Meaningful main effects or intriguing interactions?
Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics

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Abstract

The purpose of this study was to investigate the role of epistemic beliefs and knowledge representations in cognitive and metacognitive processing and conceptual change when learning about physics concepts through text. Specifically, I manipulated the representation of physics concepts in texts about Newtonian mechanics and explored how these texts interacted with individuals' epistemic beliefs to facilitate or constrain learning. In accordance with definitions from Royce's (1983) framework of psychological epistemology, texts were developed to present Newtonian concepts in either a rational or a metaphorical format. Seventy-five undergraduate students completed questionnaires designed to measure their epistemic beliefs and their misconceptions about Newton's laws of motion. Participants then read the first of two instructional texts (in either a rational or metaphorical format), and were asked to think aloud while reading. After reading the text, participants completed a recall task and a post-test of selected items regarding Newtonian concepts. These steps were repeated with a second instructional text (in either a rational or metaphorical format, depending on which format was assigned previously). Participants' think-aloud sessions were audio-recorded, transcribed, and then blindly coded, and their recalls were scored for total number of correctly recalled ideas from the text. Changes in misconceptions were analyzed by examining changes in participants' responses to selected questions about Newtonian concepts from pretest to posttest.

Results revealed that when individuals' epistemic beliefs were congruent with the knowledge representations in their assigned texts, they performed better on both *online* measures of learning (e.g., use of processing strategies) and *offline* products of learning (e.g., text recall, changes in misconceptions) than when their epistemic beliefs were incongruent with the knowledge representations. These results have implications for how researchers conceptualize epistemic beliefs and are in line with contemporary views regarding the context sensitivity of individuals' epistemic beliefs. Moreover, the findings from this study not only support current theory about the dynamic and interactive nature of conceptual change, but also advance empirical work in this area by identifying knowledge representations as a text characteristic that may play an important role in the change process.

Résumé

Le but de cette étude est d'explorer le rôle des croyances épistémiques et des représentations de connaissances en relation avec les processus cognitifs et métacognitifs en plus des changements épistémologiques lors de l'apprentissage à propos de concepts physiques au moyen de textes. Spécifiquement, la manipulation des représentations de concepts physiques au sujet de la mécanique newtonienne et d'explorer comment les textes intéragits avec les croyances épistémiques afin de faciliter ou amoindrir les apprentissages. En accord avec les définitions de la théorie d'épistémologie de Royce (1983), les textes sont développés afin de présenter des concepts newtoniens selon un format rationel ou métaphore. Soixante-quinze étudiants et étudiants au baccalauréat ont complétés des questionaires mesurant leurs croyances épistémiques et leurs idées fausses à propos des lois de la motion de Newton. Les participants ont ensuite lu le premier des deux textes (selon un format rationel ou métaphore), et ont étés instruits de verbaliser leurs pensées lors de la lecture. Après avoir lus le texte, les participants ont complétés une tâche de rappel et des items par rapports aux concepts newtoniens. Ces étapes ont été répétées avec un second texte (rationel ou métaphore, selon la condition précédente). Les verbalizations concomittantes ont été enregistrées, écrites, et codifiées, et la tâche de rappel a été scorée pour le montant total d'idées correctement rappellées du texte. Les changements épistémiques ont été analyzés en examinant les réponses des participants à certaines questions à propos des concepts newtoniens de pré-test à post-test.

Les résultats démontrent que lorsque les connaissances épistémiques sont congruantes avec les représentations de connaissances décrites dans les textes, les participants performent mieux sur les mesures d'apprentissages en ligne (ex : utilisations de processus stratégiques) et hors ligne (ex : tâche de rappel et changements épistémologiques) comparativement au cas où leurs connaissances épistémiques ne sont pas congruentes avec les représentations. Les résultats ont des implications pour comment les chercheurs et chercheures conçoits les connaissances épistémiques et sont en ligne avec les connaissances contemporaines par rapport aux rôles du context envers les croyances épistémiques des individus. De plus, les résultats de cette étude supportes les théories existantes à propos de la nature dynamique et intéractive du changement épistémologique, mais aussi avances les connaissances empiriques dans le domaine en identifiant les représentations des connaissances en tant que charactéristique du texte qui peuvent jouer un rôle important dans le processus de changement.

Dedication

I dedicate this thesis to my mom, Gloria Franco – my first and favorite teacher. And to my son, Ashton, whose curiosity could launch a thousand research programs. Thank you, both of you, for inspiring me to discover and delight in the world around us.

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Finally, given that portions of this thesis have been published as a multi-authored manuscript, I would like to identify not only the contributions of my co-authors, but also my unique contributions. Specifically, my contributions to this work include: conception and design of the study, development and adaptation of instructional texts and coding protocols, data collection, data analysis, training of research assistants, and writing. Three of my co-authors, John Ranellucci, Lavanya Sampasivam, and Xihui Wang, assisted with data collection, transcription of think-aloud data, and coding of think-aloud and recall data. Another co-author, Panayiota Kendeou, developed the initial instructional texts that were adapted for use in this study in the manner described on page 64 of this thesis. She also trained me on the think-aloud approach that was used in this study, as well as the coding of the recall data. The fifth co-author, Krista Muis, oversaw all aspects of this research in her capacity as my thesis supervisor.

Table of Contents

List of Tables

List of Figures

CHAPTER I

INTRODUCTION[1]

"Today's facts may be tomorrow's fiction."

"What is true is a matter of opinion."

"Sometimes you just have to accept answers from the experts in this field, even if you don't understand them."

"If scientists try hard enough, they can find the answer to almost every question."

The preceding statements reflect different views about the nature, sources, and limits of knowledge and are taken from measures that are commonly used to assess individuals' epistemic beliefs – i.e., their beliefs about knowledge and knowing. The study of epistemic beliefs has become a prominent line of inquiry in educational psychology, and a growing body of evidence shows that students' beliefs about knowledge and knowing are linked to various facets of their learning (e.g., Muis, 2008; Muis & Franco, 2009a; Schommer, 1990; Schommer, Crouse, & Rhodes, 1992). Most of the research to date has focused on *students'* epistemic beliefs, but leaders in the field have made a call for more studies that explore the "situated and contextual nature" of these beliefs (Hofer & Pintrich, 1997, p. 124).

For example, Bromme and colleagues (Bromme, Pieschl, & Stahl, 2010) recently advocated a contextualized approach to epistemic beliefs research wherein researchers' predictions and interpretations regarding the effects of students' epistemic beliefs are

[1] Portions of this thesis have been accepted for publication and are reprinted here from *Learning and Instruction, 22*(1), Franco, G. M., Muis, K. R., Kendeou, P., Ranellucci, J., Sampasivam, L., & Wang, X., Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics, pp. 62-77, © 2012, with permission from Elsevier. Specifically, the published article contains many of the ideas presented here, verbatim, but includes an abridged version of the literature review and discussion due to space limitations in the journal.

informed by complementary analyses of the learning content with which students engage. This is in line with current thinking by some scholars who have suggested that, to develop a more comprehensive understanding of students' epistemic beliefs, we need to explore how they interact with the epistemic climate (Muis, Bendixen, & Haerle, 2006). The epistemic climate refers to facets of knowledge and knowing that are salient in various aspects of an educational environment, such as teachers' beliefs, knowledge representations (e.g., textbooks, assessments, curricula), and instructional practices (e.g., teaching strategies or approaches) (Haerle & Bendixen, 2008).

Purpose of the Study

The current study responds to these calls by examining the role of students' epistemic beliefs and knowledge representations in cognitive and metacognitive processing and conceptual change when learning about physics. Specifically, I manipulated the representation of physics concepts in texts about Newtonian mechanics and explored how these texts interacted with individuals' epistemic beliefs to facilitate or constrain learning. Moreover, I address researchers' calls to combine quantitative approaches with dynamic process-oriented designs (e.g., Pintrich, 2002) and examine "traces" of individuals' learning (i.e., data about actual studying events recorded while learners engage in a learning task [Winne, 1982; Winne & Perry, 2000]), by including several measures of learning in my study. That is, I examined the online processes that occur while students read new material, as well as off-line products that occur after reading. For online measures of learning, I explored individuals' use of deep and shallow processing strategies during reading. Following others (e.g., Dole & Sinatra, 1998; Pintrich, Smith, Garcia, & McKeachie, 1991; Stathopoulou & Vosniadou, 2007a), I defined deep processing strategies as those that involve learners' attempts to integrate new ideas with prior knowledge (e.g., elaboration), organize and summarize ideas (e.g., paraphrasing), and metacognitively engage (e.g., monitoring understanding; reflecting on conflicts between prior knowledge and new information in the text). In contrast, shallow processing involves learners' attempts to engage with superficial aspects of the to-be-learned material (Craik & Lockhart, 1972) and is comprised of two types of strategies in this study: memorization (e.g., rehearsal or repetition of to-be-learned material), and the activation of prior knowledge without attempting to integrate it with new information (e.g., making associations).

In addition to these online processes, I also examined two off-line products of learning: text recall and conceptual change[2]. Broadly speaking, conceptual change involves changing inaccurate or misconceived prior knowledge to "correct" or scientifically accepted knowledge (Chi, 2008). In the current study, I measured conceptual change by examining whether students changed their misconceptions[3] about

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[2] In line with Krathwohl's (2002) revision of Bloom's Taxonomy of Educational Objectives, and similar to the categorization of the online measures in this study (i.e., deep versus shallow processing strategies), these offline measures could also be conceptualized as deep versus shallow. For example, conceptual change involves complex cognitive processes such as "understanding" and "evaluating," and could therefore be considered a deep learning outcome. In contrast, text recall aligns with the cognitive process of "remembering," which is considered the least complex cognitive process in Bloom's hierarchy. Accordingly, text recall could be considered a shallow learning outcome in this study. In studies of reading comprehension, text recall is an important variable because the reader's ability to represent the text in her/his memory is considered a key component of successful comprehension (Kendeou, Muis, & Fulton, 2010).

[3] These have alternately been referred to as preinstructional beliefs (Chinn & Brewer, 1993), alternative conceptions (Tyson, Venville, Harrison, & Treagust, 1997), alternative frameworks (Caravita & Halldén, 1994), and naïve theories (Vosniadou, 2007), to name a few. For simplicity, I use the term *misconceptions* throughout this paper to refer to prior

Newton's Laws of Motion, as evidenced by their responses to a conceptual knowledge test administered before and after reading.

Thus, a second purpose of this study is to add to the conceptual change literature. Across several models of knowledge and belief change, a combination of learner and text characteristics is theorized to influence the change process (e.g., Dole & Sinatra, 1998; Murphy, 1998). In recent years, one learner characteristic that has captured the attention of conceptual change researchers is epistemic beliefs. Although there is a growing body of work that has begun to document the role of epistemic beliefs in conceptual change learning (e.g., Kendeou et al., 2010; Mason & Gava, 2007; Mason, Gava, & Boldrin, 2008; Qian & Alvermann, 1995; Stathopoulou & Vosniadou, 2007a, 2007b), researchers have acknowledged a need for more research that examines the dynamic and interactive nature of conceptual change in general (Sinatra & Mason, 2008), and the complex relations between epistemic beliefs and conceptual change in particular (Alexander & Sinatra, 2007; Murphy & Mason, 2006; Pintrich, 1999). Accordingly, this study investigates the role of epistemic beliefs (a learner characteristic) and knowledge representations (a text characteristic) in conceptual change in physics.

Overview of Chapters

Prior to presenting the details of my study, I first describe the theoretical perspectives and empirical research that informed this work. These topics are addressed in Chapter 2. In particular, the first section of Chapter 2 presents an overview of various frameworks for conceptualizing individuals' beliefs about knowledge knowing, whereas the second section of Chapter 2 focuses on prominent models of conceptual change. In

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knowledge that is inconsistent with scientifically accepted ideas within a domain of study, such as physics (Pines & West, 1983; Murphy & Mason, 2006).

the third section of this chapter, I review empirical studies that have examined relations between epistemic beliefs, cognitive and metacognitive processes, and conceptual change, and situate the current study within the context of this research. I introduce my (four) research questions at the end of Chapter 2 and offer two sets of hypotheses that represent competing positions in the epistemic beliefs literature: the *main effect* position, which suggests that some beliefs about knowledge and knowing are superior to others and that these beliefs are likely to be associated with more favorable learning outcomes; and the *interaction effect* position, which emphasizes the context sensitivity of individuals' epistemic beliefs and suggests that epistemic beliefs interact in dynamic ways with various aspects of the learning environment to facilitate or constrain learning.

The particularities of my study are outlined in Chapter 3, where I describe standard methodological details such as participants, materials, and procedure. Chapter 4 presents the results of my study in accordance with the four research questions I proposed earlier in the paper. In Chapter 5, I discuss these results in relation to pertinent issues in the epistemic beliefs and conceptual change literatures. I also discuss unanticipated findings and provide a general discussion that goes beyond the scope of the current research and present new ideas for future research.

Contributions to the Literature

My research aims to contribute to the epistemic beliefs literature by examining the situated and contextual nature of individuals' epistemic beliefs and exploring the interactions between epistemic beliefs and knowledge representations, a component of the epistemic climate (Haerle & Bendixen, 2008; Muis et al., 2006) that has heretofore been relatively unexamined. My study also aims to contribute to the conceptual change literature by adding to the paucity of research investigating the complex relations between epistemic beliefs and conceptual change (Alexander & Sinatra, 2007; Murphy & Mason, 2006; Pintrich, 1999), and to the growing body of research that examines the interaction of learner and text characteristics on conceptual change. In previous studies of this nature, researchers have typically characterized texts as refutational versus "traditional" (or expository), and explored how these text formats interact with individuals' epistemic beliefs to facilitate or constrain conceptual change (e.g., Kendeou et al., 2010; Mason & Gava, 2007; Mason et al., 2008). In contrast to expository texts, whose primary function is to inform the reader (Brewer, 1980; Diakidoy, Kendeou, & Ioannides, 2003), refutation is a type of persuasive argument (Hynd, 2001) that, in the context of conceptual change learning, attempts to identify common misconceptions about a topic and then deconstruct those misconceptions through the presentation of contradictory evidence and correct explanations (Alvermann & Hague, 1989; Chambliss, 2002; Guzzetti, Snyder, Glass, & Gamas, 1993). In the domain of science, there is abundant empirical evidence that speaks to the effectiveness of refutational texts in promoting conceptual change (e.g., Alvermann & Hynd, 1989; Diakidoy et al., 2003; Guzzetti et al., 1993; Guzzetti, Williams, Skeels, & Wu, 1997), but few studies have looked beyond refutational texts to explore more nuanced elements of persuasive arguments that might interact with epistemic beliefs to facilitate or constrain changes in misconceptions. This study extends previous work by focusing on a more fine-grained text characteristic – knowledge representations – than has commonly been examined in studies of epistemic beliefs, text structure, and conceptual change.

CHAPTER II

THEORETICAL PERSPECTIVES AND RELEVANT EMPIRICAL STUDIES

Theoretical Perspectives I: Epistemic Beliefs

Given that numerous studies have demonstrated that students' epistemic beliefs are linked to various facets of learning, researchers agree that epistemological thinking "matters" (Hofer, 2001; Kuhn & Weinstock, 2002). They have not, however, reached consensus on a number of other issues in the field. For example, as Bendixen and Rule (2004) note, the field lacks a unified framework to guide research, although it does not lack for candidates. These various frameworks are the focus of this next section of the paper. Not surprisingly, the growing assortment of frameworks has yielded an equally diverse list of relevant terminology, including, for example: reflective judgment (King & Kitchener, 1994), epistemic cognition (Greene, Azevedo, & Torney-Purta, 2008; Kitchener, 1983), epistemological beliefs (Schommer, 1990), epistemological theories (Hofer & Pintrich, 1997), and epistemological resources (Hammer & Elby, 2002). Throughout the paper thus far, I have been using the term *epistemic beliefs* to refer to individuals' beliefs about knowledge and knowing because my study adopts a framework that aligns with this particular conceptualization of the construct. However, for the review of frameworks that follows here, I choose to use the term *personal epistemology* when referring generally to research programs that investigate individuals' conceptions of knowledge and knowing. Though hardly a perfect "umbrella term" (Hofer, 2001), I choose to use this term because, as noted by Greene et al., (2008), it is one that has been used quite often to describe the field in general. It should be noted, however, that when describing particular frameworks (e.g., Hammer & Elby's [2002] "epistemological resources" framework), I will invoke the terminology that is advanced by the particular research program being discussed.

My review includes eight different frameworks of personal epistemology, which, taken together, comprise the following four categories: developmental schemes, multidimensional views, metacognitive perspectives, and integrated frameworks. Why these four categories? Broadly speaking, these categories represent different epistemological perspectives in educational psychology as they have evolved over time. For example, the first category – developmental schemes – includes some of the earliest views of personal epistemology, including Perry's (1970) seminal framework. Proceeding chronologically, the review ends with the most contemporary perspectives, which I call integrated frameworks because of their tendency to incorporate various elements from their predecessors. In an effort to focus the discussion, I have limited my review to a specific subset of exemplar frameworks for each of the four categories, but it should be noted that several frameworks can and do comprise each of the categories. Although the review is not exhaustive with regard to the number of *frameworks* included (i.e., there are more than eight frameworks in the personal epistemology literature), it is my contention that the review is comprehensive with regard to the *categories* of frameworks that are represented.

Review of Frameworks

Developmental Schemes

The frameworks included in this category take the view that personal epistemology is developmental in nature and that individuals progress through a patterned sequence of changes in their conceptions of knowledge and knowing (Hofer, 2001). Hofer and

Pintrich (1997) suggest that developmental frameworks comprise one of the largest areas of research in the personal epistemology literature and that this group can be further subdivided into two categories that reflect different underlying research questions: 1) How do individuals interpret their educational experiences?, and 2) How do epistemological assumptions influence thinking and reasoning processes? Accordingly, one framework from each of these subcategories has been selected for inclusion in the broader category of developmental schemes: Perry's (1970) Scheme of Intellectual and Ethical Development, and King and Kitchener's (1994) Reflective Judgment Model.

Perry's scheme. According to Moore (2002), the focus of Perry's (1970) Scheme of Intellectual and Ethical Development – arguably one of the most influential frameworks of personal epistemology– is on understanding epistemology embedded *in the context of learning*. In developing his framework, Perry (1970) consulted data he collected from a series of open-ended interviews with undergraduate students regarding their college experiences. In accordance with popular thinking at the time, Perry initially expected to find that variations in students' interpretations of their college experiences were best accounted for personality differences (Moore, 2002). However, he instead concluded that there was stronger evidence to suggest that differences in intellectual development, not personality differences, best accounted for the variations (Hofer & Pintrich, 1997). His resulting framework, based loosely on the work of Jean Piaget, proposes nine positions of development (typically aggregated into four categories) that represent an evolution of "thinking structures and meaning-making" (Moore, 2002, p. 26) which progress sequentially toward greater complexity.

The four main categories of Perry's (1970) developmental scheme are dualism, multiplicity, contextual relativism, and commitment within relativism. Generally speaking, these categories represent a shift from black-and-white, objectivist views about knowledge and truth (dualism), to recognition of and coping with diversity and uncertainty (multiplicity), to a view of knowledge as relative and context-bound (contextual relativism), and finally to a focus on responsibility and affirmation of commitments within a relativistic world (commitment within relativism) (Hofer & Pintrich, 1997; Moore, 2002). It has been argued that the first three categories in Perry's (1970) scheme focus more explicitly on epistemological issues, whereas the final category (commitment within relativism) reflects changes that have more to do with ethical and "emotional and aesthetic assessments" (p. 205). In other developmental frameworks of personal epistemology, the types and sequence of positions that individuals may adopt for thinking about epistemological issues are quite similar to Perry's (1970) scheme, although the number of proposed positions and their accompanying labels differ across the various models (Hofer & Pintrich, 1997).

Reflective judgment model. Similar to Perry's (1970) scheme of intellectual and ethical development, King and Kitchener's (1994) reflective judgment model (RJM) is typically classified as a developmental framework. Indeed, the authors themselves (King & Kitchener, 2004) acknowledge that their initial conceptualization of the RJM had much in common with Piaget's (1965; Piaget & Inhelder, 1969) cognitive-developmental views, as well as Perry's (1970) scheme. In more recent writings, however, King and Kitchener (2004) clarify that their perspective also converges with more contemporary constructive-developmental perspectives that emphasize individual meaning-making and development through interaction with one's environment. Although the RJM is grounded in similar traditions as Perry's (1970) work, it also differs from the Perry scheme in important ways. Perhaps first and foremost, the Perry scheme and the RJM are dissimilar in that the former focuses on how individuals interpret their educational experiences, whereas the latter examines how adolescents and adults reason about ill-structured problems (King & Kitchener, 2004).

The RJM is situated within Kitchener's (1983) three-level model of cognitive processing that includes cognition (cognitive processes such as perceiving, memorizing, etcetera), metacognition (e.g., monitoring one's cognitive processes), and epistemic cognition (e.g., considering epistemological issues such as the limits and certainty of knowledge, and the criteria for knowing) (King & Kitchener, 2002). Specifically, the RJM explains the development of the third level of cognitive processing: epistemic cognition. The authors propose that epistemological development involves changes in individuals' assumptions about the process of knowing and how it is acquired; assumptions that affect the process of epistemic cognition.

Following decades of empirical work on the RJM, King and Kitchener (2004) identified three main findings: 1) there are apparent differences in individuals' underlying assumptions about knowledge (i.e., epistemic assumptions), 2) these differences are linked to the ways in which individuals reason about ill-structured problems, and 3) patterns in individuals' responses to such problems can be classified in developmental sequences. In particular, King and Kitchener (1994; 2002; 2004) identify seven distinct sets of epistemic assumptions that can be clustered into three levels of thinking: prereflective reasoning, quasi-reflective reasoning, and reflective reasoning. Each level of reasoning reflects individuals' qualitatively different views regarding two epistemic issues: 1) view of knowledge, and 2) concept of justification. Accordingly, development is characterized by increasingly complex and effective views of knowledge and justification (King & Kitchener, 2004). For example, at the prereflective level, individuals tend to believe in certain knowledge that is handed down by authorities or obtained directly through the senses. At the quasi-reflective level of reasoning, individuals begin to acknowledge elements of uncertainty or subjectivity in knowledge claims, and they perceive evidence as an idiosyncratic form of justification. Finally, at the level of reflective reasoning, individuals continue to acknowledge uncertainty, "but they are not immobilized by it; rather, they make judgments that are 'most reasonable' and about which they are 'reasonably certain,' based on their evaluation of the available data" (King & Kitchener, 2002, p. 40). This trajectory of development, from pre-reflective to reflective reasoning, overlaps quite closely with Perry's (1970) proposed developmental sequence from dualism to commitment within relativism (Hofer & Pintrich, 1997).

