towards GMFs and epistemic beliefs about GMFs significantly mediated knowledge revision (i.e., a learning differential from pre-test to post-test). Results revealed both direct and indirect effects of prior knowledge on post-test knowledge revision. Although there was a significant regression of prior knowledge on attitudes and beliefs regarding the complexity, source, and justification of knowledge related to GMFs, beliefs regarding the certainty of GMFs knowledge were not predicted in the model. While controlling for prior knowledge, only attitudes and beliefs regarding the complexity of GMFs knowledge significantly predicted knowledge revision at post-test. The indirect effects of prior

knowledge on post-test knowledge revision were mediated by participants' attitudes and beliefs pertaining to the complexity of GMFs knowledge.

Overall, results of the present study indicate that attitudes toward GMFs and beliefs in the complexity of GMFs knowledge significantly mediate relations between prior misconceptions and post-test knowledge revision such that individuals with more positive attitudes and more constructivist epistemic beliefs regarding the complexity of GMF knowledge experienced greater learning gains in terms of knowledge revision at post-test. Although previous studies have found direct relationships between attitudes and knowledge (Heddy et al., 2017) and epistemic beliefs and conceptual change (Mason & Gava, 2007; Mason et al., 2008), few studies have investigated whether these factors mediate between prior knowledge and post-test knowledge revision. The findings reported here show that, taken together, both attitudes and epistemic beliefs play a functional role in mediating relations between prior learning and post-test knowledge revision. Given the roles of attitudes and epistemic beliefs in the processing, interpretation, and evaluation of scientific knowledge, these findings provide evidence for the dynamic role these factors play in facilitating knowledge revision during conceptual change, especially considering that participants in the present study with low prior knowledge (i.e. more misconceptions) and who self-reported more negative attitudes and less constructivist epistemic beliefs regarding GMFs changed significantly fewer misconceptions at post-test compared to participants with low prior knowledge who reported more positive attitudes and epistemic beliefs regarding GMFs.

The Moderating and Mediating Roles of Refutation Texts, Attitudes, and Epistemic Beliefs in Knowledge Revision

To address H4, a moderated mediation analysis was conducted using Preacher and Hayes' (2014) PROCESS macro for SPSS. Results revealed no statistically detectable

moderation of text condition on the mediated relationship between prior knowledge and post-test knowledge revision via participants' attitudes and epistemic beliefs regarding GMFs. Although there were statistically detectable conditional indirect effects of attitudes toward GMFs and beliefs in the complexity of GMFs knowledge for participants in the refutation text condition (see Figure 15 above), there were no significant interaction effects or indices of moderated mediation in the model. Despite the findings reported above that showed participants who read a refutation text changed significantly more misconceptions at post-test compared to participants who read an expository texts (H1), and that attitudes toward GMFs and epistemic belief about GMFs significantly mediated the regression of prior learning on post-test knowledge revision (H3), the addition of text condition as a dichotomous moderator into the mediation model did not result in any statistically significant findings. In other words, there were no statistically detectable conditional indirect effects of prior knowledge on post-test knowledge revision via participant's attitudes and epistemic beliefs that varied as a function of text condition. That said, there was a significant conditional direct effect of prior knowledge on post-test knowledge revision for participants in the expository text condition such that participants who read an expository text changed significantly less misconceptions at post-test compared to participants who read a refutation text. This finding provides additional support for the repeated measures ANOVA described above (H1) that implicated refutation texts to be an effective strategy for facilitating knowledge revision.

Discussion Summary

Results from this study provide additional support for empirical findings from other studies implicating the roles of attitudes and epistemic beliefs in knowledge revision (Heddy et al, 2017; Mason et al., 2007; Murphy & Alexander, 2016; Sinatra et al., 2014; Sinatra &

Seyranian, 2016), as well as the effectiveness of refutation texts in supporting conceptual change (Heddy et al., 2017; Kendeou et al., 2014; Trevors et al., 2017b). More specifically, the findings reported here are in line with previous studies that have shown that shifts in knowledge from less to more accurate conceptions about GMFs typically result in a shift from negative to more positive attitudes towards GMFs (Heddy et al., 2017). As such, the results from this study suggest that interventions designed to foster conceptual change during knowledge revision may also facilitate the development of more positive attitudes toward negatively-charged science topics.

Regarding epistemic beliefs, the findings from this study are in line with previous research that has shown individuals with more constructivist epistemic beliefs change significantly more misconceptions after reading refutation texts compared to individuals with less constructivist epistemic beliefs who read expository texts (Franco, et al., 2012; Kendeou et al., 2011; Murphy & Alexander, 2016; Trevors et al., 2017b). Overall, findings from the present study suggest that designing learning interventions to facilitate the development of more constructivist epistemic beliefs can facilitate greater learning gains in terms of knowledge revision by equipping learners with the skills to critically evaluate and judge the veridicality of complex socio-scientific information.

Findings from this research suggest that augmenting refutation texts with persuasive attitudinal content could potentially be an effective means for not only directly targeting and changing inaccurate conceptions related to important science topics, but also for changing individuals' attitudes towards negatively charged, complex socio-scientific issues. According to Ajzen and Fishbein (2005), virtually any intervention designed to change beliefs (or knowledge) will indirectly support a change in attitudes. Thus, fostering changes to underlying systems of

beliefs may likewise lead to changes in emergent attitudes, and supporting changes in attitudes may reciprocally facilitate greater openness to diverse sources of information, including consideration of multiple perspectives, arguments and counterarguments, as well as less biased encoding and retrieval of information related to complex science topics.

Educational Implications

Results reported in this study highlight the importance of considering the role of differential attitude structures in relation to specific dimensions of epistemic beliefs (rather than general systems) in conceptual change research. Findings from the present study indicate that individuals who hold more highly differentiated, constructivist beliefs regarding the complexity of GMF knowledge also tend to express more positive attitudes toward GMFs (object-evaluation associations) and, in turn, experience greater learning gains in terms of knowledge revision at post-test. One potential avenue for future research thus entails designing refutation texts with persuasive attitudinal content to facilitate attitudinal change in addition to knowledge revision. Attitudes have important implications for how individuals select, perceive, interpret, encode and retrieve information related to complex science topics, while epistemic beliefs play an important role in how individuals evaluate and judge sources of knowledge. Overall, changing attitudes (object-evaluation associations) reciprocally influences changes in underlying systems of beliefs (evaluative knowledge structures), and the reciprocal interaction between these factors plays an important role in both knowledge acquisition and revision. Therefore, developing interventions to foster the development of more positive attitudes, as well as more constructivist epistemic beliefs, has the potential to positively impact learning and knowledge revision in relation to negatively charged, controversial socio-scientific topics that otherwise tend to elicit negative attitudes and conflict with individuals' personal beliefs. More specifically, developing

interventions to target individuals' beliefs regarding the complexity of knowledge and knowing related to controversial socio-scientific topics has the potential for equipping learners with the skills to critically evaluate and judge the veracity of information in relation to the relative complexity of a topic. Understanding knowledge and knowing to be comprised of complex processes, learners may better appreciate the diversity of scientific knowledge and knowing, and thus, become more open to discrepant sources of knowledge and information. Overall, facilitating the development of positive attitudes and more constructivist epistemic beliefs regarding the complexity of knowledge and knowing related to complex science topics may have beneficial effects on learning, knowledge revision, as well as personal, social, and economic decision-making behaviors and equip individuals with the skills to make more informed choices related to issues of global significance.

Limitations and Future Directions

Results from the present study should be interpreted with caution for several reasons. To begin, I used self-report inventories to measure attitudes and epistemic beliefs. Although self-reports of attitudes are generally reliable indicators of individuals' attitudes, they can be somewhat unreliable indicators of epistemic beliefs (Greene et al., 2014). Indeed, for this sample, reliability estimates for epistemic beliefs were not particularly high. That said, the low reliabilities for the epistemic beliefs measure could potentially reflect the relative diversity of participants' epistemic beliefs about GMFs. At any rate, utilizing think aloud protocols (TAPs) would have presumably provided a richer, more reliable data set from which to generalize findings regarding the epistemic processes at play during knowledge revision. According to Chi (1997), TAPs are particularly effective for observing emergent cognitive and metacognitive processes that arise during learning without interfering with the learning task. In terms of

attitudes, although reliability estimates for the attitude measure were quite high, and while self-report measures for attitudes are generally considered reliable indices, it should be noted that questionnaires used to measure attitudes in controlled settings may not be wholly representative of attitudes that emerge when individuals encounter relevant information or situations in vivo, and therefore, may be less reliable indicators of individuals' actual attitudes and subsequent behavioral intentions (i.e. decision-making behaviors) (Ajzen & Fishbein, 2005). For example, self-reported attitudes toward GMFs in a laboratory setting may not represent the attitudes that emerge when individuals are faced with a choice whether to purchase or consume GMFs in real-life situations. An individual may express negative attitudes toward GMFs in a questionnaire in a controlled setting (i.e., beliefs that GMFs are harmful for human consumption and should be avoided), yet still make the decision to purchase or consume GMFs outside of a controlled laboratory setting despite self-reported attitudes to the contrary. As such, self-report measures of attitudes should be interpreted with caution.