Multidimensional Views

In an influential article published two decades after Perry's (1970) pioneering study, Marlene Schommer (1990) criticized the prevailing conception of personal epistemology advanced by Perry and other developmental theorists. That is, Schommer (1990) noted that developmental frameworks assumed a unidimensional view of personal epistemology and argued that it might be more plausible to conceptualize the construct as a *multidimensional* system of beliefs about knowledge, knowing, and learning. Although Schommer (1990) is credited for advancing the view of personal epistemology as a multidimensional construct, a number of other researchers have proposed frameworks that also support a multidimensional view. In this section, I review three such frameworks: Schommer's (1990) epistemological belief system, Hofer and Pintrich's (1997) epistemological theories, and Hammer and Elby's (2002) epistemological resources.

Epistemological belief system. In her earliest work, Schommer (1990) hypothesized that a personal epistemology took the form of a system of "more or less independent dimensions" (p. 498), meaning that individual beliefs within the system were not assumed to develop in synchrony (Schommer-Aikins, 2002). Schommer (1990) initially proposed that there are at least five dimensions of epistemic beliefs: structure of knowledge, certainty of knowledge, source of knowledge[4], control of knowledge acquisition, and speed of knowledge acquisition. Moreover, Schommer (1990) suggested that for each of these dimensions, an individual's beliefs exist along a continuum. For example, for the structure of knowledge dimension, the continuum ranges from a belief in simple knowledge to a belief in complex knowledge. The certainty of knowledge dimension encompasses a range of beliefs from "knowledge is certain" to "knowledge is tentative." For the source of knowledge, the continuum ranges from a belief that knowledge is handed down by authority to a belief that knowledge is derived from reason. Regarding the dimensions that focus on characteristics of knowledge acquisition, the continuums range from a belief that learning is an innate ability versus an ability that can be acquired (control of knowledge acquisition), and the belief that learning happens quickly versus gradually (speed of knowledge acquisition). For these five dimensions,

[4] Results from factor analysis have provided empirical evidence for four of Schommer's (1990) five hypothesized dimensions. The "source of knowledge" dimension did not emerge in her analysis but is retained in other theoretical frameworks (e.g., see Hofer & Pintrich, 1997).

Schommer (1990) noted that the initial beliefs on each continuum (e.g., knowledge is simple, knowledge is certain, knowledge is handed down by authority) are "stated from a naïve epistemological persuasion" (p. 499), meaning that they represent less developed or less *sophisticated*[5] beliefs about knowledge and knowing

In later writings (e.g., Schommer, 1994; Schommer-Aikins, 2002), Schommer elaborated her initial framework. Although she maintained the original conceptualization of a multidimensional system of beliefs, she suggested that the nature of each belief may be better characterized as a frequency distribution rather than a point along a continuum (Schommer, 1994). For example, regarding the certainty of knowledge, Schommer (1994) suggests that an individual might believe that "there are few things in this world that are certain, some things that are temporarily uncertain, and many things that are either unknown or constantly evolving" (p. 29). In line with this view, she speculates that the shape of an individual's frequency distribution might be a determining factor regarding that individual's level of epistemological sophistication; that is, for a less mature learner, beliefs typically considered less sophisticated (e.g., knowledge is certain, knowledge is simple) would comprise a large proportion of the frequency distribution, whereas these beliefs would comprise a much smaller share of the frequency distribution for a more mature learner (Schommer-Aikins, 2002).

Epistemological theories. In line with Schommer's (1990) framework, Hofer and Pintrich (1997) also endorse the idea that epistemic beliefs are multidimensional, but contrary to Schommer, they propose only two core dimensions – 1) nature of knowledge,

[5] Some scholars have objected to the use of the labels "naïve" and "sophisticated" and have proposed alternatives such as less/more constructivist, less/more productive (Elby & Hammer, 2001), or less/more availing (Muis, 2004) beliefs. Accordingly, when appropriate, some of these variants are used throughout this paper.

and 2) nature of knowing – each of which can each be further subdivided into two additional dimensions, for a total of four sub-dimensions. The nature of knowledge dimension is comprised of individuals' views regarding the certainty of knowledge, or the degree to which one sees knowledge as being fixed versus fluid, and the simplicity of knowledge, or the degree to which one sees knowledge as isolated facts or highly interrelated concepts (Hofer & Pintrich, 1997). The nature of knowing dimension focuses on the process by which one comes to know and includes individuals' beliefs about the source of knowledge (i.e., knowledge resides in authority versus knowledge can be constructed by the self, or in interaction with others), and the justification for knowing, (i.e., the process by which individuals evaluate knowledge claims).

In further contrast to Schommer's (1990) framework, Hofer and Pintrich (1997) propose that individuals' views about knowledge and knowing might take the form of personal theories, or "structures of interrelated propositions that are interconnected and coherent" (Hofer, 2001, p. 36). Although they note that more empirical research is needed to test this proposal, they argue that there is at least some evidence to date that supports this view. Specifically, in line with Wellman's (1990) three criteria for characterizing a body of knowledge as a theory, Hofer and Pintrich (1997) suggest that at least two of these criteria are supported by data from personal epistemology research: 1) individuals' conceptions of knowledge and knowing tend to have some coherence among their constitutive ideas and concepts, and 2) individuals make distinctions between certain entities (e.g., nature of knowledge) and processes (e.g., nature of knowing) within the domain. With regard to Wellman's (1990) third criterion, which suggests that theories provide a causal-explanatory framework for phenomena in a domain, Hofer and Pintrich

(1997) are more tentative in their views on whether this criterion is applicable to personal epistemologies, but note that future research could examine this issue.

Epistemological resources. Similar to Schommer (1990; 1994; Schommer-Aikins, 2002), and Hofer and Pintrich (2002), Hammer and Elby (2002) also suggest that an individual's personal epistemology consists of multiple dimensions. Where their perspective diverges from other multidimensional frameworks, however, is with regard to the issue of grain size. Specifically, Hammer and Elby (2002) propose that the underlying form, or structure, of a personal epistemology is much finer-grained than either the beliefs or theories structure proposed by Schommer (1990) and Hofer and Pintrich (1997), respectively. They argue that these frameworks assume a unitary consistency, meaning that each element of an individual's personal epistemology presumably corresponds to a unit of cognitive structure. Moreover, according to Hammer and Elby (2002), the unitary perspective implies that epistemological development involves replacing "faulty" elements of this structure (e.g., the belief that knowledge is certain) with more scientifically-accepted, expert-like views (e.g., the belief that knowledge is tentative).

Hammer and Elby (2002) argue that the unitary view is problematic because it offers no account of how existing elements of an individual's cognitive structure can be transformed into more sophisticated understandings. In other words, the assumption that individuals' views about knowledge and knowing have the capacity to become more expert-like during development implies the existence of an underlying structure that permits such development through the bootstrapping of existing resources (Hammer & Elby, 2002). Given that frameworks that assume unitary structures of personal epistemology have failed to explain how this kind of bootstrapping can occur (Hammer & Elby, 2002), might there be a more fruitful way to conceptualize the form of a personal epistemology? Hammer and Elby's (2002) proposed resolution to this problem is to conceptualize the elements of a personal epistemology at a finer grain size than has heretofore been considered in other frameworks: epistemological resources. According to Elby (2009), these resources "may be largely tacit, crude, disconnected bits of cognitive machinery" (p. 144) that are activated in specific contexts. Although, as acknowledged by the authors (Hammer & Elby, 2002), more empirical work is needed to determine the particular epistemological resources that comprise this framework, they propose that the following categories might be included: resources for understanding the general nature of knowledge and how it originates, resources for understanding epistemological activities and forms, and resources for understanding different stances an individual may take toward knowledge. Importantly, within this framework, resources are generally activated not as a single element, but as a collection or network of elements comprising an epistemological frame (Elby, 2009). Over time, if a particular collection of resources – i.e., a particular epistemological frame – is activated repeatedly, the links between the resources can become more robust, and the epistemological frame may appear more like a single, coherent unit of cognitive structure (Elby, 2009).

In the context of this framework, the authors suggest that the collection of epistemological resources possessed by an expert in a particular domain is likely to be more integrated, stable, and well articulated compared to a novice's collection of epistemological resources. Moreover, Hammer and Elby (2002) argue that epistemological development should be considered in light of contextual nuances. For example, they point out that in many epistemic beliefs frameworks, the belief that "knowledge is tentative" is considered to be a sophisticated or well-developed belief regarding the certainty of knowledge, but suggest that it may actually be quite naïve to view certain types of knowledge (e.g., the earth is round, the heart pumps blood) as tentative. The authors conclude that sophistication "does not consist of blanket generalizations that apply to all knowledge in all disciplines and contexts. It incorporates contextual dependencies and judgments" (Elby & Hammer, 2001, p. 565) that take into account the discipline, the type of knowledge under discussion, and the intended use of the knowledge.

Metacognitive Perspectives

Building on previous work that has conceptualized personal epistemology as a cognitive process (e.g., Kitchener's [1983] aforementioned three-level model of cognitive processing, including cognition, metacognition, and epistemic cognition), Hofer (2004) proposed an approach to investigating personal epistemology as a metacognitive process, which she calls epistemic metacognition. Broadly speaking, metacognition is defined as knowledge of one's own cognitive processes (Flavell, 1976) and is colloquially described as "thinking about thinking" (Slavin, 2003). In Hofer's (2004) framework, this definition of metacognition is expanded to encompass "knowing about knowing" (Kitchener, 1983; Hofer, 2004) in addition to thinking about thinking. Specifically, using an existing model of metacognition (see Pintrich, Wolters, & Baxter, 2000) as a foundation, Hofer elaborates a framework of epistemic metacognition that includes the following three components: metacognitive knowledge, metacognitive judgments and monitoring, and self-regulation and control of cognition. Each of these components will be described in more detail next. It should be noted that in addition to Hofer (2004) and Kitchener (1983), Kuhn (1999a, 1999b) also discusses the metacognitive nature of personal epistemology, situating it as a component of meta-knowing which she calls "epistemological meta-knowing." However, I choose to focus specifically on Hofer's (2004) framework because it offers a more contemporary perspective that not only builds on Kitchener's and Kuhn's work, but also fits within the overall chronology of my review.

Epistemic metacognition. In a more traditional model of metacognition (Pintrich et al., 2000), the first component – metacognitive knowledge – includes knowledge about cognition and strategies, and about the self as a learner. In Hofer's (2004) expanded framework of epistemic metacognition, this component also includes beliefs about the nature of knowledge (certainty and simplicity), as well as beliefs about the self as knower. The second component, metacognitive judgments and monitoring, traditionally refers to processes (e.g., comprehension monitoring, task analysis) that reflect the overall question: "Do I understand this?" (Hofer, 2004; Pintrich et al., 2000). In Hofer's framework of epistemic metacognition, the processes involved in this component would also reflect the question: "*How* do I know this?" Accordingly, this component of the framework includes an individual's beliefs about the nature of knowing, such as the source of knowledge and the justification for knowing. As noted by Hofer (2004), "As individuals read, listen, experience, and learn, they are monitoring and judging epistemic claims, weighing evidence, evaluating authorities, and resolving conflicting information, aspects of epistemic metacognition at this level" (p. 48-49). For the third component of the framework – self-regulation and control of cognition – Hofer suggests that the focus is on regulating cognition during knowledge construction. This includes an element of "intentionality" (Hofer, 2004) wherein an individual identifies and activates plans and strategies for addressing gaps in her/his knowledge (e.g., Do I know what I need to know? Do I need to know more? If so, how will I go about this?). Taken together, these three components comprise Hofer's framework of epistemic metacognition and show how one's conceptions of knowledge and knowing can operate at the metacognitive level.

Integrated Frameworks

Recent frameworks of personal epistemology have become increasingly more complex as they attempt not only to address limitations of previous frameworks but also to accommodate new empirical findings and theoretical considerations. In this fourth and final section of the review, I consider two such complex models: Muis et al.'s (2006) Theory of Integrated Domains in Epistemology (TIDE), and Greene et al.'s (2008) framework of epistemic and ontological cognitive development.

TIDE framework. Following an extensive literature review, Muis and her colleagues (Muis et al., 2006) proposed the Theory of Integrated Domains in Epistemology (TIDE), a framework that incorporates elements from both developmental and multidimensional frameworks of personal epistemology, as well as theoretical perspectives from philosophical epistemology. The TIDE framework is noteworthy not only for its comprehensiveness, but also for offering a plausible resolution (Hofer, 2006) to a debate that had been gaining prominence in the field: the domain-generality/domain-specificity of epistemic beliefs. As noted by Muis et al., findings from some studies (e.g., Schommer-Aikins, Duell, & Barker, 2003) have shown that individuals endorsed beliefs about knowledge and knowing that were similar across different academic domains (the "domain-general" perspective), whereas other studies (e.g., Hofer, 2000) provided evidence that such beliefs differed across domains (the "domain-specific" perspective). Which perspective is more valid? As argued by Muis et al. (2006), both perspectives are valid; that is, epistemic beliefs can be *both* domain-general and domain-specific. In fact, their framework suggests that individuals' beliefs about knowledge and knowing can be differentiated at three levels: general epistemic beliefs, academic epistemic beliefs, and domain-specific epistemic beliefs.

The first level, general epistemic beliefs, represents beliefs about knowledge and knowing that: 1) develop in nonacademic contexts, and 2) are broadly articulated. According to Muis et al. (2006), once individuals enter an educational system, they begin to develop academic epistemic beliefs, which are more distinct than their general beliefs. Domain-specific beliefs are the most fine-tuned of the three types of beliefs and reflect individuals' beliefs about knowledge and knowing in reference to specific academic domains to which they have been exposed. According to Muis et al. (2006), the three levels of beliefs are reciprocally influential such that, for example, "academic epistemic beliefs are amalgamations of general epistemic beliefs in early life, but as individuals progress through higher levels of education, general epistemic beliefs are less dominant and domain-specific beliefs become more influential" (p. 31).

In the context of Muis et al.'s (2006) TIDE framework, development of epistemic beliefs is complex and multifaceted. First, there are three types of beliefs about knowledge and knowing that are subject to change: general, academic, and domain-specific epistemic beliefs. For each set of beliefs, development occurs over the course of a lifetime from a position of absolutism (e.g., knowledge is certain, simple, and handed down from authority) toward a position of evaluativism (e.g., knowledge is tentative, complex, and subject to procedures of justification). Moreover, the framework suggests that development also entails an aspect of generality/specificity. That is, as individuals advance through higher levels of education with increased disciplinary training, distinctions between their beliefs about knowledge and knowing become sharper and more explicit (Muis et al., 2006).

Model of epistemic and ontological cognitive development. Similar to Muis et al. (2006), Greene and colleagues (Greene et al., 2008) also make it a point to incorporate perspectives from philosophical epistemology in their development of an integrated framework of personal epistemology. In particular, they argue for increased attention to issues of justification, given its central role in philosophical epistemology (Pollock & Cruz, 1999). Accordingly, a defining feature of Greene et al.'s (2008) proposed model is the inclusion of a multidimensional concept of justification. Generally speaking, the authors describe their model as a "philosophically informed conceptualization of personal epistemology that is an integration of several developmental models and systems of beliefs models" (p. 144). For example, similar to other developmental frameworks of personal epistemology, Greene et al. (2008) posit several positions of epistemological development that reflect a progression toward increasingly complex views about the nature and justification of knowledge. Their proposed positions – realism, dogmatism, skepticism, and rationalism – although not identical to those posited by Perry (1970) or King and Kitchener (1994), reflect a similar overall trajectory from a belief in certain and simple knowledge, and justification based on appeal to authority (realism), to a view that knowledge is tentative and subject to scrutiny through different means of justification that reflect varying standards of validity (rationalism) (Greene et al., 2008).

Whereas some aspects of Greene et al.'s (2008) model overlap with developmental frameworks of personal epistemology, other features share much in common with multidimensional views. Most notably, in agreement with Schommer (1990), Hofer and Pintrich (1997), and Hammer and Elby (2002), Greene et al. (2008) contend that there are multiple dimensions that comprise an individual's personal epistemology: a combined "simple and certain knowledge" dimension, justification by authority, and personal justification. Greene et al. (2008) argue that the first dimension – simple and certain knowledge – reflects individuals' ontological beliefs or ontological cognition (as opposed to their epistemic beliefs, as this dimension has often been characterized by other theorists). Ontology, according to Greene et al. (2008), is the study of categories or classifications of reality[6]; thus, ontological beliefs reflect individuals' assumptions about how reality is classified or categorized. The authors argue that individuals hold ontological assumptions that can vary across academic domains and influence their views about the nature of knowledge within those domains:

> For example, a very simplistic ontology of history would include only one category of knowledge claims: facts…With time and experience some people develop a more sophisticated ontology (and thus have the opposite of a "simple" view of the nature of knowledge in that domain). This more sophisticated ontology could include the following classifications: for example, facts and interpretations. (p. 149)

[6] Ontology and epistemology are two separate, but related, branches of philosophy. Philosophical epistemology is concerned with questions about knowledge and knowing, such as: What is knowledge, and how is it acquired? In contrast, philosophical ontology is concerned with questions about reality (Greene et al., 2008). For example: How does a phenomenon exist? What is its underlying nature?

In other words, a simple view of the nature of knowledge – i.e., a simplistic or "naïve" ontology – is one that does not differentiate between various facets of knowledge (facts, interpretations, etcetera). As a result of this lack of differentiation, attributes that are ascribed to one facet of knowledge (e.g., "facts are certain") are by default also ascribed to all other concepts that are classified within the same category (i.e., "knowledge is certain"). The other two dimensions in Greene et al.'s (2008) framework – justification by authority, personal justification – reflect the framework's attention to a multifaceted concept of justification, and are deemed by the authors to be more explicitly epistemic (i.e., having to do with knowledge and knowing) as opposed to ontological. Accordingly, the authors label these dimensions as epistemic beliefs, or epistemic cognition (Greene et al., 2008).

Adopting a Multidimensional Approach

As noted above, the personal epistemology literature has produced a variety of theoretical frameworks that share a number of similarities and differences. For example, one of the key dimensions along which the frameworks can be compared is with regard to the issue of "content" – i.e., How many and what kinds of beliefs constitute a personal epistemology? For the current study, I adopt a multidimensional approach proposed by Royce (1983), wherein several beliefs about knowledge and knowing are theorized to comprise an individual's personal epistemology. In the next section, I revisit the three multidimensional frameworks reviewed above and situate Royce's (1983) framework among these perspectives.

Multidimensional Views Revisited

In Schommer's (1990) seminal multidimensional framework, individuals' epistemic beliefs are theorized to comprise five dimensions: structure of knowledge, certainty of knowledge, source of knowledge, control of knowledge acquisition (also called "innate ability"), and speed of knowledge acquisition (also called "quick learning"). These dimensions are hypothesized to be more or less independent of each other, and each dimension represents a continuum that varies in sophistication. In addition to further refinements of Schommer's (1990) initial framework (e.g., Schommer, 1994; Schommer-Aikins, 2002), several other multidimensional frameworks are found in the literature. These frameworks differ in important ways, such as their assumptions about the grain size and coherence of the elements of an individuals' belief system. For example, Hofer and Pintrich (1997) propose a multidimensional framework of epistemological theories, which are hypothesized to be of a larger grain size and more coherent structure than the beliefs described in Schommer's (1990) framework. On the other end of the grain size continuum is Hammer and Elby's (2002) framework of epistemological resources, which are more fine-grained than either beliefs or theories.

Multidimensional frameworks also differ with regard to the number and type of dimensions proposed. For example, whereas Schommer (1990) identifies five dimensions of an epistemic beliefs system, Hofer and Pintrich (1997) propose two core dimensions in their "theories" framework: 1) nature of knowledge, and 2) nature of knowing. Moreover, each of these two dimensions can be further subdivided in two, yielding a total of four sub-dimensions. The nature of knowledge dimension is comprised of individuals' views regarding the certainty of knowledge, or the degree to which one sees knowledge as being fixed versus fluid, and the simplicity of knowledge, or the degree to which one sees knowledge as isolated facts or highly interrelated concepts (Hofer & Pintrich, 1997).

The nature of knowing dimension focuses on the process by which one comes to know and includes individuals' beliefs about the source of knowledge (i.e., knowledge resides in authority versus knowledge can be constructed by the self, or in interaction with others), and the justification for knowing, (i.e., the process by which individuals evaluate knowledge claims).

Royce's Framework

In the current study, I adopt Royce's (1983) framework of psychological epistemology. Consistent with a multidimensional approach to personal epistemology, Royce (1978) identified three dimensions of epistemic beliefs which reflect different views about how knowledge is derived and justified[7]: rationalism, whereby individuals believe knowledge is derived and justified through reason and logic; empiricism, whereby individuals believe knowledge is derived and justified through direct observation and experimentation; and metaphorism (initially referred to as intuitionism), whereby individuals believe knowledge is derived via intuition and justified via universality. These three approaches to knowing are considered to represent three different epistemic beliefs that influence the particular types of cognitive processes individuals rely on when learning and processing information. For example, a person profiled as predominantly rational may, theoretically, prefer conceptualizing as a means of learning. Researchers who have conducted factor analytic work to examine what constitutes conceptualizing have found a general verbal factor and a reasoning factor (Botzum, 1951; Cattell, 1963; Horn & Cattell, 1966a). A person profiled as

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[7] This overlaps with the "nature of knowing" dimension of Hofer and Pintich's (1997) framework; that is, beliefs about how knowledge is derived and justified are comparable to beliefs about the source of knowledge and justification for knowing, respectively.

predominantly empirical may, theoretically, rely on perceptual processes as a means of learning. Researchers found that perceptual ability was comprised of a spatio-visual factor and a memorization factor (Cattell, 1971; Horn & Bramble, 1967; Horn & Cattell, 1966b). A person profiled as predominantly metaphoric may, theoretically, rely on symbolizing for learning. Two factors that loaded on to symbolizing included fluency (of ideas, expressions, and words) and imaginativeness (Horn & Bramble, 1967; Horn & Cattell, 1966b; Rossman & Horn, 1972). While Royce (1978; 1983) acknowledged these cognitive processes do not function independently and that, for a comprehensive understanding of the world, all three ways of knowing should be invoked, a person is partial to one of the cognitive processes that reflects his or her predominant epistemic belief (rationalism, empiricism, or metaphorism).