In terms of pre- and post-test reliabilities, the prior and post-test knowledge measures revealed low (Cronbach's $\alpha = .60$) to modest (Cronbach's $\alpha = .71$) reliability estimates, respectively. It is possible, however, that the low reliability for the prior knowledge test reflected participants' especially low prior knowledge, or the relative complexity of the topics being assessed (Trevors et a., 2016). Whatever the case, these measures should be improved for future research. Moreover, given that the complexity of knowledge had the poorest reliability estimate (Cronbach's $\alpha = 0.48$) out of the all subscales for the Topic Specific Epistemic Beliefs Questionnaire (TSEBQ), results should be interpreted with caution, especially considering that complexity of knowledge was the only significant predictor in the model.

Finally, measures of emotions and values regarding GMFs were not included in this study. The preponderance of research in the conceptual change literature has shifted focus away from examining exclusively 'cold' cognitive constructs of conceptual change (i.e., information processing) to investigations that additionally include 'hot' constructs, such emotions and motivation (Broughton et al., 2013; Pintrich et al., 1993; Sinatra & Seyranian, 2016; Heddy et al., 2017). Although attitudes were a primary variable of interest in the present study, the roles of emotions and their influences on attitudes were not included in this research. Including measures of emotions, however, could have otherwise provided more explanatory power regarding the processes at play during knowledge revision. According to Ajzen and Fishbein (2005), individuals' moods (and emotions) can systematically influence their beliefs and subsequent evaluations of knowledge or events such that individuals in positive mood (emotional) states will be more inclined to evaluate knowledge or events more favorably than individuals in negative mood (emotional) states. The effects of moods and emotions on beliefs can subsequently impact individuals attitudes and intentions to act (i.e., decision-making behaviors) (Ajzen & Fishbein, 2005). Therefore, future studies should include emotions as a variable interest and consider implementing mood induction protocols to control for the effects of mood and emotions in studies designed to assess the role of attitudes and epistemic beliefs in knowledge revision.

Additionally, a measure of values toward GMFs was not included in the present study. According to Rockeach (1968), values are an important factor to consider when examining relationships among attitudes and beliefs because value systems inevitably inform individuals' systems of beliefs and, in turn, the emergent attitudes that influence and shape individuals' processing of information and decision-making behaviors. Arguably, circumventing value systems and their relations to beliefs and attitudes provides a rather myopic focus on problems of

persuasion at the expense of larger issues related ‘education and re-education’ (Rockeach, 1968). As such, findings from the present study provide only a limited account of the potential multivariate factors that may influence knowledge revision. Future research should focus more explicitly on the dynamic, functional and structural relations among emotions, values, beliefs, and attitudes to obtain a more holistic understanding of how these factors operate to either facilitate or constrain learning, knowledge revision, and the processing of socio-scientific information.

Conclusion

The objectives of the present study were to advance knowledge by providing evidence for the mediating roles of attitudes and epistemic beliefs in knowledge revision, as well as additional support for the effectiveness of refutation texts in facilitating conceptual change. While attitudes play a role in how individuals select, perceive, encode and retrieve information, epistemic beliefs play a role in how individuals interpret and evaluate knowledge. Taken together, attitudes and epistemic beliefs play an integral role in how individuals process, interpret, an evaluate socio-scientific information. The results of the present study show that, taken together, both attitudes and epistemic beliefs, and the reciprocal relations between them, significantly mediate between previously acquired misconceptions and post-test knowledge revision during conceptual change while learning about GMFs from refutation texts. More specifically, the findings reported here revealed that participants who self-reported more positive attitudes towards GMFs and more constructivist epistemic beliefs regarding the complexity of GMFs knowledge also experienced greater learning gains in terms of knowledge revision at post-test compared to participants who self-reported more negative attitudes and less constructivist epistemic beliefs regarding the complexity of GMFs. Additionally, results reported in the present study revealed refutation texts

to be more effective than expository texts in facilitating knowledge revision. In other words, participants in this study who read a refutation text changed significantly more misconceptions about GMFs at post-test compared to participants who read an expository text. Overall, the results of the present study provide evidence for the mediating roles of attitudes and epistemic beliefs in knowledge revision, and highlight the need for additional research to further investigate potential structural and functional relationships among attitudes, epistemic beliefs, and refutation texts in learning and knowledge revision to gain a deeper understanding of how and in what ways these factors can be leveraged to help individuals more effectively recognize and revise their misconceptions related to important scientific topics so that they can make more informed decisions related to topics of global significance.

References

Ajzen, I. (1989). Attitude structure and behavior. In A.R. Pratkanis, S. J. Breckler, & A. G. Greenwald (Eds.), *Attitude structure and function* (pp. 241 – 274). Hillsdale, NJ: Erlbaum.

Ajzen, I., & Fishbein, M. (2005). The influence of attitudes on behavior. In D. Albarracín, B. T. Johnson, & M. P. Zanna (Eds.), *The handbook of attitudes* (pp. 173-221). Mahwah, NJ: Erlbaum.

Allum, N., Sturgis, P., Tabourazi, D., & Brunton-Smith, I. (2008). Science knowledge and attitudes across cultures: a meta-analysis. *Public Understanding of Science, 17*(1), 35–54.

Broughton, S. H., Sinatra, G. M., & Nussbaum, E. M. (2013). "Pluto has been a planet my whole life!" Emotions, attitudes, and conceptual change in elementary students learning about Pluto's reclassification. *Research in Science Education, 43*(2), 529–550.

Buehl, M. M., Alexander, P. A., & Murphy, P. K. (2002). Beliefs about schooled knowledge: Domain specific or domain general? *Contemporary Educational Psychology*, *27*(3), 415–449.

Burrell, G. and Morgan, G. (1979). *Sociological paradigms and organizational analysis: Elements of the sociology of corporate life*. London, UK: Heinemann Educational Books.

Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction, 15*(1), 1 - 40.

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences*, *6*(3), 271–315.

Chi, M.T.H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *Handbook of research on conceptual change* (pp. 61-82). Hillsdale, NJ: Erlbaum.

Chinn, C. A., Buckland, L. A., Samarapungavan, A. L. A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist, 46*(3), 141–167.

Cho, M.-H., Lankford, D. M., & Wescott, D. J. (2011). Exploring the relationships among epistemological beliefs, nature of science, and conceptual change in the learning of evolutionary theory. *Evolution: Education and Outreach*, *4*(2), 313–322.

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

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

Eagly, A. H., & Chaiken, S. (1993). *The psychology of attitudes*. Orlando, FL: Harcourt Brace Jovanovich College Publishers.

Ecker, U. K. H., Hogan, J. L., & Lewandowsky, S. (2017). Reminders and repetition of misinformation: Helping or hindering its retraction? *Journal of Applied Research in Memory and Cognition, 6*(2), 185–192.

Fabrigar, L., Macdonald, T., & Wegener, D. (2005). The structure of attitudes. In D. Albarracin, B.T. Johnson, & M.P. Zanna (Eds.), *The handbook of attitudes* (pp. 79 – 124). London, UK: Routledge.

Fishbein, M. & Icek, A. (1975). *Belief, attitude, intention and behavior: An introduction to theory and research*. California, US: Addison-Wesley.

Flesch, R. (1948). A new readability yardstick. *Journal of Applied Psychology, 32*(3), 221-233.

Franco, G. M., Muis, K. R., Kendeou, P., Ranellucci, J., Sampasivam, L., & Wang, X. (2012). Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics. *Learning and Instruction, 22*(1), 62–77.

Fulmer, G. W. (2014). Undergraduates' attitudes toward science and their epistemological beliefs: Positive effects of certainty and authority beliefs. *Journal of Science Education and Technology, 23*(1), 198-206.

Greene, J. A., Muis, K. R., & Pieschl, S. (2010). The role of epistemic beliefs in students' self-regulated learning with computer-based learning environments: Conceptual and methodological issues. *Educational Psychologist*, *45*(4), 245–257.

Greene, J.A., Sandoval, W.A., Bråten, I. (2016). An introduction to epistemic cognition. In J.A. Greene, W.A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 1- 15). New York, NY: Routledge.

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

Hair, J.F., Black, W.C., Babin, B.J., & Anderson, R.E. (2010). *Multivariate data analysis* (7th ed.). New York, NY: Pearson Higher Education.

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

Hayes, A. F., & Preacher, K. J. (2014). Statistical mediation analysis with a multicategorical independent variable. *British Journal of Mathematical and Statistical Psychology, 67*, 451–470.

Hayes, B.C. & Tariq, V.N. (2000). Gender differences in scientific knowledge and attitudes toward science: A comparative study of four Anglo-American nations. *Public Understanding of Science 9*(4), 433–47.

Heddy, B. C., Danielson, R. W., Sinatra, G. M., & Graham, J. (2017). Modifying knowledge, emotions, and attitudes about genetically modified foods. *Journal of Experimental Education, 85*(3), 515-533.

Heddy, B. C., & Sinatra, G. M. (2013). Transforming misconceptions: Using transformative experience to promote positive affect and conceptual change in students learning about biological evolution. *Science Education, 97*(5), 723–744.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology, 25*(4), 378–405.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88–140.