A multidimensional approach to epistemic beliefs research has grown in popularity over the past two decades since Schommer's (1990) seminal study. Within a multidimensional framework, a number of researchers have investigated relations between epistemic beliefs and various facets of learning, such as approaches to problem solving (e.g., Muis, 2008), metacognition (e.g., Pieschl, Stahl, & Bromme, 2008), and motivation (e.g., Bråten & Strømsø, 2004). In recent years, one type of learning that has captured the attention of epistemic beliefs researchers is conceptual change learning. The current study adds to this growing body of literature by including conceptual change as a variable of interest. To provide a context for the conceptual change components of my research, I next present a detailed definition of conceptual change and review several prominent models of how change occurs.

Theoretical Perspectives II: Conceptual Change

What is conceptual change? Broadly speaking, it is a process that involves the restructuring of prior knowledge. According to Chi (2008), there are at least three conditions of prior knowledge that can be experienced by learners: 1) "no prior knowledge," in which learners may lack any prior knowledge of the to-be-learned material, but may have related knowledge; 2) "incomplete knowledge," in which learners may have some prior knowledge of the to-be-learned content, but their knowledge is incomplete; and 3) "conflicting knowledge," in which learners may have prior knowledge of the to-be-learned material, but such knowledge is inaccurate or conflicts with the learning material. Chi (2008) further explains that these three prior knowledge conditions suggest different implications regarding the learning of complex material. For example, in accordance with the first two conditions, since the to-be-learned material is not in conflict with what the learner already knows, the new knowledge can be more easily integrated with the learner's prior knowledge. In Piagetian terms, this process – the fitting of new information into existing knowledge structures – is known as assimilation (e.g., Woolfolk, Winne, & Perry, 2009). In contrast, in the "conflicting knowledge" condition, new information cannot be easily integrated with existing knowledge, and learning involves a process of *conceptual change*. That is, learning is a process of changing inaccurate or misconceived prior knowledge to "correct" or scientifically-accepted knowledge (Chi, 2008). According to some conceptual change researchers, this process may share much in common with the Piagetian process of accommodation (Tyson, Venville, Harrison, & Treagust, 1997).

The study of conceptual change is a prominent line of inquiry that has captured the attention of researchers from a variety of backgrounds, such as cognitive psychology, science education, and developmental psychology. With such diverse perspectives brought to bear on this issue, a wide assortment of conceptual change models have been developed to explain how such change occurs, why it can be difficult to achieve, and what instructors might do to facilitate conceptual change. An overview of three pertinent models is presented next.

Review of Models

"Cold" conceptual change. Posner and colleagues' (Posner et al., 1982; Strike & Posner, 1985; Strike & Posner, 1992) model of conceptual change is arguably the most well known of the various models that populate the conceptual change literature. Some scholars (e.g., Pintrich, Marx, & Boyle, 1993; Sinatra, 2005) have described this model as presenting an account of "cold" conceptual change, noting that Posner et al. (1982) focus primarily on cognitive factors involved in the change process, at the exclusion of "hot" factors such as motivation. Indeed, the authors themselves state that a central assumption guiding the development of their model is that "learning is a rational activity" (Posner et al., 1982, p. 212), although in later writings, they acknowledge that their model should be modified to include a wider range of factors such as motives and goals (Strike & Posner, 1992). Nonetheless, the emphasis on the rational processes involved in conceptual change continues to be the most defining feature of this model.

To develop their account of rational conceptual change, Posner and colleagues (Posner et al., 1982) turned to contemporary views in the philosophy of science – most notably Kuhn (1970) and Lakatos (1970) – which have described the processes by which "scientific paradigms" (Kuhn) or "research programmes" (Lakatos) are replaced or modified to accommodate anomalous data. In line with this view, Posner et al. propose that individuals' conceptions are analogous to paradigms or research programs, and when these conceptions prove inadequate for allowing the individual to interpret new information, they must be replaced or reorganized. Degenerative conceptions are replaced with more productive ones through a process that the authors (borrowing from Piaget's vocabulary) call accommodation. They suggest that accommodation involves a radical change to an individual's conceptual system, but also emphasize that radical should not be conflated with abrupt (Strike & Posner, 1985). This is because accommodation is viewed as a contest whereby competing conceptions – the existing, dysfunctional conception (often referred to as a misconception), and a new, alternative conception – vie for greater status in an individual's conceptual system. As these different conceptions jockey for status, the process may be "characterized by temporary advances, frequent retreats, and periods of indecisions" (Strike & Posner, 1985, p. 221). Accordingly, it would be inappropriate to assume that conceptual change is abrupt, as it may often entail gradual and piecemeal adjustments.

What are the factors that are likely to improve a conception's status? In other words, what are the conditions under which accommodation, or radical conceptual change, might occur? Posner et al. (1982) identify four conditions of accommodation. The first condition is that learners must be *dissatisfied* with their existing conceptions. This is a critical first step because, as noted by Strike and Posner (1992), individuals will not engage in the more arduous process of accommodation when it is still possible to assimilate new ideas in their existing frameworks. Although there might be several sources of dissatisfaction, it is argued that anomalies – i.e., a collection of data/experiences/etcetera that cannot be interpreted by one's existing conceptions – are one of the key contributors to dissatisfaction or cognitive conflict (Strike & Posner, 1985). Importantly, as Chinn and Brewer (1993) point out, anomalies do not always guarantee that an individual will experience cognitive conflict. Their framework of responses to anomalous data describes a wide range of responses that individuals may display when they encounter such data, such as ignoring or rejecting it. Thus, the argument that anomalies will produce the first condition of conceptual change – dissatisfaction – is itself qualified by a number of conditions, not the least of which is that an individual actually recognizes that a particular finding or collection of findings is anomalous.

In addition to the condition that individuals must be dissatisfied with an existing conception, Posner et al. (1982) present three other conditions for conceptual change. These remaining conditions focus on the factors that may allow a new conception to gain status relevant to an existing conception. First, a new conception must be *intelligible*. As Strike and Posner (1985) note, citing the work of cognitive scientists, "ideas cannot function psychologically unless the student can internally represent them" (p. 219). Thus, an individual must be able to minimally comprehend a conception in order to consider it as a candidate for replacing an existing conception. Second, a new conception must appear initially *plausible*. It is suggested that there are several ways in which a new conception could meet the plausibility condition, including the degree to which it is consistent with other ideas in an individual's conceptual system, and whether it appears capable of resolving anomalies (Posner et al., 1982). Finally, a new conception must be *fruitful*, meaning that it has the potential to generate new avenues of inquiry and lead to new insights or discoveries. In later writings, Strike and Posner (1992) highlight that their theory of conceptual change is largely an epistemological theory (i.e., a theory of knowledge), because it focuses on the criteria by which knowledge is included or excluded from an individual's conceptual system. These criteria include intelligibility, plausibility, and fruitfulness.

"Hot" conceptual change. In an influential article criticizing cold, "cognition-only" models of conceptual change, Pintrich and colleagues (Pintrich et al., 1993) highlighted the need for more inclusive models that consider the influence of hot, irrational factors in the change process. They take issue, for example, with Posner et al.'s (1982) assumption that individual conceptual change is analogous to the kind of change that happens in scientific communities, noting that a classroom community and a scientific community likely do not operate in the same fashion[8]. Although Pintrich et al. (1993) accept the four conditions – dissatisfaction, intelligibility, plausibility, fruitfulness – that were proposed in the classic model of conceptual change, they argue that such conditions are influenced by a broader range of factors than have not heretofore been considered by conceptual change researchers. Specifically, they argue that cognitive, motivational, and classroom contextual factors interact with the four conditions in dynamic ways to produce change in individuals' conceptions and ideas.

[8] However, in line with social constructivist views of learning, some researchers have advocated the design of classroom environments that more closely resemble the authentic activities of scientists and other disciplinary experts (e.g., Brown, Collins, & Duguid, 1989), so it is not improbable that some classrooms do, in fact, operate in a fashion similar to that of scientific communities. Some examples of novel classroom environments that may more closely approximate the character of scientific communities include Rogoff and colleagues' Community of Learners model (e.g., Rogoff, Matusov, & White, 1996), and Scardamalia and Bereiter's Knowledge Building approach (e.g., Scardamalia & Bereiter, 2006).

Regarding cognitive factors, Pintrich et al. (1993) identify a number of cognitive and metacognitive processes on which the conditions leading to conceptual change are likely to depend. Such processes include: selective attention, activation of prior knowledge, deep processing, and metacognitive evaluation and control. For example, as mentioned earlier, in order to become dissatisfied with an existing conception (Posner et al.'s [1982] first condition for change), it is imperative that individuals are able to selectively attend to anomalies or discrepant information. Moreover, in order to judge the intelligibility of a new conception (the second condition for change), individuals would need to engage in metacognitive monitoring activities such as self-testing and checking their understanding of the new idea. Metacognitive processes would also be relevant when determining the plausibility or fruitfulness of a new conception relative to an existing conception (the third and fourth conditions for change).

Importantly, one of the central assumptions in Pintrich et al.'s (1993) model is that the aforementioned cognitive processes are influenced in complex ways by a variety of motivational factors, such as individuals' goals, beliefs, values, and interest, to name a few. For example, self-efficacy beliefs –i.e., individuals' beliefs about their ability to perform specific tasks (Bandura, 1977) – are hypothesized to have a paradoxical relationship with conceptual change. On the one hand, if individuals have confidence in their own thinking and learning strategies and believe that they have the cognitive resources that are necessary to produce change, then it is likely that high self-efficacy beliefs would facilitate conceptual change. On the other hand, if individuals have a high level of confidence in their existing beliefs and conceptions, then it is possible that such levels of self-efficacy might engender resistance to new ideas, thus impeding conceptual change (Pintrich et al., 1993). Students' achievement goals, or integrated patterns of beliefs that reflect their reasons for engaging in achievement behavior (Ames, 1992), are another motivational factor that is theorized to affect conceptual change in Pintrich et al.'s model. For example, mastery goals – which emphasize learning and mastery of new material – are theoretically and empirically linked to deeper cognitive processing strategies (e.g., Elliot, McGregor, & Gable, 1999; Pintrich, 1999) in the broader literature examining relations between motivation and cognition. In light of such evidence, Pintrich et al. argue that mastery goals would likely facilitate conceptual change because students who endorse such goals are more apt to engage in the effortful cognitive processing necessary to produce such change.

Finally, in line with socio-constructivist perspectives of motivation (see Hickey, 1997), Pintrich et al. (1993) acknowledge that students' motivational goals, beliefs, etcetera, are likely to be "created, shaped, and constrained by various aspects of the classroom context" (p. 176). Accordingly, classroom contextual factors comprise the third major set of factors in their model (in conjunction with the aforementioned cognitive and motivational factors). Such classroom factors include task, authority, and evaluation structures. For example, classroom environments that focus on challenging tasks that have multiple pathways to solutions, authority structures that allow opportunities for students to take responsibility for learning and assume leadership roles, and evaluation practices that are varied, private, and focused on individual progress and improvement, are likely to make mastery goals more salient to students in those classrooms (Ames, 1992; Meece, Anderman, & Anderman, 2006). In turn, as described in the preceding paragraph, the adoption of a mastery goal could facilitate conceptual change. Thus, in the model proposed by Pintrich and colleagues, it is the dynamic interaction of cognitive, motivational, and classroom contextual factors, together with the four conditions of dissatisfaction, intelligibility, plausibility, and fruitfulness, that determines the likelihood of successful conceptual change.

The "warming" trend. In just over a decade after Pintrich et al. (1993) introduced their model of "hot" conceptual change, Sinatra (2005) commemorated the impact of this work, noting that the field may be "changed inexorably by Pintrich's vision" (p. 107). In the same tribute article, Sinatra extended the metaphor of cold versus hot conceptual change to suggest that Pintrich and colleagues inspired a "warming" trend in conceptual change research. In other words, following Pintrich's article, subsequent models of conceptual change began to acknowledge the role of motivational and affective factors in the change process (Sinatra, 2005). One such model, proposed by Dole and Sinatra (1998), is the Cognitive Reconstruction of Knowledge Model (CRKM). The CRKM is noteworthy not only for being one of the first "warm" conceptual change models, but also for incorporating perspectives from the social psychology literature regarding persuasion. In particular, Dole and Sinatra (1998) borrow heavily from a social psychology model called the Elaboration Likelihood Model (Petty & Cacioppo, 1986), which describes the processes by which attitude change occurs. Additionally, the development of the CRKM was influenced by ideas from both cognitive psychology and science education.

According to the Dole and Sinatra (1998), the most important element of the change process is something that they call the continuum of engagement, which refers to the levels of information processing, strategy use, and metacognitive processes that individuals employ when attending to new information. The continuum can range from low cognitive engagement (involving shallow processing strategies) to high metacognitive engagement (involving deep processing strategies). Although high levels of engagement do not guarantee that conceptual change will occur, they do increase the likelihood of its occurrence (Dole & Sinatra, 1998). Moreover, it is possible that even low levels of engagement can produce conceptual change, but the authors argue that such change is likely to be fleeting and unstable. Ultimately, the outcome of engagement – i.e., whether it results in conceptual change or not – is influenced by a variety of factors that interact in dynamic ways.

What factors influence individuals' levels of engagement? Dole and Sinatra (1998) propose that it is a combination of learner and message characteristics that interact to affect levels of engagement. By message characteristics, they refer to "features of the instructional content or persuasive discourse designed to promote change" (Sinatra, 2005, p. 110); that is, the to-be-learned material. In the context of the CRKM, change is hypothesized to unfold in a non-linear fashion; accordingly, neither the learner nor the message characteristics takes priority in the model. For the sake of presenting these ideas in an organized fashion, however, I discuss the learner characteristics first.

In particular, the CRKM identifies seven learner characteristics that can be clustered into two categories: characteristics related to the learner's existing conception (three variables), and motivational factors (four variables). Regarding the learner's existing conception, or prior knowledge, Dole and Sinatra (1998) specify that the strength and coherence of an existing conception, along with a learner's level of commitment to the conception, are three qualities that have the potential to influence change. For each of these factors, greater degrees of the quality (i.e., more strength, greater coherence, higher commitment) are associated with lower likelihoods of conceptual change. The second category of learner characteristics – motivational factors – includes dissatisfaction (similar to Posner et al. [1982]), personal relevance, social context (e.g., the influence of peers, instructors, individuals in positions of authority), and need for cognition. According to Sinatra (2005), need for cognition, or an individual's inherent level of motivation to process information, is the most "trait-like" of the four motivational characteristics. The others – dissatisfaction, personal relevance, and social content – are viewed more as products of individuals' interactions with their environment.

The seven learner characteristics operate in conjunction with four message characteristics to influence learners' engagement (Dole & Sinatra, 1998). The four message characteristics are identified as comprehensibility, coherence, plausibility, and rhetorical persuasiveness (labeled as "rhetorically compelling" in the model). Two of these factors (comprehensibility, plausibility) relate directly to Posner et al.'s (1982) model and refer, respectively, to how intelligible the message is, and how reasonably true it appears to the individual. Regarding coherence, the authors suggest that a message is likely to appear coherent if it provides a well-integrated account of a phenomenon. Finally, for a message to be rhetorically compelling, it must be persuasive and convincing.

A final feature of the CRKM, rooted in the Elaboration Likelihood Model (Petty & Cacioppo, 1986), is the notion of a "peripheral cue." According to Dole and Sinatra (1998), peripheral cues, or variables that are tangential to the message's content (e.g., an attractive source or a pleasant environment) have the potential to engage an individual in processing the message, even if the message's primary characteristics (comprehensibility, plausibility, etcetera) are not sufficiently compelling. Peripheral cues are typically associated with superficial levels of engagement and weak conceptual change, but it should be noted that in some instances such cues can trigger the kind of deeper engagement that leads to more enduring change (Dole & Sinatra, 1998).

The CRKM suggests that dynamic interactions between learner and message characteristics influence the degree to which an individual processes the to-be-learned content, which subsequently impacts the likelihood of conceptual change. This notion of degree of processing, referred to by the authors as the continuum of engagement, is the most important component of the model (Dole & Sinatra, 1998). The more deeply an individual engages with the to-be-learned content – through effortful processing of information, and metacognitive and reflective thinking – the more likely the possibility that radical, enduring conceptual change will occur.

In sum, contemporary models of conceptual change reflect the view that change is complex, dynamic, and multifaceted (Murphy & Mason, 2006; Sinatra & Mason, 2008). For example, even though there are differences between Pintrich et al.'s (1993) conceptual change framework and Dole and Sinatra's (1998) CRKM (e.g., the research traditions they draw on, the particular factors they identify), both agree that conceptual change involves that dynamic interaction of factors related to the learner and the to-be-learned material, and both highlight the role of cognitive and metacognitive processing in the change process. It is these two points in particular that inform the current study. Specifically, drawing on ideas from Pintrich et al. (1993) and Dole and Sinatra (1998), I examine: 1) the interactive effects of learner and text characteristics on conceptual change, and 2) the indirect effects of learner and text characteristics on conceptual change as observed in “traces” (Winne, 1982; Winne & Perry, 2000) of individuals’ cognitive and metacognitive processes (i.e., data about actual studying events recorded while learners engage in a learning task). In particular, I focus on the role of epistemic beliefs (a learner characteristic) and knowledge representations (a text characteristic) in conceptual change in physics. Prior to presenting the details of my study, I next describe pertinent empirical studies related to epistemic beliefs, cognitive processing strategies, and conceptual change. I then introduce my research questions and hypotheses.

Empirical Studies

Epistemic Beliefs and Cognitive Processing Strategies

A number of researchers have examined relations between students’ beliefs and their use of cognitive processing strategies (e.g., Cano, 2005; Muis & Franco, 2009a; Phan, 2008; Ravindran, Greene, & DeBacker, 2005; see also Muis [2004] for a review). For example, Schommer et al. (1992) investigated whether students’ beliefs in simple knowledge predicted mathematical text comprehension and investigated whether effects of beliefs on learning were mediated by study strategies. One hundred thirty-eight college students completed a questionnaire designed to measure their epistemic beliefs. Participants then read a passage about statistics, rated their confidence in understanding the passage, and completed a mastery test (assessing recall and application of information from the passage) and a study strategies inventory. The study strategies inventory included items designed to measure cognitive information processing, such as memorization (a shallow processing strategy) and knowledge integration (a deep processing strategy). Results revealed that a belief in simple knowledge was negatively related to comprehension and metacomprehension. The more students believed in simple knowledge, the worse they did on the comprehension test and the more overconfident they were in their understanding of the passage. Of particular relevance to the current study, results from path analysis showed that the influence of simple knowledge on comprehension was mediated by an overall processing strategy. That is, the more students believed in simple knowledge, the more they engaged in memorization strategies and the less they were able to summarize important concepts. Accordingly, Schommer et al. (1992) argued that epistemic beliefs directly and indirectly affect achievement.

In another study examining relations between epistemic beliefs and cognitive processing strategies, Kardash and Howell (2000) surveyed the epistemic beliefs of 40 undergraduate students in accordance with Schommer's (1990) framework. Participants then read a dual-positional text about the relationship between HIV and AIDS, and were instructed to think out loud while reading. One day after reading the text, participants completed a recall test. Participants' think-alouds were transcribed and coded for evidence of various cognitive processes, such as "using background knowledge" and "developing awareness." Results showed that epistemic beliefs were related to students' frequency of strategy use, but not the types of strategies used. In particular, students who espoused more constructivist, or sophisticated, beliefs about the speed of learning (e.g., learning takes time and effort) used more strategies than students who espoused less constructivist beliefs. There were no significant relations between epistemic beliefs and total sentence recall (Kardash & Howell, 2000), although the authors speculated that this could be caused by a number of factors related to the administration of the recall measure (e.g., that the test was administered one day after reading the text, as opposed to immediately after).

More recently, Chan (2007) investigated relations between epistemic beliefs, conceptions of learning, and learning strategies with a sample of Hong Kong Chinese teacher education students. Two hundred thirty-one students completed a set of questionnaires (translated into Chinese) designed to measure the constructs of interest. In particular, the epistemic beliefs scale was adapted from Schommer's (1990) instrument and measured four dimensions of beliefs about knowledge, knowing, and learning: authority/expert knowledge, certainty knowledge, innate/fixed ability, and learning effort/process. Learning strategies were measured using Biggs and colleagues' (Biggs, Kember, & Leung, 2001) revised two factor study process questionnaire, which focuses on two approaches to learning: a deep approach and a surface approach. Results from path analysis revealed statistically significant relations between epistemic beliefs and learning strategies. Specifically, a belief in authority/expert knowledge and a belief in certainty knowledge were positively related to a surface approach to learning. That is, the more students believed in certain knowledge that is handed down from authorities (typically considered to be more naïve, or less constructivist, beliefs about knowledge and knowing), the more likely they were to report using strategies that focus on rote learning and rehearsal.

Similarly, Paulsen and Feldman (2007) found that students who espoused more naïve epistemic beliefs were less likely to adopt cognitive and behavioral learning strategies that are "educationally productive" (p. 390). In their study, 502 undergraduate students completed Schommer's (1990) Epistemological Questionnaire (EQ), which assessed four dimensions of beliefs about knowledge, knowing, and learning: simple knowledge, certain knowledge, fixed ability, and quick learning. The Motivated

Strategies for Learning Questionnaire (MSLQ; Pintrich et al., 1991) was used to assess participants' use of cognitive and behavioral learning strategies. In particular, four types of cognitive strategies were measured: rehearsal (a shallow processing strategy), organization (a deep processing strategy), elaboration (a deep processing strategy), and metacognition (a deep processing strategy). (The authors also measured four types of behavioral strategies, but they are omitted from further discussion here, as they are not relevant to the current study). Using multiple regression analysis, Paulsen and Feldman (2007) found that epistemic beliefs were significantly related to students' self-reported use of cognitive processing strategies. In particular, students who espoused naïve beliefs about the structure of knowledge (i.e., they endorsed the view that knowledge is simple) were more likely to report using rehearsal strategies (shallow processing) and less likely to report using elaboration strategies (deep processing).