Kapucu S. & Bahçivan E. (2015). High school students' scientific epistemological beliefs, self-efficacy in learning physics and attitudes towards physics: A structural equational model. *Research in Science & Technological Education, 33*(2), 252-267.

Kata, A. (2012). Anti-vaccine activists, Web 2.0, and the postmodern paradigm: An overview of tactics and tropes used online by the anti-vaccination movement. *Vaccine, 30*(25), 3778–3789.

Kendeou, P., Muis, K. R., & Fulton, S. (2011). Reader and text factors on reading comprehension processes. *Journal of Research in Reading, 34*, 365-383.

Kendeou, P., & O'Brien, E. J. (2014). The knowledge revision components (KReC) framework: Processes and mechanisms. In D. Rapp, & J. Braasch (Eds.), *Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences* (pp. 353-377). Cambridge, MA: MIT Press.

Kendeou, P., Walsh, E. K., Smith, E. R., & O'Brien, E. J. (2014). Knowledge revision processes in refutation texts. *Discourse Processes, 51*, 374-397.

Kendeou, P., Smith, E. R., & O'Brien, E. J. (2013). Updating during reading comprehension: Why causality matters. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(3), 854–865.

King, P. M., & Kitchener, K. S. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults* (1st ed.). San Francisco, CA: Jossey-Bass Publishers.

Kızılgüneş B., Tekkaya C., & Sungur S. (2009) Modeling the relations among students' epistemological beliefs, motivation, learning approach, and achievement. *Journal of Educational Research, 102*(4), 243-256.

Krause, S., Kelly, J., Corkins, J., Tasooji, A., & Purzer, S. (2009). *Using students' previous experience and prior knowledge to facilitate conceptual change in an introductory materials course*. Paper presented to the Frontiers in Education Conference, San Antonio, TX.

Kruglanski, A. W., & Stroebe, W. (2005). The influence of beliefs and goals on attitudes: Issues of structure, function, and dynamics. In D. Albarracín, B. T. Johnson, & M. P. Zanna

(Eds.), *The handbook of attitudes* (pp. 323-368). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology, 140,* 5-55.

Lombardi, D., Nussbaum, E. M., & Sinatra, G. M. (2016). Plausibility judgments in conceptual change and epistemic cognition. *Educational Psychologist, 51*(1), 35–56.

Maio, G. R. & Haddock, G. (2010). The influence of attitudes on information processing and behavior. In G.R. Maio & G. Haddock (Eds.), *The psychology of attitudes and attitude change* (pp. 47-66). London, UK: SAGE Publications Ltd.

Mason, L. (2000). Role of anomalous data and epistemological beliefs in middle students' theory change on two controversial topics. *European Journal of Psychology of Education, 15*, 329-346.

Mason, L. (2002). Developing epistemological thinking to foster conceptual change in different domains. In M. Limón & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 301 – 335). New York, NY: Kluwer Academic Publishers.

Mason, L. & Gava, M. (2007). Effects of epistemological beliefs and learning text structure on conceptual change. In S. Vosniadou, A. Baltas, & X. Vamvakoussi (Eds.), *Reframing the problem of conceptual change in learning and instruction* (pp. 165-196). Oxford, UK: Elsevier Science.

Mason, L., Gava, M., & Boldrin, A. (2008). On warm conceptual change: The interplay of text, epistemological beliefs, and topic interest. *Journal of Educational Psychology, 100*, 291-309.

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

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

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

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

Muis, K. R., Chevrier, M., & Singh, C. A. (2018). The role of epistemic emotions in personal epistemology and self-regulated learning. *Educational Psychologist*, 1-20.

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

Murphy, P. K., & Alexander, P. A. (2016). Interrogating the relation between conceptual change and epistemic beliefs. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 439-459). New York, NY: Routledge.

Nunnally, J.C. (1978). *Psychometric theory* (2nd ed.). New York, NY: McGraw-Hill.

Pekrun, R., Vogl, E., Muis, K. R., & Sinatra, G. M. (2016). Measuring emotions during epistemic activities: The epistemically-related emotion scales. *Cognition & Emotion, 31*(6), 1268–1276.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167–199.

Qian, G., & Alvermann, D. (1995). Role of epistemological beliefs and learned helplessness in secondary school students' learning science concepts from text. *Journal of Educational Psychology, 87*, 282 - 292.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. In J. Sikula (Ed.), *Handbook of research on teacher education* (pp. 102-119). New York, NY: Macmillan.

Rokeach, M. (1968). A theory of organization and change within value-attitude systems. *Journal of Social Issues, 24*(1), 13–33.

Rosenberg, M.J. & Hovland, C.I. (1960). Cognitive, affective, and behavioral components of attitudes. In M.J. Rosenberg, C.I. Hovland, W.J. McGuire, R.P. Abelson, & J.W. Brehm. (Eds.), *Attitude organization and change: An analysis of consistency among attitude components*. New Haven, CT: Yale University Press.

Şahan, H. (2017). The mediating role of scientific attitudes in the relationship between teacher candidates' scientific epistemological beliefs and approaches to scientific research. *Educational Research and Reviews, 12*(11), 604–610.

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*(3), 498-504.

Schommer, M. (1994). Synthesizing epistemological belief research: Tentative understandings and provocative confusions. *Educational Psychology Review, 6*(4), 293–319.

Silverman, J. C. (2007). Epistemological beliefs and attitudes toward inclusion in pre-service teachers. *Teacher Education and Special Education: The Journal of the Teacher Education Division of the Council for Exceptional Children, 30*(1), 42–51.

Sinatra, G. M., Brem, S. K., & Evans, E. M. (2008). Changing minds? Implications of conceptual change for teaching and learning about biological evolution. *Evolution: Education and Outreach*, *1*(2), 189–195.

Sinatra, G. M., & Broughton, S. H. (2011). Bridging reading comprehension and conceptual change in science education: The promise of refutation text. *Reading Research Quarterly, 46*(4), 374–393.

Sinatra, G. M., & Hofer, B. K. (2016). Public understanding of science. *Policy Insights from the Behavioral and Brain Sciences, 3*(2), 245–253.

Sinatra, G. M., & Seyranian, V. (2016). Warm change about hot topics: The role of motivation and emotion in attitude and conceptual change about controversial science topics. In L. Corno & E. Anderman (Eds.), *Handbook of educational psychology* (pp. 245–256). Washington, DC: Taylor & Francis.

Slusher, M. P., & Anderson, C. A. (1996). Using causal persuasive arguments to change beliefs and teach new information: The mediating role of explanation availability and evaluation bias in the acceptance of knowledge. *Journal of Educational Psychology, 88*(1), 110-122.

Stathopoulou, C., & Vosniadou, S. (2007). Conceptual change in physics and physics-related epistemological beliefs: A relationship under scrutiny. In S. Vosniadou, A. Baltas, & X. Vamvakoussi (Eds.), *Advances in learning and instruction series: Reframing the conceptual change approach in learning and instruction* (pp. 145-163). New York, NY: Elsevier Science.

Strømsø, H. I., Bråten, I., & Samuelstuen, M. S. (2008). Dimensions of topic-specific epistemological beliefs as predictors of multiple text understanding. *Learning and Instruction, 18*(6), 513–527.

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

Thacker, I. E., Muis, K. R., Danielson, R. W., Sinatra G. M., Pekrun, R., Winne, P. H., Chevrier, M. (2017, April). *The influence of attitudes and emotions in learning from multiple texts*. Poster presented to the Annual meeting of the American Educational Research Association, San Antonio, USA.

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

Trevors, G. J., Kendeou, P., & Butterfuss, R. (2017a). Emotion processes in knowledge revision. *Discourse Processes, 54*(5–6), 406–426.

Trevors, G. J., Kendeou, P., Bråten, I., & Braasch, J. L. G. (2017b). Adolescents' epistemic profiles in the service of knowledge revision. *Contemporary Educational Psychology*, *49*, 107–120.

Trevors, G. J., Muis, K. R., Pekrun, R., Sinatra, G. M., & Winne, P. H. (2016). Identity and epistemic emotions during knowledge revision: A potential account for the backfire effect. *Discourse Processes, 53*(5–6), 339–370.

Tsai, C.C. (1998). An analysis of scientific epistemological beliefs and learning orientations of Taiwanese eighth graders. *Science Education, 82*(4), 473- 489.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction, 4*(1), 45–69.

Wakefield, A., Murch, S., Anthony, A., Linnell, J., Casson, D., Malik, M., & … Walker-Smith, J. (1998). RETRACTED: Ileal-lymphoid-nodular hyperplasia, non-specific colitis, and pervasive developmental disorder in children. *The Lancet, 351*(9103), 637-641.

Wogalter, M. S., DeJoy, D., & Laughery, K. R. (2005). *Warnings and risk communication*. Philadelphia, PA: Taylor & Francis.

World Health Organization. (2018). *Europe observes a 4-fold increase in measles cases in 2017 compared to previous year*. Retrieved March 18, 2018, from http://www.euro.who.int/en/media-centre/sections/press-releases/2018/europe-observes-a-4-fold-increase-in-measles-cases-in-2017-compared-to-previous-year.

World Health Organization. (2014). *Frequently asked questions on genetically modified foods.* Retrieved July 27, 2018, from http://wwwwhoint/foodsafety/areas work/food-technology/faq-genetically-modified-food/en/.