Results from these studies and others (e.g., Cano, 2005; Dahl, Bals, & Turi, 2005; Ryan, 1984) have led some researchers to hypothesize that epistemic beliefs play an important role in self-regulated learning (e.g., Hofer & Pintrich, 1997; Muis, 2007; Schommer, 1998; Winne & Hadwin, 1998), defined by Schunk (2001) as "learning that results from students' self-generated thoughts and behaviors that are systematically oriented toward the attainment of their learning goals" (p. 125). For example, in her integrated model of epistemic beliefs and self-regulated learning, Muis (2007) theorized that one of the ways in which epistemic beliefs are related to self-regulated learning is via the standards that students set for learning. These standards may subsequently influence the type of strategies students select for carrying out their learning task. As noted by Muis (2007), if a student believes that knowledge is simple and consists of isolated facts (typically considered to be a less sophisticated, or less constructivist, epistemic belief), then s/he may set learning standards that involve rote memorization of information and may select "shallow" learning strategies that fail to integrate information and make important connections between concepts. This explanation shares Bromme et al.'s (2010) view that epistemic beliefs provide a schema, or apprehension structure, for the to-be-learned material.

Importantly, the studies reported above (which, for the most part, reflect the current state of research on epistemic beliefs and cognitive processing strategies) contain a number of limitations that my research aims to address. First, all four studies adopt a decontextualized approach to epistemic beliefs research; that is, they fail to take into account aspects of the epistemic climate (Haerle & Bendixen, 2008; Muis et al., 2006) that may interact with individuals' beliefs about knowledge and knowing to further influence the types of strategies that learners choose. My study aims to address this limitation by including knowledge representations as an independent variable and examining the ways in which epistemic beliefs interact with knowledge representations to facilitate or constrain learning. Second, all of the studies reviewed above have adopted Schommer's (1990) framework of epistemic beliefs. Perhaps this would not be seen as a limitation if the field was united in endorsing Schommer's (1990) view as the preeminent framework for conducting epistemic beliefs research, but this is not the case. Not only is there *not* a unified framework in the epistemic beliefs literature (Bendixen & Rule, 2004), but also Schommer's (1990) framework in particular has been the subject of much debate because of its inclusion of learning beliefs in addition to beliefs about knowledge and knowing (Hofer & Pintrich, 1997). Moreover, Schommer's (1990) Epistemological

Questionnaire –which was adopted and adapted by all of the studies reported above – is also problematic because it often produces different factor structures across different studies (as can be observed across the sample of studies reviewed here). My study offers a different theoretical perspective on this topic by adopting Royce's (1983) multidimensional framework and his corresponding instrument, the Psycho-Epistemological Profile (PEP; Royce & Mos, 1980). Finally, the aforementioned studies are limited in that, with the exception of Kardash and Howell (2000), they relied on self-report measures to assess individuals' use of cognitive processing strategies. Like Kardash and Howell (2000), the current study distinguishes itself from others like it because I use a think-aloud protocol to gather "traces" (Winne, 1982; Winne & Perry, 2000) of actual (versus self-reported) strategy use, recorded while learners engage in the task of learning physics through text.

Epistemic Beliefs and Conceptual Change

In addition to addressing various limitations of the studies reviewed in the previous section, my study is also noteworthy for including conceptual change as an off-line measure of learning in conjunction with an online assessment of individuals' use of cognitive processes. Although views about knowledge and knowing have long been considered in various theoretical frameworks of conceptual change (e.g., Pintrich et al., 1993; Strike & Posner, 1992), it is only recently that researchers have begun to investigate these relations empirically (e.g., Kendeou et al., 2010; Mason & Gava, 2007; Mason et al., 2008; Stathopoulou & Vosniadou, 2007a, 2007b), with the exception of an early study by Qian and Alvermann (1995). In their research, Qian and Alvermann (1995) surveyed the prior knowledge and epistemic beliefs of 212 high school students.

Epistemic beliefs were measured in accordance with four dimensions of Schommer's (1990) framework: simple knowledge, certain knowledge, quick learning, and innate ability. Two weeks later, participants read and studied a passage about Newton's theory of motion, and then completed an achievement test to assess their conceptual understanding and reasoning with regard to Newton's theory. Results showed that students who espoused more constructivist beliefs were more likely to achieve conceptual change after reading than students who espoused less constructivist beliefs.

In another study, Stathopoulou and Vosniadou (2007b) also found that students' beliefs about knowledge predicted their conceptual understanding in physics. Specifically, results showed "consistent main effects for epistemological sophistication" (Stathopoulou & Vosniadou, 2007b, p. 276) in that students who espoused more constructivist beliefs about knowledge outperformed students who espoused less constructivist beliefs on an instrument designed to measure conceptual understanding of Newtonian mechanics. In a complementary study, the same authors (Stathopoulou & Vosniadou, 2007a) found that students' selection of study strategies (e.g., deep versus shallow) may mediate the relationship between epistemic beliefs and conceptual change. Based on interview, think-aloud, and observation data from 10 students (five of whom espoused more constructivist epistemic beliefs and achieved deep conceptual understanding of physics, and five of whom espoused less constructivist beliefs and performed poorly on the measure of physics understanding), Stathopoulou and Vosniadou (2007a) found that students who espoused more constructivist epistemic beliefs and achieved conceptual change adopted deep study strategies and demonstrated metaconceptual awareness (i.e., awareness of their own beliefs). On the other hand, students who espoused less constructivist beliefs and performed poorly on the conceptual test adopted shallow strategies. Moreover, these students did not show evidence of metaconceptual awareness. The authors suggest that results from this study provide preliminary evidence of the indirect effects of epistemic beliefs on conceptual change.

Mason and colleagues (Mason, 2000, 2001; Mason & Gava, 2007; Mason et al., 2008) have investigated relations between epistemic beliefs and conceptual change in a number of studies. For example, Mason and Gava (2007) studied the effects of epistemic beliefs and text structure (refutational versus non-refutational) on changes in misconceptions about natural selection and biological evolution. One hundred ten eighth graders completed a prior knowledge test, a reading comprehension test, and a questionnaire to measure their epistemic beliefs in accordance with Schommer's (1990) framework. Participants were assigned to one of two conditions: 1) an experimental condition, wherein participants read a refutational text about natural selection and biological evolution, and 2) a control condition, wherein participants read a non-refutational text about the same topic. After reading, students in both conditions completed tasks designed to measure their text comprehension, conceptual change, and metaconceptual awareness. Specifically, conceptual change was assessed by examining changes in participants' answers from before reading to after reading on the same set of questions that comprised the prior knowledge test. Results from a repeated measures ANCOVA revealed a significant interaction between epistemic beliefs and text structure with regard to conceptual change. That is, participants who espoused more sophisticated beliefs and who read the refutational text experienced more changes in misconceptions than the other groups.

In another study, Mason and colleagues (Mason et al., 2008) investigated not only epistemic beliefs and text structure but also topic interest in relation to conceptual change learning. Participants were 94 fifth-grade students who completed several instruments designed to measure their prior knowledge, reading comprehension, topic interest, and epistemic beliefs about science. Similar to the aforementioned study by Mason and Gava (2007), participants were then assigned to one of two reading conditions: 1) an experimental condition, wherein participants read a refutational text about light, and 2) a control condition, wherein participants read a non-refutational text (also about light). After reading their assigned text, participants rated how much they liked the text, answered a series of questions about the text to assess retention of facts, and completed an immediate and delayed posttest of their conceptual knowledge of light (identical to the prior knowledge test, so that the authors could examine changes in misconceptions from pretest to posttest). Results from repeated measures ANCOVAs revealed a number of interactions among the independent variables. Of particular relevance to the current study, participants who espoused more sophisticated epistemic beliefs, had higher topic interest, and read the refutational text produced the most conceptual change.

More recently, Kendeou and colleagues (Kendeou et al., 2010) investigated relations between epistemic beliefs, text structure (refutational text versus non-refutational text), and conceptual change processes. Forty-six undergraduate students completed a prior knowledge test of misconceptions in Newtonian mechanics and a questionnaire designed to measure their epistemic beliefs. Participants then read two experimental texts (one refutational and one non-refutational text, presented in a counterbalanced order) about Newton's laws of motion, and were asked to think aloud while reading. Participants' think-aloud sessions were transcribed and coded by two independent raters. The coding scheme was adapted from previous research (Kendeou & van den Broek, 2005, 2007; Pritchard, 1990) and consisted of eight categories of cognitive processes in which readers engaged while reading the instructional texts. Of particular relevance to the current study, one of the categories – called "conceptual change processes" – focused on "responses that showed that readers were engaging in conceptual change" (Kendeou et al., 2010), such as experiencing conflict between their prior knowledge and new ideas presented in the text. Results from an analysis of covariance showed that conceptual change processes were associated with an interaction between epistemic beliefs and text structure. Specifically, individuals who espoused more sophisticated epistemic beliefs engaged in more conceptual change processes when reading refutational text compared to individuals who espoused less sophisticated epistemic beliefs. For the non-refutational text, however, there were no statistically detectable differences between the groups with regard to conceptual change processes. Kendeou et al.'s (2010) study is noteworthy in that it treated conceptual change as an online process in which readers engaged while reading as opposed to an off-line product that occurred after reading. Even though the authors characterized conceptual change in a different way than previous studies have, results were still in line with conceptual change theory that suggests that knowledge revision is influenced by a combination of learner and text characteristics (e.g., Dole & Sinatra, 1998; Murphy, 1998).

A Double-Track Approach

Taken together, results from the studies reviewed above (and others: e.g., Cano, 2005; Kardash & Scholes, 1996; Muis & Franco, 2009a; Schommer, 1990) demonstrate that epistemic beliefs have both direct and indirect effects on learning, with a more sophisticated or constructivist view of knowledge being linked to better learning outcomes than a less sophisticated or constructivist view. In light of the consistent main effects that have been associated with constructivist epistemic beliefs, findings from this line of research have promoted the view that there are some types of epistemic beliefs that are "superior" with regard to learning. Recently, however, researchers have started to question the idea that there is a defined set of beliefs that is more sophisticated or superior than other beliefs (e.g., Bromme, Kiehnues, & Stahl, 2008; Elby & Hammer, 2001; Greene, Muis, & Pieschl, 2010; Murphy, Alexander, & Muis, in press; Schommer-Aikins, 2002), suggesting instead that epistemological sophistication consists of a wide range of beliefs about knowledge and knowing (some constructivist, some not) that are accessed appropriately depending on the context. For example, as noted by Hammer and Elby (2002), in many models of epistemic beliefs, the belief that "knowledge is tentative" is considered to be a sophisticated view regarding the certainty of knowledge; however, the authors make the case that in some situations, it may be quite unproductive to view some types of knowledge (e.g., the earth is round, the heart pumps blood) as tentative.

Accordingly, researchers have called for an approach to epistemic beliefs research that goes beyond the investigation of main effects of students' beliefs and takes into account dynamic interactions between students' beliefs and aspects of the learning context or epistemic climate (e.g., Elby & Hammer, 2001; Hofer & Pintrich, 1997; Muis et al., 2006). For example, as mentioned above, Bromme and colleagues (2010) call for a "double-track" approach to research on epistemic beliefs wherein researchers' predictions and interpretations of the effects of epistemic beliefs on learning are informed by a complementary analysis of the learning content with which individuals engage. One aspect of the learning content that has received little attention in the epistemic beliefs literature to date is knowledge representation. Mislevy and colleagues (Mislevy et al., 2010) define knowledge representation, broadly speaking, as the way in which information about the world is represented, differentiating between internal knowledge representation, or the way in which we represent knowledge in our brains, and external knowledge representation, or "a physical or conceptual structure that depicts entities and relationships in some domain, in a way that can be shared among different individuals or the same individual at different points in time" (Mislevy et al., 2010, p. 4). Moreover, in their framework outlining various aspects of the epistemic climate, Haerle and Bendixen (2008) highlight textbooks, curricula, and assessments as examples of knowledge representations that could be explored in the context of epistemic beliefs research.

To date, only a handful of epistemic beliefs studies reflect Bromme and colleagues' (2010) notion of a double-track approach. In one such study, Windschitl and Andre (1998) explored the interaction between epistemic beliefs and type of learning environment on college students' conceptual change of cardiovascular concepts. Two hundred fifty university students completed a survey designed to measure their epistemic beliefs in accordance with Schommer's (1990) framework. They also completed pretests designed to assess their prior knowledge of various cardiovascular concepts. In groups of 15 (based on their assigned laboratory sections), students were then randomly assigned to one of two computer simulation environments: 1) a "constructivist" environment, in which students were allowed to create and test hypotheses regarding cardiovascular phenomena; and 2) an "objectivist" environment, in which students followed a written guide to perform prescribed exercises in the simulated environment. Following three weeks of sessions with their respective learning environments (~ 7 hours total), students completed a posttest to re-assess their knowledge of cardiovascular concepts. Results revealed an interaction between epistemic beliefs and type of learning environment. Specifically, students who espoused more constructivist epistemic beliefs performed best in the constructivist environment, whereas students who espoused less constructivist beliefs performed better in the objectivist environment.

In another study, Muis (2008) examined relations between epistemic beliefs and metacognitive strategy use (planning, monitoring, and control) in the context of mathematics problem solving. Participants completed inventories to assess their self-reported metacognitive strategy use and their epistemic beliefs (in accordance with Royce's [1983] framework), then participated in two problem-solving sessions. For both self-reported and actual metacognitive self-regulation during problem solving, students who espoused predominantly rational beliefs had the highest self-reported mean and actual frequency of use of planning, monitoring, and control strategies. Moreover, students who espoused rational beliefs justified their solutions as correct using the logical information (e.g., proofs and theorems) they derived to solve the problems, whereas students who espoused empirical beliefs justified their solutions as correct based on empirical information, such as physically measuring lines and circles created during problem solving. Finally, students who espoused predominantly rational beliefs correctly solved more problems than students in the other groups.

Muis' (2008) interpretation of these results was informed by a complementary analysis of the epistemic nature of the domain of mathematics. Given that mathematics is a rational domain (Royce, 1978; Triadifillidis, 1998), Muis explained that, in the context of mathematics problem-solving, individuals who espouse predominantly rational epistemic beliefs should be expected to outperform individuals espousing empirical or metaphorical beliefs because there is more rational information on which to focus. That is, because sources of information in the mathematics problems entail rational elements, individuals who espouse predominantly rational beliefs may perceive greater amounts of information to coordinate and evaluate, the consequence of which is greater levels of metacognition and achievement.

In a subsequent study addressing similar issues, Muis and Franco (2010) examined relations between epistemic beliefs, metacognition, and achievement in the context of learning in an educational psychology course. Royce's (1983) framework was again used to classify students' (N = 231) epistemic beliefs as: 1) predominantly rational, 2) predominantly empirical, or 3) a combination of both rational and empirical. Participants then completed a self-report questionnaire designed to measure their use of metacognitive strategies. Results showed that students who espoused a combination of rational and empirical beliefs had a higher frequency of metacognitive strategy use compared to students who espoused predominantly empirical beliefs. Moreover, in a second component of the same study, a sub-group of 78 students participated in a problem solving session wherein they were asked to read a short chapter on motivation and then think aloud while solving two problems related to the chapter. Students' think-aloud episodes were transcribed and coded for evidence of metacognitive processes (specifically, regulation of cognition). Similar to the results from the first component of the study, results from the think-aloud sessions revealed that students who espoused a combination of both rational and empirical beliefs engaged in more regulation of cognition compared to students who espoused predominantly empirical beliefs and students who espoused predominantly rational beliefs. Students who espoused both rational and empirical beliefs also correctly solved more problems compared to students whose beliefs were classified as predominantly empirical.

Consistent with a double-track approach (Bromme et al., 2010), Muis and Franco (2010) considered the epistemic nature of the learning context when formulating their predictions and interpretations regarding the effects of participants' epistemic beliefs. Specifically, drawing on ideas from Royce (1978) and MacKay (1988), Muis and Franco (2010) argued that educational psychology is an academic domain that is both rational (developed from theoretical considerations) and empirical (theories are empirically tested) in its epistemic characterization. Accordingly, in the context of learning educational psychology material, individuals who espouse epistemic beliefs that are both rational and empirical may outperform individuals who espouse predominantly rational or predominantly empirical beliefs because of the congruency between those individuals' beliefs (rational *and* empirical) and the epistemic nature of the domain (rational *and* empirical).

Based on results from these studies, Muis (2008; Muis & Franco, 2010) proposed the "consistency hypothesis," which suggests that in the context of a learning situation, when the epistemic nature of the domain is consistent with an individual's epistemic beliefs, more metacognitive strategy use should result. Results from a more recent study (Muis, Kendeou, & Franco, 2011), however, challenge the consistency hypothesis and suggest an important revision to the original proposition. Specifically, Muis et al. (2011)

questioned whether the focus of the consistency is at the underlying epistemological level (as suggested in the original proposition) or at the representational level (i.e., regarding the epistemic nature of the learning materials with which students engage). To investigate this question, Muis and colleagues (2011) surveyed the epistemic beliefs of 83 university undergraduate students and classified them according to three dimensions of Royce's (1983) framework: 1) predominantly rational, 2) predominantly empirical, and 3) predominantly metaphorical. Participants then read a text about Newton's Laws of Motion, which included metaphors as examples of the various laws described. Participants were asked to think aloud while reading, and later completed a recall task when they were finished reading. Think-aloud sessions were transcribed and coded for evidence of metacognitive processing, and a rubric was used to score recall responses. Results revealed that students who espoused predominantly metaphorical beliefs engaged in more metacognitive processing compared to students who espoused predominantly rational or predominantly empirical beliefs. Moreover, path analyses revealed that metacognitive monitoring positively predicted recall performance.

As explained by Muis et al. (2011), these results suggest that a match between epistemic beliefs and knowledge representations may be the more important "consistency" in the consistency hypothesis than a match between epistemic beliefs and the underlying epistemology of the domain of focus. Why? Royce (1978) hypothesized that, similar to the individual, each discipline of knowledge involves all three epistemologies (i.e., rationalism, empiricism, and metaphorism), but the epistemologies for each are weighted differently. That is, each discipline can be characterized by a hierarchical structure of rationalism, empiricism, and metaphorism. For example, Royce

(1978) argued that physics can be characterized as a predominantly rational domain because the structural features of physics are composed of laws, proofs, and theorems (followed by empiricism, wherein the various laws, proofs, and theorems are empirically tested via observation)[9]. In light of this characterization, the original consistency hypothesis would predict that individuals who espouse predominantly rational epistemic beliefs would outperform individuals who espouse predominantly empirical or metaphorical beliefs with regard to metacognitive processing. However, in Muis et al.'s (2011) study, the material with which participants engaged – although drawn from the domain of physics – could more appropriately be characterized as predominantly metaphorical because the physics concepts were explained through the use of metaphors, not proofs and theorems. Interestingly, students who espoused predominantly metaphorical beliefs outperformed students who espoused predominantly rational beliefs, thus highlighting the importance of knowledge representations in evaluating the effects of individuals' epistemic beliefs during learning.

Muis et al.'s (2011) study is noteworthy for being one of few studies to take into account the role of knowledge representations in evaluating the effects of epistemic beliefs on learning. My study builds on this work and addresses several of its limitations. For example, Muis and colleagues (2011) included only one type of deep processing strategy in their analysis: metacognitive processing. In the current study, a wider range of students' cognitive processing strategies is taken into account, including several categories of deep processing strategies – e.g., elaboration, paraphrase, metacognitive comments – which align with definitions of deep processing found elsewhere in the

[9] For other perspectives on how physics (and other academic disciplines) can be characterized, please refer to Biglan (1973) and Becher and Trowler (2001).

literature (e.g., Dole & Sinatra, 1998; Pintrich, Smith, Garcia, & McKeachie, 1991; Stathopoulou & Vosniadou, 2007a). In addition to deep processing strategies, my study also looks at shallow processing, a variable which Muis et al. (2011) do not include in their study. Moreover, whereas Muis et al. (2011) only include one off-line product of learning (text recall), the current study examines not only text recall but also conceptual change. Thus, by including two online measures of learning as well as two off-line measures, the current study will yield a more in-depth picture of the interactive effects of epistemic beliefs and knowledge representations on learning than was possible in Muis et al.'s (2011) study.

Importantly, my study also advances Muis et al.'s (2011) work by including in its design two types of knowledge representations: metaphorical and rational. In Muis et al.'s (2011) research design, only metaphorical knowledge representations were examined. The inclusion of another knowledge representation allows not only for more complex analyses, but also more robust findings than were heretofore possible. In the next section, I describe the particularities of my study in more detail.

The Current Study

To respond to researchers' calls for a more contextualized and double-track (Bromme et al., 2010) approach to epistemic beliefs research, and to add to the paucity of literature examining the role of knowledge representations in particular, the current study examined the role of epistemic beliefs and knowledge representations in cognitive and metacognitive processing and conceptual change in the context of learning physics. I used Royce's (1983) multidimensional framework to characterize participants' epistemic beliefs, as well as the knowledge representations (i.e., physics texts) with which participants engaged. Specifically, undergraduate students were randomly assigned to one of four text-based conditions: 1) the presentation of Newton's First Law using "rational" knowledge representations, followed by Newton's Third Law using "metaphorical" knowledge representations; 2) the presentation of Newton's First Law using "metaphorical" knowledge representations, followed by Newton's Third Law using "rational" representations; 3) the presentation of Newton's Third Law (metaphorical), followed by Newton's First Law (rational); or 4) the presentation of Newton's Third Law (rational), followed by Newton's First Law (metaphorical). (The first and third conditions used identical texts, but differed in the order presented; similarly, the second and fourth condition used identical texts, but differed in the order of presentation).

Prior to reading each text, students in all conditions first completed the Force Concept Inventory (FCI; Halloun, Hake, Mosca, & Hestenes, 1995; Hestenes, Wells, & Swackhamer, 1992) to measure their prior knowledge and misconceptions about Newtonian physics, and then completed the Psycho-Epistemological Profile scale (Royce & Mos, 1980) to measure their epistemic beliefs and to identify them as primarily rational or metaphorical in their approaches to knowing. Students were then asked to think out loud as they were presented with the texts. After each text, students were given a filler task, followed by a recall task and a posttest assessment of relevant FCI questions.

Broadly speaking, this study asks: Do individuals' epistemic beliefs interact with knowledge representations to facilitate or constrain learning about physics concepts? Stated in more specific terms, my research explores the following four questions: (1) Are there group differences in students' use of deep processing strategies as a function of epistemic beliefs (metaphorical or rational) and/or type of knowledge representation (metaphorical or rational)? (2) Are there group differences in students' use of shallow processing strategies as a function of epistemic beliefs and/or type of knowledge representation? (3) Are there group differences in students' recall of text material as a function of epistemic beliefs and/or type of knowledge representation? (4) How is conceptual change facilitated or constrained by interactions between epistemic beliefs and knowledge representations?

Taking into account the literature reviewed above, I present two plausible sets of hypotheses (see Table 1 for an overview). First, in line with studies that have found main effects for "sophisticated" epistemic beliefs on various measures of learning, and in line with Muis' (2008) original consistency hypothesis (wherein the underlying epistemology of physics – characterized by Royce [1978] as a rational domain – supersedes the role of knowledge representations in interacting with individuals' epistemic beliefs to influence learning), I predict a main effect for epistemic beliefs across all research questions (i.e., the *main effect* position). That is, I predict that individuals espousing rational beliefs will: engage in deeper processing of the text (Hypothesis 1a), correctly recall more text material (Hypothesis 3a), and change more misconceptions (Hypothesis 4a) than individuals espousing metaphorical beliefs, regardless of text type (i.e., rational versus metaphorical knowledge representation). Regarding shallow processing strategies (Hypothesis 2a), based on the empirical studies reviewed above, the main effect position would predict that individuals espousing metaphorical beliefs will engage in more shallow processing of the text.

In contrast to the *main effect* position, taking into account contemporary perspectives that emphasize the context sensitivity of individuals' epistemic beliefs, as well as results from the few studies that have looked beyond students' beliefs to consider aspects of the learning context (e.g., Muis et al., 2011), one might expect that individuals' epistemic beliefs interact with knowledge representations in dynamic ways to facilitate or constrain learning (i.e., the *interaction effect* position). From this perspective, I predict that students will: engage in deeper processing (Hypothesis 1b), correctly recall more text material (Hypothesis 3b), and change more misconceptions (Hypothesis 4b) when there is congruency between their epistemic beliefs and knowledge representations (e.g., rational beliefs and rational knowledge representations, or metaphorical beliefs and metaphorical knowledge representations) than when there is inconsistency between students' beliefs and knowledge representations (e.g., rational beliefs and metaphorical knowledge representations, and vice versa). Regarding shallow processing, I predict that individuals will engage in more shallow processing of the text when their epistemic beliefs are incongruent with the knowledge representations (Hypothesis 2b).

Table 1. *Overview of Abbreviated Research Questions and Hypotheses*.

Research Question			Hypotheses: Main Effect Position		Hypotheses: Interaction Effect Position
1	Group differences in use of **deep processing** strategies?	1a	Participants espousing predominantly **rational** beliefs will engage in deeper processing of the text	1b	Participants whose beliefs are **congruent** with knowledge representations will engage in deeper processing of the text
2	Group differences in use of **shallow processing** strategies?	2a	Participants espousing predominantly **metaphorical** beliefs will engage in more shallow processing of the text	2b	Participants whose beliefs are **incongruent** with knowledge representations will engage in more shallow processing of the text
3	Group differences in **recall of text** material?	3a	Participants espousing predominantly **rational** beliefs will correctly recall more text material	3b	Participants whose beliefs are **congruent** with knowledge representations will correctly recall more text material
4	How is **conceptual change** facilitated or constrained?	4a	Participants espousing predominantly **rational** beliefs will change more misconceptions	4b	Participants whose beliefs are **congruent** with knowledge representations will change more misconceptions

My study aims to contribute to the epistemic beliefs literature in two important ways. First, by examining the interaction between epistemic beliefs and knowledge representations, I respond to researchers' calls for an approach to epistemic beliefs research that takes into account the situated and contextual nature of students' beliefs (e.g., Elby & Hammer, 2001; Hofer & Pintrich, 1997; Muis et al., 2006). Second, by including both online and offline measures of learning, I gather a rich set of data that adds to our understanding of both the direct and indirect effects of epistemic beliefs on learning. In addition to these contributions, my study also responds to researchers' calls for more studies that examine the complex relations between epistemic beliefs and conceptual change (Alexander & Sinatra, 2007; Murphy & Mason, 2006; Pintrich, 1999) and adds to the growing body of research that examines the interaction of learner (e.g., epistemic beliefs) and text (e.g., knowledge representation) characteristics on conceptual change. Moreover, as noted above, this study advances conceptual change research by focusing on a more fine-grained text characteristic – knowledge representations – than has commonly been examined in studies of epistemic beliefs, text structure, and conceptual change.

CHAPTER III

METHODOLOGY

Research Design

A mixed methods design was used to answer the research questions posed in the previous section. Mixed methods research combines techniques from quantitative and qualitative research paradigms and, according to some proponents, offers researchers "the best chance of answering their specific research questions" (Johnson & Onwuegbuzie, 2004, p. 15). Why was a mixed methods design selected for the current study? First, this design addresses the quantitative and qualitative underpinnings of the four research questions I investigated. The first three questions, which focused on group differences, necessitated a quantitative investigation in which different experimental conditions could be compared. The fourth question – How is conceptual change facilitated or constrained by interactions between epistemic beliefs and knowledge representations? – required a more in-depth examination of the conceptual change data. Specifically, I addressed this question by performing content analysis of participants' responses to the FCI. Finally, a mixed methods approach was chosen because it responds to calls from leaders in the field who have recommended that researchers use a diversity of methodologies when investigating individuals' beliefs about knowledge and knowing (e.g., Pintrich, 2002). Accordingly, this study incorporated multiple data sources.

Participants

Seventy-five McGill University undergraduate students[10] (N = 56 females)

[10] Eighty-two students originally completed the study, but only 7 were profiled as predominantly empirical. These students were removed from the analyses due to the small sample size.

volunteered to participate in the study by responding to an advertisement posted in the McGill Classifieds, a self-serve advertisement service provided by the Media Relations Office and affiliated with the official McGill website[11]. To avoid potential confounds that may have arisen as a result of language barriers, only students for whom English is a first language were eligible to participate in the study. Participants represented a variety of academic disciplines. Specifically, 24% were science, mathematics, or engineering majors, 36% were arts majors, 16% were social science majors, 10% were business majors, and the remaining 14% were undeclared. The mean age for this sample was 21.80 (SD = 4.03). Moreover, the mean Grade Point Average (GPA) for all secondary courses was 3.73 (SD = .34), and the mean GPA for all post-secondary courses to date was 3.32 (SD = .44).

Materials and Coding Protocols

Demographics Questionnaire. A demographics questionnaire was used to collect conventional demographic information such as age, gender, and undergraduate major (see Appendix C).

The Force Concept Inventory. The Force Concept Inventory[12] (FCI; Halloun et al., 1995) was used to assess students' prior knowledge of introductory physics. The FCI is a 30-item multiple choice inventory that can be used to identify and classify

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[11] Given that I am also a McGill student and have easier access to this population because of my own affiliation with the university, my sample was one of convenience.

[12] The FCI is used extensively as a learning tool by high school physics teachers and university faculty; because of this, the authors of the FCI wish to protect its integrity and deny permission to include a copy of the instrument in any doctoral dissertation or Master's degree thesis. Please refer to the following website for more information about the FCI, and to request a download password: http://modeling.asu.edu/R&E/Research.html

individuals' misconceptions regarding six dimensions of the Newtonian concept of force: (1) kinematics; (2) impetus; (3) active force; (4) action/reaction pairs; (5) concatenation of influences; and (6) other influences on motion. For each item, participants are required to choose between Newtonian concepts and common sense alternatives. Each correct response is given one point, and each incorrect response is given a zero, with a maximum score of 30 points. According to Hestenes et al. (1992), data from numerous studies suggest that a score of 60% or below (i.e., 18 or fewer correct responses) on the FCI indicates low prior knowledge of Newtonian concepts such that students' grasp of the concepts is "insufficient for effective problem solving" (p. 151). The FCI has been used as a tool for measuring students' misconceptions in a number of studies of physics-related conceptual change (e.g., Kendeou et al., 2010; Savinainen, Scott, & Viiri, 2005). For this sample, Cronbach's alpha was .83.

The Psycho-Epistemological Profile Scale. The Psycho-Epistemological Profile (PEP; Royce & Mos, 1980) was used to measure participants' epistemic beliefs. In accordance with Royce's (1983) multidimensional framework of psychological epistemology, the PEP is designed to measure individuals' beliefs about how knowledge is derived and justified along three dimensions: empiricism, rationalism, and metaphorism. The 90-item instrument includes 30 items per dimension. Responses are recorded on a five-point Likert scale ranging from "completely disagree" (a rating of 1) to "completely agree" (a rating of 5). A sample empiricism item is "Most great scientific discoveries come about by careful observation of the phenomena in question." A sample rationalism item is "Most people who read a lot, know a lot because they acquire an intellectual proficiency through sifting of ideas." A sample metaphorism item is "When people are arguing a question from two different points of view, I would say that each should endeavour to assess honestly his or her own attitude and bias before arguing further."

Following Muis (2008), rationalism, empiricism, and metaphorism scores were computed by summing all 30 items for a total subscale score for each dimension (the minimum score possible was 30 and the maximum score possible was 150). Then, to label an individual as predominantly rational, empirical, or metaphorical in their epistemic beliefs, their highest score across the three subscales on the PEP had to be at least two standard errors greater than the next highest score to ensure no overlapping categorization. All participants' highest score met this criterion.

Instructional Texts. Four short texts of comparable length (approx. 650 words) and conventional readability indices (average Flesch-Kincaid Reading Grade Level was 8.3) were used to engage participants in learning about Newtonian concepts. The texts were adapted from material used by Kendeou and van den Broek (2007), which was initially based on a college-level physics textbook (Hewitt, 2002). All four texts were written in a refutational argument format, which, according to Hynd (2001), is the "superior" argument structure for cases in which the aim of instruction is conceptual change. Moreover, there is some evidence to suggest that students prefer refutational over non-refutational text (Guzzetti, Hynd, Williams, & Skeels, 1995; Hynd, 2001).

Although the four texts were designed to be similar in the ways described above, they differed with regard to: 1) the topic of focus, and 2) the way in which Newtonian concepts were presented (i.e., knowledge representations). Specifically, two of the texts focused on Newton's First Law of Motion, and the other two texts focused on Newton's

Third Law of Motion. Moreover, for each topic (Newton's First and Third laws), the pertinent Newtonian concepts were presented either "rationally" (using brief theorems and mathematical formulas), or "metaphorically" (using examples that appeal to universal insight or awareness [Royce & Mos, 1980])[13]. For example, the following excerpt from the rational text on Newton's First Law of Motion uses a formula to elaborate Newton's definition of inertia: "Object's resistance to a change in its state of motion is what we call *inertia*. The properties of inertia can be represented by the equation $\sum \vec{F} = 0$ which states that when the vector sum of all forces acting on an object is zero, the object remains in its current state (in motion or in rest)." A comparable passage from the metaphorical text of Newton's First Law of Motion describes inertia using examples that appeal to universal awareness: "Object's resistance to a change in its state of motion is what we call *inertia*. Demonstrations of inertia are when we stamp our feet to remove snow from them, shake a garment to remove dust, or tighten the loose head of a hammer by slamming the hammer handle-side-down on a firm surface." Tables 2 and 3 provide additional excerpts from the instructional texts. Please see Appendices E, F, G, and H for the full version of each text.

[13] Although Royce's (1983) multidimensional framework includes three dimensions (rationalism, metaphorism, and empiricism), I chose to focus only on rational versus metaphorical texts in the current study because it was more feasible to do so. Creating a third text would have yielded a more complex design. I also felt more confident in my ability to approximate Royce's definitions of rationalism and metaphorism in the presentation of pertinent Newtonian concepts.

Table 2. *Excerpts from Newton's First Law Instructional Texts*.

Concept / Misconception	Rational Text	Metaphorical Text
Inertia	The properties of inertia can be represented by the equation $\sum \vec{F}=0$ which states that when the vector sum of all forces acting on an object is zero, the object remains in its current state (in motion or in rest).	Demonstrations of inertia are when we stamp our feet to remove snow from them, shake a garment to remove dust, or tighten the loose head of a hammer by slamming the hammer handle-side-down on a firm surface.
Objects do not have a natural tendency to come to a stop	Another difficult idea for students to understand is that, when no net force is acting on them, objects do not naturally come to a stop. Objects have a natural tendency to remain in their state, but they require an external net force to change this state. That is, an object will not stop, speed up, or change its direction unless there is an external net force pushing or pulling on it. ---> For example, suppose a force of 10N is applied on an object. Now suppose a second force of equal magnitude is applied to the object in the opposite direction: <--- -10N These two forces cancel each other and their vector sum is zero: ---> <--- $\sum \vec{F} = 10N + - 10N = 0$	Many students have difficulty understanding Newton's first law because it is in direct opposition to a very popular conception about motion. This incorrect conception is the idea that objects have the natural tendency to come to a stop unless a force keeps them moving. Imagine a situation where we slide a book across the table and we watch it slide to a rest. The book does not come to a rest position because we stopped pushing it. Rather, the book comes to a rest because of the presence of the force of friction. In a frictionless environment, the book would continue moving.

Table 3. *Excerpts from Newton's Third Law Instructional Texts.*

Concept / Misconception	Rational Text	Metaphorical Text
Law of action and reaction	The third law is as follows: "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first." The mathematical formula for Newton's third law is a vector relationship: $\vec{F}_{AB} = - \vec{F}_{BA}$ (F = force; AB = Object A on Object B; BA = Object B on Object A) One force is called the action force and the other is called the reaction force.	Consider, for example, the interaction between a hammer and a stake. The hammer exerts a force on a stake and drives it into the ground. But this force is only half the story, for there must be a force to halt the hammer in the process. What exerts this force? The stake! Newton reasoned that while the hammer exerts a force on the stake, the stake exerts a force on the hammer. Such observations led Newton to his third law-the law of action and reaction. The third law is stated as follows: "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first." One force is called the action force and the other is called the reaction force.
Relationship between force, mass, and acceleration	Some students have difficulty with the term interaction. They understand interaction to mean a struggle between opposing forces where the most "forceful" exerts greater force. For example, some students wonder: "If forces are always equal and opposite, then how do two objects of different size get different accelerations in the same interaction?" Newton reasoned that the same force acting on objects of different mass will	Some students have difficulty with the term interaction. They perceive interaction as a struggle between opposing forces where the most 'forceful' exerts greater force. Let us take for instance a rifle that is fired. There is an interaction between the

Table 3. *Excerpts from Newton's Third Law Instructional Texts*.

Concept / Misconception	Rational Text	Metaphorical Text
	produce different accelerations because force is a function of an object's mass and acceleration. $F_{net} = ma$ (F_{net} = net force; m = mass; a = acceleration) Expressed differently, acceleration is the ratio of force to mass: $F_{net} / m = a$ Two objects differing in size, or mass, can experience different accelerations in an interaction, even though the forces exerted on both objects are equal: Object A (larger mass): Object B (smaller mass): $F_{net} / {\large m} = a$ $F_{net} / m = {\large a}$	rifle and the bullet. A pair of forces acts on both the rifle and the bullet. The force exerted on the bullet is as great as the reaction force exerted on the rifle, hence the rifle kicks. Given that the forces are equal in magnitude, why doesn't the rifle recoil with the same speed as the bullet? Because the rifle has greater mass than the bullet, and acceleration is the ratio of force to mass, the rifle has less acceleration. The acceleration of the bullet is huge because the same force is divided by a small mass.

To ensure the texts were developed as intended, a physics expert (Dr. Richard Harris, a physics professor at McGill University) confirmed the accuracy and readability of each text version. Moreover, as an additional measure of treatment fidelity, at the end of the study participants were asked to review each of their assigned texts and answer the following question: "Which of the following statements best describes the text? a) The text focuses on universal insight or awareness to teach the concepts of Newton's First/Third Law, b) The text focuses on logic and mathematics to teach the concepts of Newton's First/Third Law, or c) The text focuses on observation and sensory experiences to teach the concepts of Newton's First/Third Law." This question was designed to elicit participants' perceptions of their assigned texts as metaphorical, rational, or empirical, respectively.

Cognitive and Metacognitive Processing Strategies. To answer research questions one and two, a think-aloud task was used to gather evidence of students' use of cognitive and metacognitive processing strategies during reading. Students' think alouds were recorded, transcribed and then coded for evidence of deep and shallow processing. In line with other scholars (e.g., Dole & Sinatra, 1998; Pintrich et al., 1991; Stathopoulou & Vosniadou, 2007a), deep processing strategies included those that involved learners' attempts to integrate new ideas with their prior knowledge, organize and summarize ideas, and metacognitively engage. These three types of deep processing strategies were labelled "elaboration," "paraphrase," and "metacognitive comments," respectively (see Table 4 for explicit definitions and examples of each type of strategy). For each transcript, every instance of elaboration, paraphrase, and metacognitive comments was allotted one point, and these scores were summed to yield a composite score for deep processing for each participant.

Table 4. *Descriptions and Examples of Deep Processing Strategies*.

Type of Strategy	Description	Example: Line from Text	Example: Participant Response
Deep processing			
Elaboration	Participants attempt to integrate new ideas with prior knowledge by providing explanations in response to ideas presented in the text.	If it is at rest, it continues to be in a state of rest.	So, right, obviously, if you leave an office chair on the floor, it's not gonna move on its own unless something compels it to move.
Paraphrase	Participants attempt to summarize ideas in the text by restating them in their own words.	Every material object continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.	Okay, so it's always continuous and the same, unless otherwise.
Metacognitive Comments	Participants demonstrate awareness of their own thinking by self-questioning, monitoring their understanding, or acknowledging cognitive conflict (i.e., their prior knowledge conflicts with ideas presented in the text).	For instance, obstacles to motion like chairs or walls do exert forces; they do not just get in the way.	*Self-questioning:* Does that mean that they exert forces back on the objects that hit them, or what exactly is meant by this?
		Thus, the idea that only animate, moving objects can exert forces is incorrect.	*Monitoring understanding:* Right, that makes sense.
		That is, when Object A is resting on Object B, the direction of the normal forces on Object A is perpendicular to the surface of Object B.	*Acknowledging cognitive conflict:* See, I would think that they'd be parallel and facing each other.

On the other hand, participants' statements were coded for evidence of shallow processing if they involved memorization of the new material, or the activation of prior knowledge without attempting to integrate it with new information. These two types of shallow processing strategies were labelled "repetition/rehearsal" and "association," respectively (see Table 5 for examples). For each transcript, every instance of repetition/rehearsal and association was allotted one point, and these scores were summed to yield a composite score for shallow processing for each participant.

Table 5. *Descriptions and Examples of Shallow Processing Strategies*.

Type of Strategy	Description	Example	
		Line from Text	Participant Response
Shallow processing			
Repetition/rehearsal	Participants respond to the current sentence in the text by repeating the exact contents of the sentence.	The pair of forces is equal in size and time.	Okay, so the pair of forces is equal in size and time.
Association	Participants activate their prior knowledge without attempting to integrate it with new information; they express a thought that "comes to mind" in response to information presented in the text.	Newton's First Law of Motion.	This reminds me of high school.

Transcripts were coded independently by two research assistants who did not have knowledge of participants' epistemic beliefs while coding. Raters were trained on the coding protocol using think-aloud transcripts from a previous study (see Muis, Kendeou, & Franco, 2011), which were similar to the data collected for this study. Throughout the training period (which consisted of 4-5 sessions), a "confusion matrix" (Bakeman & Gottman, 1997) was used to monitor areas of disagreement and to facilitate discussion about such disagreements. Cohen's kappa was calculated for each of the transcripts that were coded during training, and when acceptable kappa values were achieved for all categories of codes, raters proceeded to code transcripts from the current study. For these data, agreement between the two raters was calculated for each type of strategy (elaboration, paraphrase, metacognitive comments, repetition/rehearsal, and association; see Table 7) and found to be acceptable[14], ranging from $K = .53$ to $K = 1$. Disagreements were resolved through discussion.

Text Recall. To answer the third research question, recall of text material was measured by asking the participants to "please type everything you remember from the text you just read, as closely as you can remember." Responses were coded based on matches between participants' recalled statements and original statements from the text. More specifically, responses were divided into clauses and matched to the text according to a "gist criterion," (e.g., Kardash & Howell, 2000) meaning that recalled statements and

[14] As noted by Lombard and colleagues in their review of literature regarding the assessment and reporting of interrater reliability (Lombard, Snyder-Duch, & Bracken, 2002), it is difficult to identify established standards for acceptable levels of reliability. These authors suggest that, while coefficients of .80 or greater are considered acceptable in most circumstances, more liberal criteria are applied to reliability indices that are known to be more conservative, such as Cohen's kappa (Lombard et al., 2002). For example, in one widely cited source (Landis & Koch, 1977), a kappa value ranging from .41-.60 is considered to represent "moderate" levels of agreement.

original text statements were considered a match when the recalled statement communicated the same idea as the original statement. For example, an original statement from the text was: "The focus of this text is Newton's first law, sometimes referred to as the 'law of inertia.'" An example of a matched recall statement, based on the gist criterion, is: "This is about Newton's first law, which is also known as the law of inertia." Each match counted as 1 point and participants' matches were summed to provide an overall recall score for each individual. Only unique matches were included in the total; in other words, if a participant recalled the same statement more than one time in the course of her/his recall response, that statement was only scored once. For both of the texts focusing on Newton's First Law of Motion, the maximum number of uniquely recalled statements was 33 (i.e., the total number of statements in the text). For the two texts focusing on Newton's Third Law of Motion, the maximum number of uniquely recalled statements was 39. Recalls were coded independently by two research assistants and compared to establish acceptable inter-rater reliability. Reliability was acceptable (K = .84), and any disagreements were resolved through discussion.

Conceptual Change. To answer research question 4, students completed 10 of the original 30 items from the FCI, five for each of the laws (Cronbach's alpha = .75). These items were chosen specifically as they targeted students' misconceptions about Newton's First and Third Laws. Each correct response was given one point, and each incorrect response was given a zero.