Xiao, S., & Sandoval, W. A. (2017). Associations between attitudes towards science and children's evaluation of information about socio-scientific issues. *Science & Education, 26*(3), 247–269.

Zhang, C., Wohlhueter, R., & Zhang, H. (2016). Genetically modified foods: A critical review of their promise and problems. *Food Science and Human Wellness*, *5*(3), 116–123.

Appendix A

Demographics questionnaire

1. What is your age?

Age: _____

2. What is your gender?

- Female
- Male
- Other (please specify)

3. Are you Hispanic or Latino? (A person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin, regardless of race.)

- Yes
- No
- Other (please specify)

4. Are you White, Black or African-American, Canadian Aboriginal, American Indian or Alaskan Native, Asian, Native Hawaiian or other Pacific islander, or some other race?

- White
- Black or African-American
- Canadian Aboriginal or American Indian or Alaskan Native
- Asian
- Native Hawaiian or other Pacific Islander
- From multiple races
- Other (please specify)

5. Grade Point Average in all your secondary studies (e.g., high school GPA, 0-4.33)

GPA: _____

6. What is your current post-secondary institution?

- McGill University
- Simon Fraser University
- University of Southern California
- University of Munich
- Other (please specify)

7. Grade Point Average in all your post-secondary studies (e.g., university/college GPA, 0-4.33)

GPA: _____

8. Academic major(s) (e.g., mathematics, political sciences, etc., if applicable)

Major: _____

9. Academic minor(s), if applicable.

Minor: _____

10. Number of courses enrolled in this semester

# of courses: _____

11. Number of courses taken at your current post-secondary institution

# of courses: _____

12. Year of post-secondary study (e.g., 1st, 2nd, 3rd, etc.)

Year: _____

13. Average hours studying per week

Hours: _____

14. What is the highest level of school your mother completed or the highest degree she received?

- Less than high school degree
- High school degree or equivalent (e.g., GED)
- Some university/college but no degree
- Associate degree
- Bachelor degree
- Graduate degree

15. Which of the following best describes your mother's occupation?

- Has never worked outside the home for pay
- Small business owner (< 25 employees) (Includes owners of small business such as retail shops, services, restaurants)
- Clerk (Includes office clerks, secretaries, typists, data entry operators, customer service clerks)
- Service or sales worker (Includes travel attendants, restaurant service workers, personal care workers, protective service workers, salespersons)

- Skilled agricultural or fishery worker (Includes farmers, forestry workers, fishery workers, hunters and trappers)
- Craft or trade worker (Includes builders, carpenters, plumbers, electricians, etc.; also metal workers, machine mechanics, handicraft workers)
- Plant or machine operator (Includes plant and machine operators, assembly-line operators, motor-vehicle drivers)
- General laborers (Includes domestic helpers and cleaners; building caretakers; messengers, porters and doorkeepers; farm, fishery, agricultural, and construction workers)
- Corporate manager or senior official (Includes corporate managers such as managers of large companies [25 or more employees] or managers of departments within large companies; legislators or senior government officials; senior officials of special-interest organizations; military officers)
- Professional (Includes scientists, mathematicians, computer scientists, architects, engineers, life science and health professionals, teachers, legal professionals, social scientists, writers and artists, religious professionals)
- Technician or associate professional (Includes science, engineering, and computer associates and technicians; life science and health technicians and assistants; teacher aides; finance and sales associate professionals; business service agents; administrative assistants)
- Other (please specify)

16. What is the highest level of school your father completed or the highest degree he received?

- Less than high school degree
- High school degree or equivalent (e.g., GED)
- Some university/college but no degree
- Associate degree
- Bachelor degree
- Graduate degree

17. Which of the following best describes your father's occupation?

- Has never worked outside the home for pay
- Small business owner (< 25 employees) (Includes owners of small business such as retail shops, services, restaurants)
- Clerk (Includes office clerks, secretaries, typists, data entry operators, customer service clerks)
- Service or sales worker (Includes travel attendants, restaurant service workers, personal care workers, protective service workers, salespersons)
- Skilled agricultural or fishery worker (Includes farmers, forestry workers, fishery workers, hunters and trappers)
- Craft or trade worker (Includes builders, carpenters, plumbers, electricians, etc.; also metal workers, machine mechanics, handicraft workers)
- Plant or machine operator (Includes plant and machine operators, assembly-line operators, motor-vehicle drivers)