Procedure

Participants were tested individually in a laboratory setting. After consenting to participate in the study, participants filled out the demographics questionnaire, the FCI, and the PEP. Next, participants were given one of the four instructional texts to read. To ensure that there were no order effects, the texts were counterbalanced so that participants were exposed to a rational and metaphorical version, and to Newton's First and Newton's Third Laws of Motion. For example, if a participant was first given the metaphorical version of Newton's First Law, then the second text would be the rational version of Newton's Third Law. Prior to reading the texts, participants were given specific instructions on how to read and think aloud (see Ericsson & Simon [1993]) and had an opportunity to practice with an unrelated text about tornados. The rehearsal text and instructional texts were each presented on a set of cue cards, one line at a time, and participants were asked to read each sentence out loud and say whatever comes to mind. They were also instructed to read each sentence carefully and make sure they understood what they were reading because they would be "asked some questions about the text later on." Moreover, participants were told that once they had moved on to a new cue card, they could not return to a previous sentence in the text.

After reading the first of two instructional texts, participants were given a mathematics worksheet to prevent rehearsal. Next, participants were presented with a blank Microsoft Word document and asked to type everything they remembered from the text (text recall). Following the recall task, participants were given a posttest version of the FCI that focused on a specific subset of questions (5 items) corresponding to the Newtonian Law (first or third) that was explained in the text they had just read. Participants were then given the second instructional text and all steps were repeated. Finally, participants were asked to review both of their assigned texts and respond to the "treatment fidelity" question described above. The entire session took approximately 1 hour and 30 minutes and participants were compensated for their time. As previously mentioned, think-alouds were audio-recorded, transcribed, and then blindly coded. Recalls were printed and blindly coded in accordance with the aforementioned coding scheme.

CHAPTER IV

RESULTS

Preliminary Analyses

First, to ensure the knowledge representations were developed as intended, I explored participants' ratings for each of the texts. For each of the four texts, the majority of participants perceived the knowledge representations in their intended format (i.e., rational or metaphorical). Specifically, for Newton's First Law in metaphorical form, 73% of the participants perceived it as aligning with the proposed definition of metaphorism; for the rational version of the first law, 84% of the participants perceived it as rational; for Newton's Third Law in metaphorical form, 68% perceived it as metaphorical; and for the rational version of the third law, 70% perceived it as rational. Accordingly, I felt confident that each text represented the content in the format it was designed to represent.

Data were then screened for normality. All variables were normally distributed with skewness and kurtosis values within acceptable ranges; skewness ranged from -1.53 to 1.59, and kurtosis ranged from -.63 to 3.35. Of the 75 students, 27 espoused predominantly rational beliefs and the other 48 espoused predominantly metaphorical beliefs. Means, standard deviations, and reliability coefficients are presented in Table 6 for the PEP subscales as a function of predominant epistemic belief.

Table 6. *Descriptive Statistics and Reliability Coefficients for PEP Subscales.*

	Predominantly Rational		Predominantly Metaphorical		
PEP Subscales	Mean	SD	Mean	SD	α
Empiricism [a]	99.48	17.38	98.40	12.21	.86
Metaphorism [a]	98.81	17.81	111.92	11.47	.89
Rationalism [a]	107.52	16.03	101.35	9.81	.83

Note: SD = standard deviation, [a] 30-150 range.

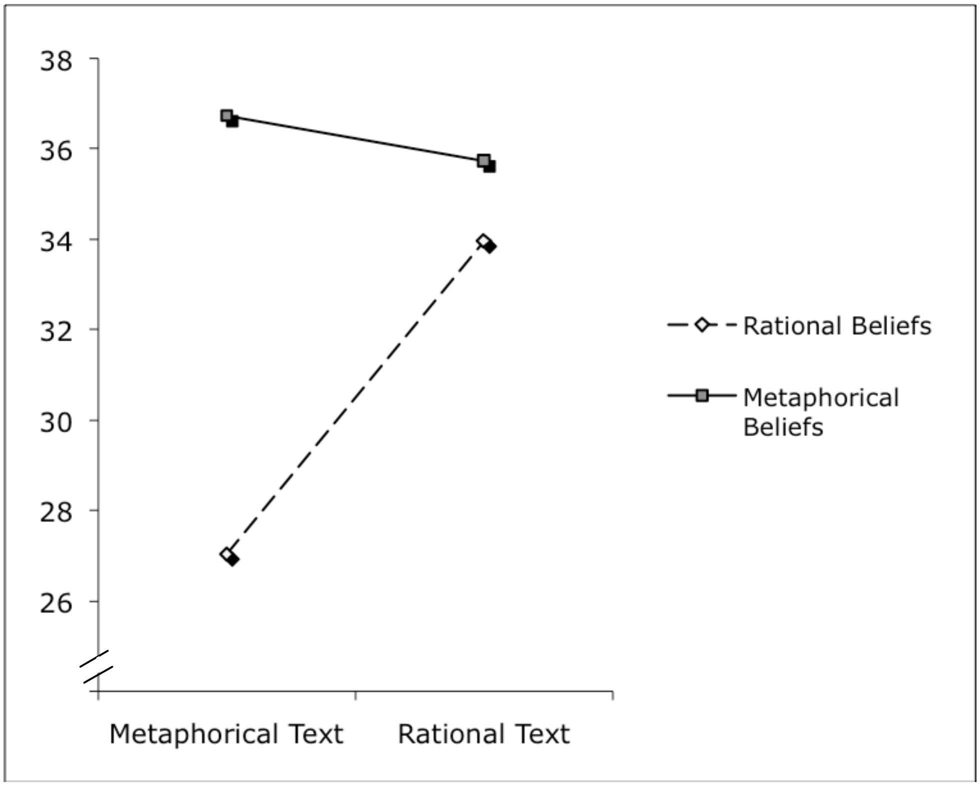
No order effects were found as a function of text order on cognitive processing strategies or recall of text material. Finally, no differences in prior knowledge of Newtonian physics were found between epistemic groups (all $p > .10$). Importantly, for prior knowledge of Newtonian physics, six participants scored marginally higher than the 60% threshold identified by Hestenes et al. (1992). However, because these participants demonstrated misconceptions on the FCI items related to Newton's First and Third Laws (i.e., no-one scored 100% on these items), all participants were retained in the sample for subsequent analyses.

Cognitive Processing Strategies

Deep Processing. To examine whether there were group differences in students' use of deep processing strategies as a function of epistemic beliefs and/or type of knowledge representation (research question 1), a 2 (epistemic beliefs type) by 2 (text type) repeated measures analysis of variance (ANOVA) was conducted. Raw frequencies (i.e., number of utterances), means and standard deviations are presented in Table 7 for use of deep processing strategies as a function of epistemic beliefs and text type. Results revealed a main effect of text type, $F(1, 73) = 8.43$, $p = .01$, $\eta^2 = .10$, a significant interaction between text type and epistemic beliefs, $F(1, 73) = 15.08$, $p < .001$, $\eta^2 = .17$, but no main effect of epistemic beliefs, $F(1, 73) = 2.75$, $p =.10$. In general, students engaged in deeper processing of the rational text compared to the metaphorical text. Moreover, students who espoused predominantly metaphorical beliefs engaged in deeper processing of the metaphorical text than individuals who espoused predominantly rational beliefs ($p = .008$, $d = 2.73$). For the rational text, this finding was not statistically detectable.

Finally, paired-samples t-tests revealed that when the knowledge representation format of the text (i.e., rational versus metaphorical) was consistent (congruent) with individuals' epistemic beliefs, individuals used more deep processing strategies compared to when the format was inconsistent (incongruent, see Figure 1). Specifically, for the rational group, statistically significant differences in deep processing were found between text type, $t(26) = -4.37$, $p < .001$, $d = .84$. Students who espoused predominantly rational beliefs engaged in deeper processing of information when the text was rational compared to the metaphorical text. In contrast, for individuals who espoused predominantly metaphorical beliefs, no statistically detectable differences were found in levels of deep processing between the two types of texts, $t(47) = .804$, $p = .43$, though the trend was consistent with the expected direction.

Figure 1. *Use of Deep Processing Strategies as a Function of Epistemic Beliefs and Text Type.*



Shallow Processing. To examine whether there were group differences in students' use of shallow processing strategies as a function of epistemic beliefs and/or type of knowledge representation (research question 2), a 2 (epistemic beliefs type) by 2 (text type) repeated measures analysis of variance (ANOVA) was conducted. Means and standard deviations are presented in Table 7 for use of shallow processing strategies as a function of epistemic beliefs and text type. Results were not statistically detectable for text type, epistemic beliefs, or the interaction between the two (all $p > .05$).

Table 7. *Raw Frequencies, Means, and Standard Deviations for Use of Cognitive Processing Strategies as a Function of Epistemic Beliefs and Text Type*.

		Predominantly Rational Beliefs		Predominantly Metaphorical Beliefs	
		Congruent / Rat. Text (N = 13)	Incongruent / Met. Text (N = 14)	Congruent / Met. Text (N = 24)	Incongruent / Rat. Text (N = 24)
Processing Strategies	*K*	*Frequency* Mean (SD)	*Frequency* Mean (SD)	*Frequency* Mean (SD)	*Frequency* Mean (SD)
Deep processing		*917* 33.96 (15.18)	*730* 27.04 (13.65)	*1763* 36.73 (15.33)	*1715* 35.73 (15.20)
Elaboration	.84	*303* 11.22 (8.02)	*271* 10.04 (7.50)	*642* 13.37 (9.97)	*654* 13.62 (10.37)
Paraphrase	.67	*77* 2.85 (3.43)	*81* 3.00 (3.21)	*137* 2.85 (3.11)	*190* 3.96 (3.54)
Metacognitive Comments	.85	*537* 19.89 (11.62)	*378* 14.00 (8.83)	*984* 20.50 (9.24)	*871* 18.15 (9.11)

Table 7. *Raw Frequencies, Means, and Standard Deviations for Use of Cognitive Processing Strategies as a Function of Epistemic Beliefs and Text Type*.

		Predominantly Rational Beliefs		Predominantly Metaphorical Beliefs	
		Congruent / Rat. Text (N = 13)	Incongruent / Met. Text (N = 14)	Congruent / Met. Text (N = 24)	Incongruent / Rat. Text (N = 24)
Processing Strategies	*K*	*Frequency* Mean (SD)	*Frequency* Mean (SD)	*Frequency* Mean (SD)	*Frequency* Mean (SD)
Shallow processing		*107* 3.96 (3.58)	*115* 4.26 (4.43)	*186* 3.88 (3.49)	*170* 3.54 (3.74)
Repetition/rehearsal	1	*31* 1.15 (2.35)	*25* 0.93 (1.73)	*40* 0.83 (1.64)	*37* 0.77 (1.78)
Association	.53	*76* 2.81 (2.63)	*90* 3.33 (3.67)	*146* 3.04 (3.16)	*133* 2.77 (3.45)

Note: SD = standard deviation. SD is presented in parentheses. N = number of participants. Rat. = Rational; Met. = Metaphorical. *K* = Cohen's kappa (inter-rater agreement).

Text Recall

My third research question focused on whether text type interacted with epistemic beliefs to influence the extent to which students recalled information from each text. A repeated measures ANOVA revealed no main effect of text type, $F(1, 73) = 1.14$, $p = .29$, no main effect of epistemic beliefs, $F(1, 73) = .003$ $p = .96$, but a significant text type by epistemic beliefs interaction, $F(1, 73) = 3.70$, $p = .05$, $\eta^2 = .05$. Means and standard deviations are presented in Table 8 for recall of text material across text type as a function of epistemic beliefs.

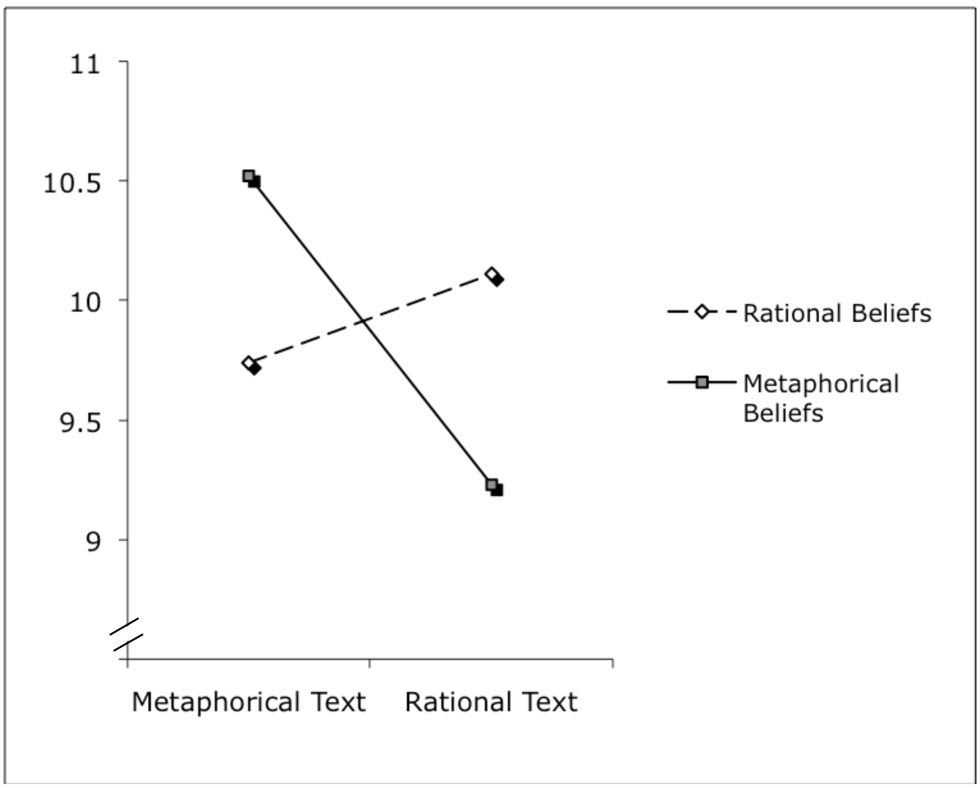
Table 8. *Means and Standard Deviations for Recall of Text Material Across Text Type as a Function of Epistemic Beliefs.*

	Text Recall		
	Metaphorical Text	Rational Text	
Epistemic Beliefs	Mean (SD)	Mean (SD)	N
Predominantly Rational	9.74 (4.01)	10.11 (5.27)	27
Predominantly Metaphorical	10.52 (4.55)	9.23 (3.90)	48
Groups Combined	10.24 (4.35)	9.55 (4.42)	75

Note: SD = standard deviation. SD is presented in parentheses. N = number of participants.

Specifically, as shown in Figure 2, students recalled more textual information when the text type was consistent with their epistemic beliefs compared to when it was inconsistent. Moreover, this interaction was a result of differences found between recall on the rational versus the metaphorical text for the metaphorical epistemic group. That is, students who espoused predominantly metaphorical beliefs recalled significantly more textual information with the metaphorical text than the rational text, $t(47) = 2.49$, $p = .01$, $d = .53$. The same pattern was found for the rational group, but the difference was not statistically detectable ($p > .05$).

Figure 2. *Recall of Text Material as a Function of Epistemic Beliefs and Text Type.*



Conceptual Change

Conceptual change is defined in this study as the changing of inaccurate prior knowledge, or misconceptions, to correct or scientifically-accepted knowledge (Chi, 2008). In light of this definition, it seemed most appropriate to use content analysis and descriptive statistics to identify patterns of conceptual change in the FCI data and bring to light meaningful information about which misconceptions were successfully overcome or not. Specifically, I conducted two levels of content analysis of participants' responses to relevant FCI items: 1) a participant-level analysis, in which I examined, for each of the 75 participants, changes in their misconceptions from pretest to posttest; and, 2) an item-level analysis, in which I explored the instances of conceptual change that occurred for each of the ten FCI items that were used to measure individuals' conceptions of Newtonian mechanics (five each for Newton's First Law and Newton's Third Law). Taken together, results from these two analyses corroborate each other and provide a detailed account of the changes in misconceptions that occurred in this study. I discuss both of these analyses next.

Participant-level analysis. To analyze changes in misconceptions at the participant level, I first inspected raw scores from the three administrations of the FCI (i..e, the initial pretest, and the two abbreviated posttests). Specifically, for each participant, I examined his or her responses to the ten items that comprised the two FCI posttests (five items per posttest), and to the corresponding ten items from the full version of the FCI (which was used as a pretest). From these data, I was able to identify unique instances of conceptual change for each participant, indicated by an incorrect response on a pretest FCI item, followed by a correct response on the paired posttest FCI item. Next, I summed each participant's instances of conceptual change and created two categories of scores: 1) *total instances of conceptual change – congruent condition* (i.e., instances of conceptual change that occurred after a participant who espoused predominantly rational epistemic beliefs read a text with rational knowledge representations, or after a participant who espoused predominantly metaphorical epistemic beliefs read a text with metaphorical knowledge representations); and, 2) *total instances of conceptual change –*

incongruent condition (i.e., instances of conceptual change that occurred after a participant who espoused predominantly rational epistemic beliefs read a text with metaphorical knowledge representations, or after a participant who espoused predominantly metaphorical epistemic beliefs read a text with rational knowledge representations). To conserve space, an excerpt of these results (for the first ten participants) is presented in Table 9. The full table, with results for all 75 participants, is available in the Appendix (see Appendix M).

Table 9. *Total Instances of Conceptual Change for Participants 1-10, Presented as a Function of Congruent or Incongruent Text Conditions.*

Participant #	Congruent	Incongruent	Total
1	0	0	0
2	1	0	1
3	0	0	0
4	1	0	1
5	4	1	5
6	0	0	0
7	0	0	0
8	3	0	3
9	0	0	0
10	4	1	5

Several findings emerged from this approach to data reduction. First, it was evident that conceptual change did indeed occur in this study, although the rate of its occurrence was modest. Specifically, out of 492 *possible* instances of changes in misconceptions (i.e., within the entire sample of participants, the total number of incorrect responses to pretest FCI questions that had the potential to be correctly resolved on a matched posttest item), there were 197 (40%) *actual* instances of conceptual change (i.e., responses that were successfully changed from incorrect [pretest] to correct [posttest] on matched FCI items). Moreover, overall, 81% of participants (N = 61) experienced at least one or more instances of conceptual change, and 17% of participants (N = 13) experienced five or more instances of conceptual change.

When results were analyzed according to congruent versus incongruent conditions, findings revealed that rates of conceptual change were higher in the congruent condition. For example, out of 247 possible instances of conceptual change in the congruent condition, there were 111 (45%) actual instances. In contrast, out of 245 possible instances of conceptual change in the incongruent condition, there were 86 (35%) actual instances. Furthermore, a greater number of participants experienced conceptual change after reading instructional text in which the knowledge representations were congruent with their epistemic beliefs than when conditions were incongruent. That is, 64% of the sample (N = 48) experienced one or more instances of conceptual change in the congruent condition, but only 52% of the sample (N = 39) experienced one or more instances of conceptual change in the incongruent condition. Finally, individual participants who experienced high levels of conceptual change did so more often in a congruent condition than in an incongruent condition. Specifically, 16% of participants (N = 12) had four or more (out of a possible five) instances of conceptual change in the congruent condition, which is twice the number of participants (N = 6, or 8%) who experienced four or more instances of conceptual change in the incongruent condition. These results are displayed in Figure 3.

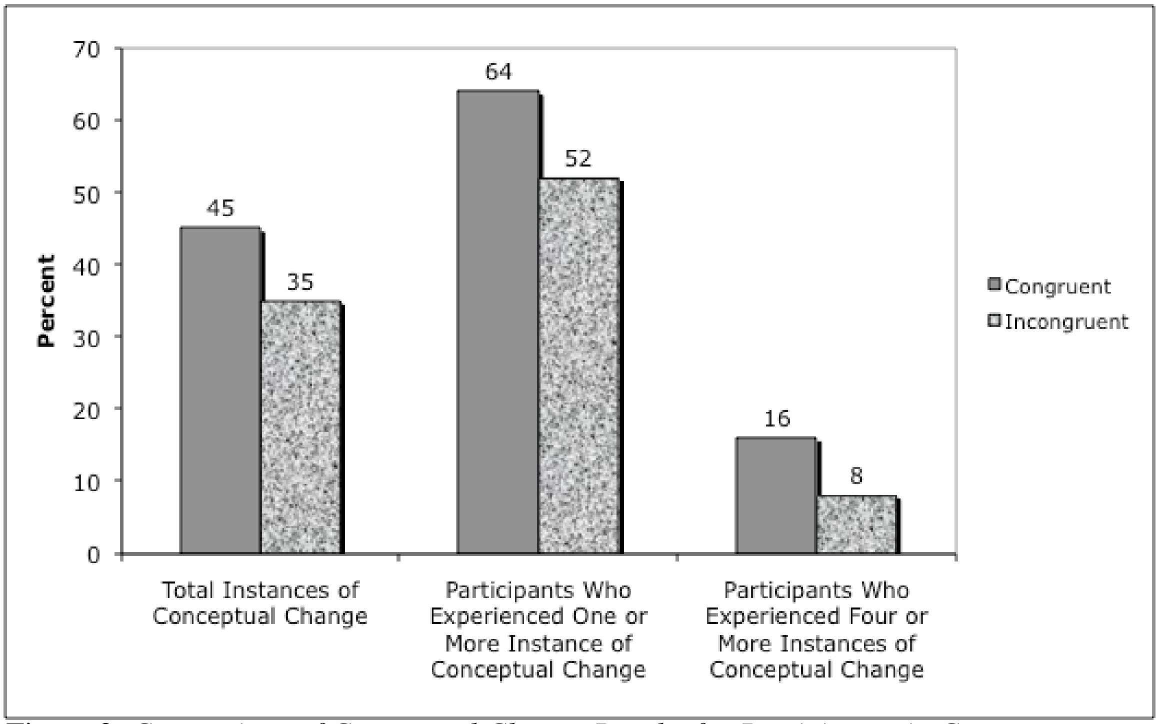


Figure 3. *Comparison of Conceptual Change Results for Participants in Congruent versus Incongruent Conditions.*

Item-level analysis. To further explore changes in misconceptions, for each of the items for each law, I calculated the number and percentage of participants who correctly changed their misconception on that item from pretest to posttest. In Tables 10 (first law) and 11 (third law), I present these numbers as a function of congruency or incongruency between participants' epistemic beliefs and text type. In general, comparing across the two laws, a greater number of participants changed their misconceptions on Newton's Third Law items compared to Newton's First Law items (155 total instances of change for Third Law items versus 42 instances of change for First Law items). In other words, students' misconceptions related to Newton's First Law were more resilient to change than their misconceptions related to Newton's Third Law. However, for both laws, the patterns of change were similar in that they favored the congruency condition. That is, a greater percentage of participants changed their misconceptions when the format of the text was congruent with their epistemic beliefs than when the format was incongruent. For Newton's First Law (Table 10), this pattern was observed for four out of the five FCI items (all except item 6). Although the numbers were small overall, for some items, the difference between the two groups was noteworthy. For example, for item 23 (which targets misconceptions regarding impetus and concatentation of influences), 22% of participants (N = 8) correctly changed their misconceptions from pretest to posttest when the format of the text was congruent with their beliefs, compared to 3% of participants (N = 1) when the format of the text was incongruent with their beliefs.

Table 10. *Frequency and Percentage of Participants Who Successfully Changed Their Misconceptions Across Relevant FCI Pretest and Posttest Items for Newton's First Law, as a Function of Congruency or Incongruency Between Epistemic Beliefs and Text Type*.

FCI Item	Concept(s) Assessed by Item	Congruent (N = 37)	Incongruent (N = 38)
1st Law			
6	Impetus; concatenation of influences; other influences on motion	3 (8%)	6 (16%)
7	Impetus; concatenation of influences; other influences on motion	5 (14%)	5 (13%)
8	Impetus; concatenation of influences	2 (5%)	1 (3%)
17	Active force; gravity	7 (19%)	4 (11%)
23	Impetus; concatenation of influences	8 (22%)	1 (3%)
Total		25 (14%)	17 (9%)

Note: N = number of participants. Congruent when rational text with rational epistemic beliefs, or metaphorical text with metaphorical epistemic beliefs. Incongruent when rational text with metaphorical epistemic beliefs, or metaphorical text with rational epistemic beliefs.

For Newton's Third Law items (Table 11), consistent with the patterns observed for Newton's First Law, the results favored the congruency condition for four out of the five FCI items (all except item 21[15]). Moreover, for three of the items (4, 15, 28), more than

[15] Interestingly, this item is actually more relevant to Newton's 2nd Law than Newton's 3rd Law, but I included it in the third law subset to ensure equivalent numbers of posttest

half of participants in the congruency condition changed their misconceptions from pretest to posttest, whereas this was the case for only one item (4) in the incongruent condition. The largest difference between the two conditions can be observed for item 15 (which targets misconceptions regarding active force, action/reaction pairs, and other influences on motion); for this item, 58% of participants (N = 22) correctly changed their misconceptions when the format of the text was congruent with their beliefs, compared to 38% (N = 14) when the format was incongruent.

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items for the two laws, and because the third law texts briefly discuss the relationship between force, mass, and acceleration (which is the focus of Newton's 2nd Law).

Table 11. *Frequency and Percentage of Participants Who Successfully Changed Their Misconceptions Across Relevant FCI Pretest and Posttest Items for Newton's Third Law, as a Function of Congruency or Incongruency Between Epistemic Beliefs and Text Type*.

FCI Item	Concept(s) Assessed by Item	Congruent (N = 38)	Incongruent (N = 37)
3rd Law			
4	Action/reaction pairs: other influences on motion	24 (63%)	21 (57%)
15	Active force; action/reaction pairs; other influences on motion	22 (58%)	14 (38%)
16	Active force; action/reaction pairs; other influences on motion	18 (47%)	12 (32%)
21	Impetus; concatenation of influences	2 (5%)	4 (11%)
28	Active force; action/reaction pairs;	20 (53%)	18 (49%)
Total		86 (45%)	69 (37%)

Note: N = number of participants. Congruent when rational text with rational epistemic beliefs, or metaphorical text with metaphorical epistemic beliefs. Incongruent when rational text with metaphorical epistemic beliefs, or metaphorical text with rational epistemic beliefs.

Taken together, for eight of the ten FCI items related to Newton's First and Third Laws, a greater percentage of participants changed their misconceptions when the format of the text was congruent with their beliefs than when the format was incongruent. For Newton's First Law, the total instances of changes in misconceptions from pretest to posttest were 25 (14%) for the congruent condition, and 17 (9%) for the incongruent condition. Moreover, for Newton's Third Law, the total instances of changes in misconceptions from pretest to posttest were 86 (45%) for the congruent condition, compared to 69 (37%) for the incongruent condition. Figures 4 and 5 present the percent of participants who successfully changed their misconceptions on Newton's First and Third Law items, respectively.

Figure 4. *Percent of Participants Who Successfully Changed Their Misconceptions on Newton's First Law Items.*

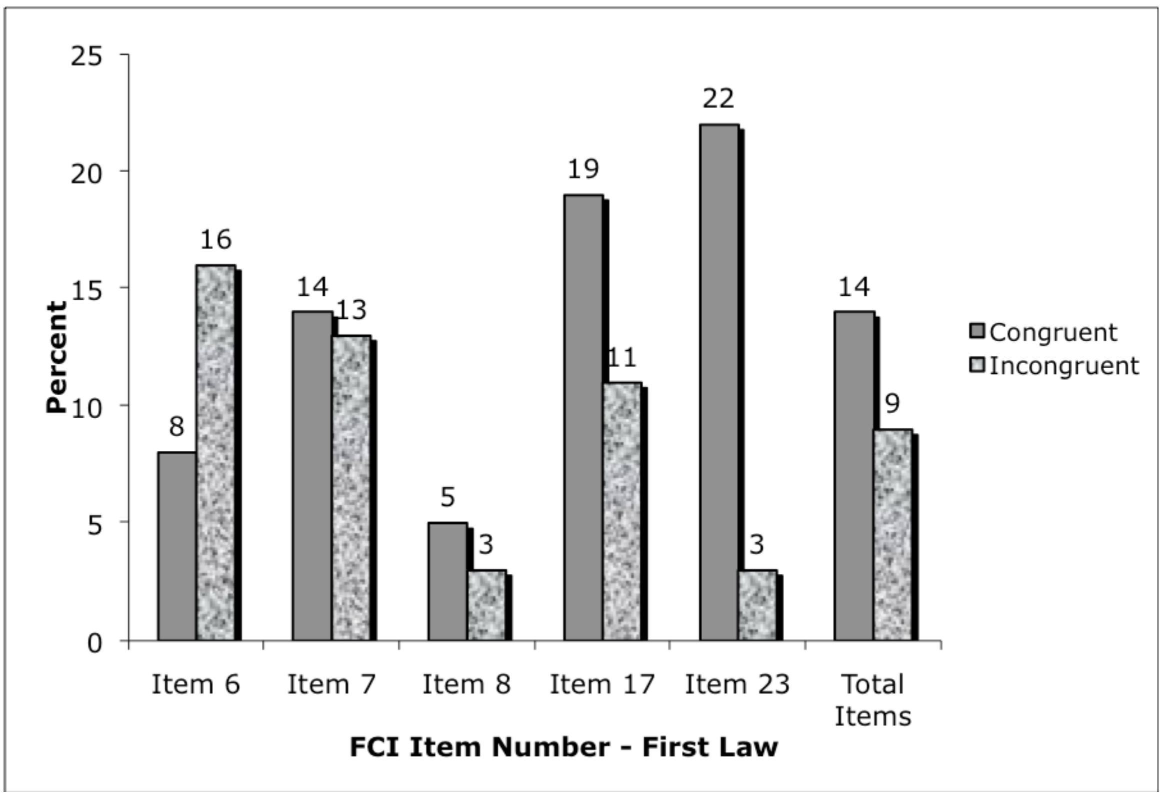
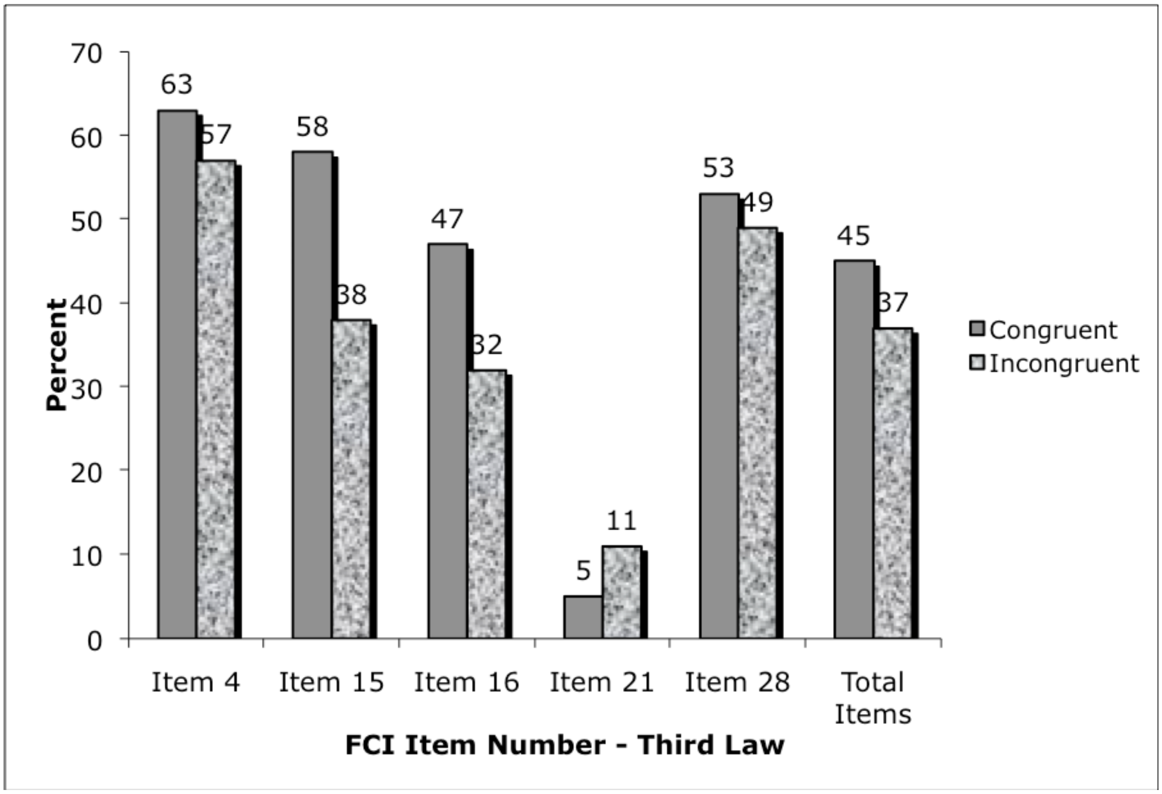


Figure 5. *Percent of Participants Who Successfully Changed Their Misconceptions on Newton's Third Law Items*.



In sum, across the participant-level and the item-level analyses of FCI data, patterns consistently showed that conceptual change was more likely to occur in conditions where individuals' epistemic beliefs were congruent with the knowledge representations in their assigned instructional text. I discuss these results, as well as the results from all of my research questions, in the next section.

CHAPTER V

DISCUSSION

The purpose of this study was to investigate the role of epistemic beliefs and knowledge representations in cognitive and metacognitive processing and conceptual change in the context of learning physics. I used Royce's (1983) multidimensional framework to characterize participants' epistemic beliefs as rational or metaphorical, and then manipulated the knowledge representations (i.e., physics texts) with which participants engaged such that representations and individuals' epistemic beliefs were either congruent (e.g., rational knowledge representations and rational epistemic beliefs) or incongruent (e.g., rational knowledge representations and metaphorical epistemic beliefs). In response to researchers' calls to combine quantitative approaches with dynamic process-oriented designs (e.g., Pintrich, 2002), I included several measures of learning: cognitive processing strategies (deep and shallow), text recall, and changes in misconceptions. Broadly stated, my research question asked: Do individuals' epistemic beliefs interact with knowledge representations to facilitate or constrain learning about physics concepts? Results from this study suggest that the answer to this question is *yes*. That is, across all three measures of learning, results supported the *interaction effect* position in that participants: engaged in deeper processing of their assigned texts (Hypothesis 1b), correctly recalled more text material (Hypothesis 3b), and changed more misconceptions (Hypothesis 4b) when their epistemic beliefs were congruent with the knowledge representations in their physics texts than when there was incongruency between their beliefs and knowledge representations. I discuss the implications of these findings below, focusing in particular on their relevance to both the epistemic beliefs and conceptual change literatures.

Implications for Epistemic Beliefs Research

Conceptualization of Epistemic Beliefs. A number of studies have documented relations between students' epistemic beliefs and various facets of their learning, such as their use of learning strategies (e.g., Schommer, 1990), self-regulation during problem solving (e.g., Muis, 2008), motivation (e.g., Muis & Franco, 2009a), and academic performance (e.g., Schommer et al., 1992), to name a few. Results from these studies typically demonstrate that a more sophisticated or constructivist view of knowledge (e.g., knowledge is complex and tentative) is associated with more positive learning outcomes than a more naïve, or less constructivist, view (e.g., knowledge is simple and certain). Recently, however, researchers have started to question the utility of categorizing individuals' epistemic beliefs as sophisticated/naïve and conducting investigations in light of this dichotomy. Accordingly, scholars have called for an approach to epistemic beliefs research that goes beyond students' beliefs and takes into account aspects of the context that may interact with epistemic beliefs to facilitate or constrain learning. My study adds to the paucity of research that has begun to examine the situated and contextual nature of students' epistemic beliefs, and provides evidence to support recent thinking that we need to go beyond a sophisticated versus naïve dichotomy when characterizing students' beliefs. Specifically, results from this study show that there is not one type of epistemic belief that is superior to another with regard to facilitating the particular learning outcomes measured (cognitive processing, text recall, and conceptual change); rather, it is the relationship between an individual's epistemic beliefs and the learning content with which s/he engages that appears to be a more significant factor. For this study, when participants' epistemic beliefs were congruent with the knowledge representations of the to-be-learned physics material, individuals performed better on three different measures of learning than when their beliefs were incongruent with the knowledge representations. These findings support Bromme and colleagues' (Bromme et al., 2010) call for a double-track approach to future research on epistemic beliefs. Accordingly, in line with Bromme et al. (2010), I argue that epistemic beliefs researchers should consider the epistemic nature of learning tasks – as well as other aspects of the epistemic climate (Haerle & Bendixen, 2008; Muis et al., 2006) – when exploring relations with individuals' epistemic beliefs.

In addition to challenging the view that some epistemic beliefs are more or less sophisticated or superior than others, findings from my study also challenge and extend Muis' (2008) consistency hypothesis. I discuss this issue next.

The Consistency Hypothesis. Muis' (2008) consistency hypothesis purports that in the context of a learning situation, more regulation of cognition should result when an individual's epistemic beliefs are consistent with the underlying epistemology of the academic domain of focus. Results from my study challenge and extend this hypothesis by suggesting that the ways in which knowledge is represented in the domain may be a more influential factor on cognitive and metacognitive processing than the epistemic nature of the domain itself. For example, taking Royce's (1978) view that physics is a rational domain, the consistency hypothesis (Muis, 2008) would predict that individuals who espouse predominantly rational beliefs should engage in more metacognitive processing of information, regardless of the text type (metaphorical or rational) compared to students who espouse predominantly metaphorical beliefs, and that those individuals should have higher levels of achievement (i.e., a main effect for epistemic beliefs). However, findings from this study revealed several interaction effects between epistemic beliefs and text type. For example, individuals who espoused predominantly metaphorical beliefs engaged in deeper processing of the metaphorical text compared to individuals who espoused predominantly rational beliefs. Moreover, on two measures of learning outcomes (text recall and changes in misconceptions), individuals performed better when their epistemic beliefs were consistent with the text type. In line with Muis et al. (2011), I interpret these findings to suggest that a match between epistemic beliefs and knowledge representations may be the more important relation in the consistency hypothesis than a match between epistemic beliefs and the underlying epistemology of the domain of focus.

Also in accordance with previous work by Muis (i.e., Muis, 2007), findings from my study provide some support for hypothesized relations between epistemic beliefs and self-regulated learning. In the next section, I briefly discuss Muis' (2007) model and describe how results from the current study can be interpreted within the context of a self-regulated learning framework.

Self-Regulated Learning. Several theorists have argued that students' beliefs influence the types of information they monitor and evaluate during learning (e.g., Hofer, 2004; King & Kitchener, 2004; Kuhn, 2000; Muis, 2007). Results from my study are consistent with these arguments and, in particular, provide empirical support for Muis' (2007) integrated model of self-regulated learning and epistemic beliefs. Although there are several models of self-regulated learning that advance various constructs and mechanisms (for reviews, see Puustinen & Pulkkinen, 2001; Zimmerman & Schunk, 2001), most of these models share some fundamental beliefs: the belief that self-regulated learners are actively engaged in the learning process; that these learners are capable of controlling aspects of their thoughts, feelings, and behaviors; that self-regulated learners set goals and monitor their progress toward these goals; and that they enact self-regulatory activities to help them achieve their learning goals (Boekaerts & Corno, 2005; Cleary & Zimmerman, 2004; Pintrich, 2000; Zimmerman, 1990).

To help establish why individuals' beliefs about knowledge and knowing influence various cognitive and metacognitive processes during learning, Muis (2007) proposed an extension of previous models of self-regulated learning by incorporating beliefs about knowledge and knowing within the self-regulated learning framework. Similar to most models of self-regulated learning, but particularly Winne and Hadwin's (1998) and Pintrich's (2000), Muis identified four phases of self-regulated learning and four areas for regulation. The four phases include 1) task definition, 2) planning and goal setting, 3) enactment, and, 4) evaluation. The four areas for regulation include a) cognition (e.g., knowledge activation, knowledge of strategies), b) motivation and affect (e.g., achievement goals, achievement attributions, self-efficacy), c) behavior (e.g., time, effort), and d) context (resources, social context). Of particular relevance to this study, Muis hypothesized that during Phase 2 of self-regulated learning, individuals' epistemic beliefs translate into epistemological standards, which may subsequently inform individuals' metacognitive processes during learning. These influences, in turn, may further influence learning outcomes. Interestingly, in the current study, differences were found in cognitive and metacognitive processes, as well as learning outcomes (measured by recall of text material and by change in misconceptions), as a function of interactions between individuals' epistemic beliefs and the nature of the task (i.e., text type). These results are consistent with Muis' (2007) hypothesized relations.

In sum, results from the current study have implications for three theoretical issues in the epistemic beliefs literature: researchers' conceptualizations of epistemic beliefs, Muis' (2008) consistency hypothesis, and relations between epistemic beliefs and self-regulated learning. In addition to making a contribution to the epistemic beliefs literature, a second aim of my study was to add to research on conceptual change. In the next section, I discuss the implications of this study for two specific areas of conceptual change research: text characteristics, and the CRKM.

Implications for Conceptual Change Research

Text Characteristics. As mentioned previously, in the majority of studies that have examined the interactive effects of epistemic beliefs and text characteristics on conceptual change, researchers have typically focused on one aspect of texts: argument structure. In this context, these texts are often characterized as refutational versus "traditional" (or expository), and researchers have explored how these formats interact with individuals' epistemic beliefs to facilitate or constrain knowledge restructuring (e.g., Kendeou et al., 2010; Mason & Gava, 2007; Mason et al., 2008). This study extends previous work by focusing on a more fine-grained text characteristic than has heretofore been investigated. Specifically, I go beyond the refutational versus expository text comparison by manipulating the knowledge representations in refutational texts and exploring the interaction of these representations with individuals' epistemic beliefs to promote conceptual change. Results from my study provide preliminary evidence that conceptual change may be influenced by these finer-grained characteristics of texts.

Although conceptual change was examined only immediately following the experimental manipulation, results revealed that a greater percentage of individuals changed their misconceptions from pretest to posttest when their epistemic beliefs were congruent with the knowledge representations in their assigned text than when their beliefs were incongruent. This pattern was observed for FCI items related to both Newton's First Law and Newton's Third Law, although individuals were more successful overall in changing their misconceptions related to Newton's Third Law.

Support for the CRKM. Of particular interest for conceptual change theory, results from this study provide tentative support for Dole and Sinatra's (1998) Cognitive Reconstruction of Knowledge Model (CRKM). As noted earlier, the CRKM suggests that the most important element of the change process is "the continuum of engagement." The continuum of engagement refers to the levels of information processing, strategy use, and metacognitive processes that individuals employ when attending to new information and can range from low cognitive engagement (involving shallow processing strategies) to high metacognitive engagement (involving deep processing strategies). Although high levels of engagement do not guarantee that conceptual change will occur, they do increase the likelihood of its occurrence (Dole & Sinatra, 1998). Ultimately, however, the outcome of engagement – i.e., whether it results in conceptual change or not – is influenced by a combination of learner and message characteristics that interact in dynamic ways. Although my study did not directly test the CRKM, results showed that individuals' epistemic beliefs (a learner characteristic) interacted with knowledge representations (a message characteristic) to facilitate deeper processing of physics texts. That is, when individuals' beliefs were congruent with the knowledge representations in their assigned texts, they engaged in deeper processing strategies. Similarly, when beliefs and knowledge representations were congruent, a greater percentage of individuals changed their misconceptions from pretest to posttest. Both of these findings are in line with ideas proposed by the CRKM (Dole & Sinatra, 1998).

Additional Findings and Implications

As discussed above, the main findings from this study – i.e., that participants engaged in deeper processing of their assigned texts, correctly recalled more text material, and changed more misconceptions when their epistemic beliefs were congruent with the knowledge representations in their physics texts – lend support to my research hypotheses and can be linked to recent theoretical and empirical work in both the epistemic beliefs and conceptual change literatures. However, it should be noted that this study also produced some results that are not as "neatly" accounted for by my predictions and are more difficult to interpret. Here, I identify these (three) findings and discuss some possible explanations for their occurrence.

Processing of the Rational Texts. My first research question explored whether there were group differences in students' use of deep processing strategies as a function of epistemic beliefs and/or type of knowledge representation. Results supported the *interaction effect* position in that individuals used more deep processing strategies when the text format (i.e., type of knowledge representation) was congruent with their epistemic beliefs compared to when the format was inconsistent. However, results also revealed a main effect of text type, indicating that, in general, students engaged in deeper processing of the rational texts compared to the metaphorical texts. Why might this be the case?