- General laborers (Includes domestic helpers and cleaners; building caretakers; messengers, porters and doorkeepers; farm, fishery, agricultural, and construction workers)
- Corporate manager or senior official (Includes corporate managers such as managers of large companies [25 or more employees] or managers of departments within large companies; legislators or senior government officials; senior officials of special-interest organizations; military officers)
- Professional (Includes scientists, mathematicians, computer scientists, architects, engineers, life science and health professionals, teachers, legal professionals, social scientists, writers and artists, religious professionals)
- Technician or associate professional (Includes science, engineering, and computer associates and technicians; life science and health technicians and assistants; teacher aides; finance and sales associate professionals; business service agents; administrative assistants)
- Other (please specify)

18. Was English the first language you learned to speak?

- Yes
- No

19. If no, how old were you when you learned to speak English?

Age when learned to speak English: _____

20. Was English the first language you learned to write?

- Yes
- No

21. If no, how old were you when you learned to write English?

Age when learned to write English: _____

22. In politics today, which political party is closest to your personal views?

- Bloc Québécois
- Conservative Party
- Green Party
- Independent / Non-Affiliated
- Liberal Party
- New Democratic Party (US only)
- Democratic (US only)
- Republican
- Other (please specify)

23. When it comes to politics, would you describe yourself as liberal, conservative, or neither liberal nor conservative?

- Extremely liberal
- Moderately liberal
- Slightly liberal
- Neither liberal nor conservative
- Slightly conservative
- Moderately conservative
- Extremely conservative

Appendix B

Prior knowledge assessment on genetically modified foods

Directions: Below are statements about genetically modified foods. Please rate how consistent the statement is with your own knowledge.

1. Genetically modifying foods occur through…
   a. natural processes.
   b. artificial processes.
   c. All of the above
   d. None of the above

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

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

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

5. Which of the following can genetically modify plants or animals?
   a. Farmers/Gardeners
   b. Scientists
   c. Animals
   d. All of the above

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

7. Injecting hormones into a plant or animal may change what about that organism?

a. The size of the plant or animal
b. The genetic makeup of that plant or animal
c. All of the above
d. None of the above

8. Adding or inhibiting a plant's or animal's DNA occurs only in...
a. laboratories
b. nature
c. farms
d. all of the above

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

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

Appendix C

Attitudes about genetically modified foods

Please mark how strongly you agree or disagree with each of the statements listed below. Please circle the number that best matches the strength of your attitude.

1. Genetically modified foods are okay with me.

Strongly disagree	Disagree	Unsure	Agree	Strongly agree
1	2	3	4	5

2. Genetically modified foods are beneficial to society.

Strongly disagree	Disagree	Unsure	Agree	Strongly agree
1	2	3	4	5

3. I approve of genetically modified foods.

Strongly disagree	Disagree	Unsure	Agree	Strongly agree
1	2	3	4	5

4. I would eat food that has been genetically modified.

Strongly disagree	Disagree	Unsure	Agree	Strongly agree
1	2	3	4	5

Appendix D

Topic Specific Epistemic Beliefs Questionnaire

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

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

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

Source of Knowledge About GMFs [Reverse-Score Items]
13. I often feel that I just have to accept that what I read about genetic modification problems can be trusted.
14. When I read about issues concerning genetic modification, the author's opinion is more important than mine.
15. With respect to genetic modification problems, I feel I am on safe ground if I only find an expert statement.
16. When I read about genetic modification problems, I only stick to what the text expresses.
17. My personal judgments about genetic modification problems have little value compared to what I can learn about them from books and articles.

Justification for Knowing About GMFs

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

Appendix E

Refutation text

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

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

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

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

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

qualities. For example, farmers have used selective pollination of plants in hopes of producing sweeter fruits or more colorful flowers. Even today, farmers and gardeners use cross-pollination in hopes of producing plants with more desirable traits.

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

Appendix F

Expository text

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

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

The production of genetically modified foods does not involve injecting hormones into a plant or animal. Injecting hormones into a plant or animal can increase its growth rate or its size. However, injecting hormones does not modify the genetic makeup of the plant or animal. In contrast, genetically modified foods have had some of their characteristics changed at the gene level.

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

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

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

Appendix G

Post-test knowledge assessment on genetically modified foods

Directions: Below are statements about genetically modified foods. Please rate how consistent the statement is with your own knowledge.

1. Genetically modifying foods occur through…
   a. natural processes.
   b. artificial processes.
   c. All of the above
   d. None of the above

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

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

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

5. Which of the following can genetically modify plants or animals?
   a. Farmers/Gardeners
   b. Scientists
   c. Animals
   d. All of the above

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

7. Injecting hormones into a plant or animal may change what about that organism?

a. The size of the plant or animal
b. The genetic makeup of that plant or animal
c. All of the above
d. None of the above

8. Adding or inhibiting a plant's or animal's DNA occurs only in...
a. laboratories
b. nature
c. farms
d. all of the above

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

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