One possible explanation as to why the rational texts elicited deeper processing strategies is because they may have been more difficult to understand than the metaphorical texts. Of course, it could be argued that if the texts were too difficult – i.e., not "comprehensible" (Dole & Sinatra, 1998) – then individuals may be more likely to disengage in their processing as opposed to employing deeper processing strategies. However, as noted in the methods section, participants in this study were explicitly instructed to read each sentence of their assigned texts carefully, and to make sure they understood what they were reading because they would be "asked some questions about the text later on." Assuming that participants were indeed trying to understand what they were reading, as per the study's instructions, then it could be the case that participants needed to use deeper strategies (e.g., paraphrasing, self-questioning) in order to make sense of the concepts as they were presented in the rational texts. Based on Royce's definition of rationalism, these concepts were presented through the use of formulas and theorems and may have seemed abstract and inaccessible to participants in this study who, in general, had low prior knowledge of physics. In contrast, the same concepts presented "metaphorically" may have been easier to understand – therefore eliciting the use of fewer deep processing strategies – because the very definition of metaphorism upon which the text was based (see Royce & Mos, 1980) emphasizes intuitive ideas that can be universally understood.

Building from this idea, it is plausible that the rational texts differed from the metaphorical texts in other important ways that influenced participants' use of deep processing strategies while reading. For example, referring back to Dole and Sinatra's (1998) CRKM, there are four "message characteristics" (i.e., characteristics of the to-be-learned material) that are theorized to influence the degree to which individuals engage and process to-be-learned material: comprehensibility, coherence, plausibility, and rhetorical persuasiveness. Comprehensibility – or the degree to which the message is intelligible and understandable – was addressed in the preceding paragraph. That is, it could be the case that the rational texts were less comprehensible than the metaphorical texts and therefore required deeper processing strategies to achieve the goal of "understanding" the texts (as directed by the instructions given to participants). However, it might also be the case that the rational texts were more coherent than the metaphorical texts in offering a more tightly-integrated account of the pertinent Newtonian concepts. Or perhaps some feature of the rational texts made them more plausible or rhetorically compelling to participants, subsequently resulting in deeper engagement with the text (Dole & Sinatra, 1998). For example, the use of mathematical equations and more formal language in these texts may have contributed to the perception of their being more credible. Of course, these ideas are just speculative, as my study did not account for participants' perceptions of these various text characteristics, but future research could explore these possibilities by asking participants (and/or perhaps independent raters not affiliated with the study) to rate the degree to which they find the texts to be comprehensible, coherent, plausible, and rhetorically persuasive.

Use of Shallow Processing Strategies. My second research question examined whether there were group differences in students' use of shallow processing strategies as a function of epistemic beliefs and/or type of knowledge representation. In line with a *main effect* position, I predicted that individuals espousing metaphorical beliefs would engage in more shallow processing of the instructional text as compared to individuals espousing rational beliefs (Hypothesis 2a). In contrast, the *interaction effect* position predicts that individuals would engage in more shallow processing of the instructional text when their beliefs were incongruent with the knowledge representation than when their beliefs were congruent (Hypothesis 2b). Interestingly, neither of these predictions was supported in this study; rather, results revealed no differences in shallow processing as a function of epistemic beliefs, text type (knowledge representations), or the interaction between epistemic beliefs and text type.

This unexpected finding makes me question the assumptions made about shallow processing strategies: namely, that they are less productive and therefore more likely to occur in conditions that are theoretically less favorable (e.g., when beliefs are incongruent with knowledge representations, or when individuals espouse less constructivist beliefs). Some studies have shown this to be the case. For example, as reported above in the literature review, Schommer et al. (1992) found that students who espoused less constructivist epistemic beliefs were more likely to use shallow processing strategies when reading a passage about statistics; specifically, the more students believed in simple knowledge, the more they engaged in memorization strategies and the less they were able to summarize important concepts. Likewise, in a qualitative study examining relations between epistemic beliefs, cognitive strategy use, and conceptual change Stathopoulou and Vosniadou (2007a) found that students who espoused more constructivist epistemic beliefs and achieved conceptual change adopted deep study strategies, whereas students who espoused less constructivist beliefs and performed poorly on the conceptual test adopted shallow strategies.

On the other hand, other studies have found that epistemic beliefs are not related to type of strategy use (deep versus shallow), but instead are related to the frequency of strategy use (e.g., Kardash and Howell, 2000). Moreover, contrary to my assumptions, there is some evidence to suggest that students' use of shallow processing strategies might be better predicted by particular variables or conditions that are theoretically considered to be *more favorable* than their alternatives. For example, in a recent study examining relations between achievement goals, cognitive processing strategies, and conceptual change, Ranellucci and colleagues (Ranellucci, Muis, Duffy, Wang, Sampasivam, & Franco, 2011) found that mastery goals (typically considered to be favorable) predicted the use of deep and shallow processing strategies whereas performance avoidance goals (typically considered to be unfavorable) were negatively related to deep processing strategies but unrelated to shallow processing strategies.

Taking all of this into account, it seems plausible to suggest that predictions regarding shallow processing strategies are not as straightforward as one might assume. In some cases, shallow processing strategies are associated with less favorable conditions (e.g., Schommer et al., 1992; Stathopoulou & Vosniadou, 2007a), but in other cases (as in the current study, as well as Kardash & Howell, 2000), they are unrelated to a particular condition, or instead associated with more favorable conditions (Ranellucci et al., 2011). Accordingly, just as it may not be appropriate to characterize particular types of epistemic beliefs as being more sophisticated or productive than others (Elby & Hammer, 2001; Hammer & Elby, 2002), it may also be inappropriate to assume that shallow processing strategies are less productive and automatically associated with less favorable conditions.

The above arguments notwithstanding, it also seems reasonable to suggest that the failure of this study to find group differences in shallow processing could be a function of how shallow processing was defined and measured. As described in the methods section (and shown in Table 5), shallow processing was comprised of two types of strategy use: repetition/rehearsal, and association. In contrast, three types of strategies comprised the deep processing variable (of which one of the categories – metacognitive comments – was further subdivided into three, yielding a total of five types of strategies; see Table 4). Although these coding schemes were borrowed from previous research that examined similar types of questions, perhaps they were not well suited for the particularities of this study. Specifically, the shallow processing coding scheme may not have been nuanced enough to capture the range of strategies that participants in this study used to engage with their instructional texts. Or perhaps another approach to coding shallow processing altogether, such as observing quantity (e.g., length of participants' responses to the instructional text) versus quality (i.e., type of response/strategy), would have yielded results that were more in line with the original predictions.

Misconceptions Regarding Newton's First Law. My fourth research question asked: How is conceptual change facilitated or constrained by interactions between epistemic beliefs and knowledge representations? Results from two types of content analysis showed that, in general, participants changed their misconceptions more when their epistemic beliefs were congruent with the knowledge representations in the texts than when their beliefs were incongruent. This finding was in line with predictions made from the *interaction effect* position. However, an additional and unexpected finding was that, in general, participants' misconceptions regarding Newton's First Law were more resistant to change than their misconceptions regarding Newton's Third Law (as evidenced from FCI post-test data, which showed 42 total instances of change for First Law items versus 155 instances of change for Third Law items). What are some possible explanations for this finding?

On the one hand, this finding could be attributed to limitations in the study's methods. For example, it could be the case that the instructional texts used to explain Newton's First Law were less effective than the texts used to explain Newton's Third Law. Or perhaps the FCI items selected to measure misconceptions related to the First Law were not as well aligned with the concepts addressed in the corresponding instructional texts as compared to the Third Law. (It should be noted that although the instructional texts were not designed for "teaching to the test" [i.e., the selected post-test FCI items], it nonetheless could be possible that the Third Law texts had this unintended effect whereas the First Law texts did not.)

Methodological limitations aside, the various conceptual change frameworks reviewed earlier in this paper offer some plausible, theory-based explanations for this finding (e.g., Dole & Sinatra, 1998; Pintrich et al., 1993; Posner et al., 1982). Taken together, these frameworks posit a number of factors that may influence whether or not an individual will experience changes in his or her misconceptions. Broadly speaking, the factors can be categorized as: 1) those related to the learner and 2) those related to the to-be-learned material. Factors related to the learner include dissatisfaction with an existing conception, strength and coherence of an existing conception, and degree of commitment to the conception. Regarding the first factor – dissatisfaction- the more dissatisfied an individual is with his or her existing conception, the greater the likelihood that s/he will change that conception (Posner et al., 1982). On the other hand, for each of the latter factors, there is an inverse relationship between the degree of the quality (i.e., more strength, greater coherence, higher commitment) and the likelihood of conceptual change (Dole & Sinatra, 1998). Although my study did not examine these particular factors, it is possible that any one of them – or some combination of them – could account for the finding that individuals in this study were less likely to change their First Law misconceptions. For example, perhaps individuals find the concept of inertia, which is the focus of Newton's First Law, to be more coherent than the concept of action/reaction pairs (which is the focus of Newton's Third Law). Or perhaps individuals, on a whole, are more satisfied with their existing conceptions of inertia, and less so with their conceptions of action/reaction pairs. Of course, these ideas are just conjecture and need to be empirically investigated.

Across the various conceptual change frameworks, factors related to the to-be-learned material include the degree to which the ideas presented are intelligible, plausible, fruitful, and/or rhetorically compelling (Dole & Sinatra, 1998; Pintrich et al., 1993; Posner et al., 1982). Taking these factors into account, perhaps individuals in this study found the First Law instructional texts to be less effective in their presentation of Newtonian concepts as intelligible, plausible (etcetera) compared to the Third Law texts, the consequence of which was lower rates of conceptual change after reading the First Law texts. Although all of the instructional texts followed a refutational format (which, in line with conceptual change theory, is designed to elicit dissatisfaction with existing conceptions and introduce intelligible, plausible, and fruitful new ideas), it is possible that subtle differences between the First and Third Law texts contributed to different learning outcomes for students reading those texts. Future studies could explore these issues further by including measures to assess text characteristics, as well as characteristics of the participants' existing conceptions (i.e., strength, coherence, commitment).

General Discussion

Although this study yielded some unexpected results, the main findings are in line with predictions and, in general, support the *interaction effect* position; namely, when individuals' epistemic beliefs were consistent with the knowledge representations in their assigned texts, they performed better on various measures of learning than when their epistemic beliefs were inconsistent with the knowledge representations. These results arouse curiosity about *why* consistency between individuals' epistemic beliefs and various knowledge representations may facilitate learning. Although my research did not explore this question specifically, I offer three plausible explanations that await further investigation. To extend one position, posited by Muis (2008; Muis & Franco, 2010), individuals may perceive greater amounts of information to coordinate and evaluate when their beliefs are consistent with the epistemic nature of the learning task (rather than the underlying epistemology of the domain). For example, because sources of information in the metaphorical text entailed metaphorical elements, it could be that individuals who espoused predominantly metaphorical beliefs perceived greater amounts of information to process in those texts compared to individuals who espoused predominantly rational beliefs, the consequence of which was more effortful processing and subsequently better performance for those individuals under those conditions. This explanation shares Bromme et al.'s (2010) view that epistemic beliefs provide a lens, or apprehension structure, through which learners perceive a learning task and anticipate to-be-learned knowledge.

Building on this idea, from a cognitive load perspective (e.g., Paas, Renkl, & Sweller, 2003), it could be that consistency between individuals' epistemic beliefs and the epistemic nature of knowledge representations in a learning task reduces the demand on individuals' working memory, thus freeing up more resources that can be allocated to processing information in a way that facilitates recall and knowledge restructuring. For example, Paas et al. (2003) discuss the notion of intrinsic cognitive load, which is a property that is inherent to the material being learned. Renkl and Atkinson (2003) elaborate that intrinsic cognitive load "refers to the number of elements that the learner must attend to simultaneously to understand the learning material" (p. 17). They further suggest that intrinsic cognitive load is dependent on an individual's level of prior domain knowledge, and that cognitive load is higher when prior knowledge is low because the learner has fewer schemas available to make the learning process more efficient (Renkl & Atkinson, 2003). Drawing on these perspectives, I wonder: might intrinsic cognitive load be higher for individuals whose epistemic beliefs are inconsistent with the knowledge representations of the to-be-learned material? Taking Muis' (2007) and Bromme et al.'s (2010) view that epistemic beliefs act as a schema-like lens through which individuals perceive a learning task, it could be that if this schema is inconsistent with the to-be-learned content, individuals must exert cognitive effort toward revising/developing their beliefs' schema, which draws resources away from other tasks such as cognitive processing of the information. Conversely, individuals whose epistemic beliefs are consistent with the to-be-learned content would have more resources available for information processing, the result of which could be increased achievement on learning tasks, for example. Of course, these conjectures need to be empirically scrutinized.

I also speculate that motivation may be a mediating factor in the relationship between individuals' epistemic beliefs, knowledge representations, and various facets of learning. Several studies have provided empirical evidence that demonstrates relations between epistemic beliefs, learning outcomes, and motivational constructs such as achievement goals (e.g., Muis & Franco, 2009a) and interest (e.g., Mason et al., 2008). Although motivation was not a variable of focus in this study, it could be that individuals feel more cognitively engaged in learning material that is presented in a way that is consistent with their worldview, which may in turn motivate these individuals to engage in more effortful learning strategies of the to-be-learned content. Again, these speculations warrant further investigation.

Limitations and Future Directions

Several important limitations need to be acknowledged for the current study. First, my conclusions are based on the assumption that the instructional texts used to engage participants in learning about Newtonian concepts could be categorized as either predominantly rational or predominantly metaphorical in nature. Although I took steps to try to validate this assumption (e.g., asking participants to rate their perceptions of the texts; having the texts reviewed by a physics expert), I must also acknowledge the possibility that the texts might not accurately reflect the epistemic characteristics that I intended. Moreover, as there are many dimensions by which texts can be characterized, it is possible that the texts differed in other unintended but important ways that may have influenced the ways in which participants engaged with them.

Second, although the think-aloud methodology has received extensive validation as a tool to reveal comprehension processes in learning from text (Afflerbach, 2000; Coté & Goldman, 1999; Magliano & Millis, 2003), it should be noted that the constraints of the task (e.g., asking participants to read the assigned texts one sentence at a time) created an artificial learning context that limits the ecological validity of the findings and may have influenced outcomes in unintended ways. Future studies could structure the think-aloud task so that it more closely approximates a natural context for reading (i.e., presenting instructional text in its entirety, rather than separated line by line). In the current study, I chose to present the text one line at a time as an attempt to control for variations in participants' tendencies to think out loud; that is, the transition from one index card to another was intended to serve as a "built-in" prompt to cue participants to think out loud at these designated intervals (as opposed to thinking aloud at their own leisure). However, because this approach may have interfered with participants' natural processing of the text, future studies could enhance the validity of these data by incorporating additional measures that are less intrusive, such as reading times or eye tracking devices (Kendeou & van den Broek, 2005).

Third, the design of my study did not include any delayed measures of learning, as both the recall task and posttest FCI questions were administered immediately after participants finished reading their assigned texts. This issue is especially relevant to the conceptual change outcome in my study, in light of evidence from other studies that have shown that the effects of instructional interventions on conceptual change diminish over time (e.g., Broughton, Sinatra, & Reynolds, 2010; Salisbury-Glennon & Stevens, 1999). Would the interactive effects of epistemic beliefs and knowledge representations on conceptual change persist over time, and for how long? Future studies could examine this issue by including both immediate and delayed posttest measures.

Fourth, as with any study, difficult design decisions were made in an effort to strive for parsimony. Consequently, I chose to exclude some variables that may be of interest for future research in this area. For example, as noted above, motivational constructs such as interest, self-efficacy, and/or achievement goals may play a role in mediating the relationship between epistemic beliefs, knowledge representations, and learning outcomes such as text recall and conceptual change. Indeed, in the “warmer” models of conceptual change such as Pintrich and colleagues’ (1993) framework and Dole and Sinatra’s (1998) CRKM, motivational constructs are highlighted as important factors that may influence the extent to which individuals change their misconceptions. Moreover, there is empirical evidence to support these hypothesized relations (e.g., Mason et al., 2008; Ranellucci et al., 2011). Accordingly, future research could build on the current study by incorporating motivational constructs in the research design. Importantly, future research could also expand the design of this study by including the “empiricism” component of Royce’s (1983) framework. The current study focused on two of the three components of Royce’s (ibid) framework: rationalism and metaphorism; however, researchers could construct a third instructional text that includes data from actual physics experiments to describe Newtonian concepts in a way that reflects Royce’s definition of empiricism, and then examine learning processes and outcomes for individuals whose beliefs are congruent with the text (i.e., those with predominantly empirical epistemic beliefs) and incongruent (i.e., those who espouse predominantly rational or metaphorical beliefs).

Another possibility for future research is to examine the relations between epistemic beliefs and knowledge representations in media other than printed text. Would similar results be observed if the knowledge representations were presented in an online, hypermedia format? Or if the Newtonian concepts were taught via lecture or video formats that were designed to reflect rational, metaphorical, or empirical elements? The current study focused on only one kind of media (printed text), because as noted by Mason et al. (2008), text is the primary medium through which learners acquire disciplinary knowledge. However, future studies could include other instructional formats to ascertain the extent to which results from this study generalize to other media.

Finally, this study is limited in that it measures individuals' epistemic beliefs at one point in time (before participants engaged in reading the instructional texts) and therefore ignores the possibility that these beliefs may have varied during the course of the experiment. Indeed, several theorists (e.g., Muis, 2007; Pintrich et al., 1993) have suggested that participation in particular learning experiences such as self-regulated learning and conceptual change may influence individuals' beliefs about knowledge and knowing, and recent empirical work on epistemic beliefs has demonstrated that differences in the way to-be-learned material is presented (e.g., conceptually versus procedurally, or media versus text) influences students' levels of beliefs (Muis & Franco, 2009b; Muis, Franco, & Gierus, 2011) or the extent to which students make epistemological judgments with regard to the information being presented, such as its trustworthiness (Stahl, 2009). Thus, it is possible that certain learning tasks in my study (e.g., a think-aloud versus recall task) and/or particular characteristics of the texts with which participants engaged (e.g., their refutational argument structure, or the differences in rational versus metaphorical knowledge representations) may have elicited variations in participants' epistemic beliefs. I did not account for these variations in the current study, but future work could explore this issue by measuring participants' epistemic beliefs at several points during the course of the experiment.

Conclusion

The aforementioned limitations notwithstanding, this research makes several important contributions. For example, my work advances epistemic beliefs research by moving beyond the study of students' beliefs and examining how these beliefs interact with aspects of the epistemic climate – specifically, knowledge representations – to facilitate or constrain learning. Moreover, by including multiple measures of learning (online processes and offline products), this study adds to our understanding of both the direct and indirect effects of epistemic beliefs on learning. In addition to these contributions, my study also adds to the conceptual change literature by providing tentative support for the idea that changes in misconceptions are associated with a combination of learner (e.g., epistemic beliefs) and text (e.g., knowledge representation) characteristics, and by examining a more fine-grained text characteristic than has heretofore been investigated.

The findings from this study are noteworthy not only in the context of research, but also in practice. For researchers, this study shows that variations in the way knowledge is represented differentially interact with individuals' beliefs and are associated with different learning outcomes, which supports contemporary views regarding the situated and contextual nature of individuals' epistemic beliefs. For practitioners, this study reminds us that it is important for individuals to have access to alternative representations of to-be-learned content, because the same content presented in two different ways can elicit different responses from individuals with different sets of beliefs. As writer and diarist Anaïs Nin famously said: “We don’t see things as they are, we see them as we are.”

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APPENDIX A

CONSENT FORM

TITLE OF STUDY: Fostering conceptual change in physics: Exploring interactions between text structure and epistemic profiles.

INVESTIGATORS: Dr. Krista R. Muis, Gina Franco, Doris Nussbaumer, John Ranellucci, and Lavanya Sampasivam.

CONTACT PHONE NUMBER: 514-398-3445

Purpose of the Study
Our objectives are to explore relations between individuals' epistemic beliefs and the underlying epistemic structure of a text, and how these interact to influence conceptual change in physics.

Participants
You are being asked to participate in the study because you are an undergraduate student at McGill University.

Procedures
If you would like to participate, we will ask you for some basic information about yourself (your age, gender, year in university, etc), and we'll ask you to complete two questionnaires. Once you complete the questionnaires, we will engage you in learning about Newton's Laws where you will be asked to think out loud while you read the texts. Once you complete the think alouds, we will ask you to complete two more questionnaires. This study will take approximately 90 minutes of your time, for which you will be compensated (see below).

Benefits of Participation
Benefits include an opportunity for you to reflect upon your beliefs about knowledge and knowing, and to learn about the science of everyday phenomena.

Risks of Participation
There are risks involved in all research studies. This study may include only minimal risks. A possible risk is anxiety normally associated with filling out questionnaires.

Cost /Compensation
For your time, you will receive $10.

Contact Information
If you have any questions or concerns about the study, you may contact Dr. Krista R. Muis at **514-398-3445.** For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact **the McGill REB Office at 514-398-6831.**

Voluntary Participation
Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your

relations with the university. You are encouraged to ask questions about this study at the beginning or any time during the research study.

Confidentiality
All information gathered in this study will be kept completely confidential. No reference will be made in written or oral materials that could link you to this study. All records will be stored in a locked facility at McGill for 3 years after completion of the study. After the storage time the information gathered will be destroyed.

Participant Consent:
I have read the above information and agree to participate in this study. I am at least 18 years of age. A copy of this form has been given to me.

______________________________________ ____________________
Signature of Participant Date

____
Participant Name (please print)

APPENDIX B

DEFINITION OF TERMS

Below is a brief glossary of terms that appear frequently throughout this paper. Definitions are also given in the body of the paper whenever a term is introduced for the first time, but because the terms appear in a scattered manner throughout the paper, it seems useful and important to also present a consolidated list of definitions here for the reader.

Epistemic beliefs are individuals' beliefs about knowledge and knowing. Across different theoretical frameworks, researchers propose different types and dimensions of epistemic beliefs. For example, beliefs about the *nature* of knowledge (i.e., Is knowledge simple or complex? Is it fixed or fluid?) and beliefs about the *source* of knowledge (i.e., Where does knowledge come from?) appear in several frameworks in the epistemic beliefs literature (e.g., Hofer & Pintrich, 1997; Muis et al., 2006; Schommer, 1990). In the current study, I adopt an epistemic beliefs framework proposed by Royce (1983), which focuses on beliefs about how knowledge is derived and justified.

Personal epistemology is used in this paper as an "umbrella term" (Hofer, 2001) for describing various research programs that investigate individuals' conceptions of knowledge and knowing. That is, the term personal epistemology is intended to encompass many varied conceptualizations of individuals' views about knowledge and knowing, of which an "epistemic beliefs" framework is just one example. Other examples of personal epistemology frameworks include: developmental structures, epistemological resources, and epistemological theories. To clarify, I use the term epistemic beliefs in this paper when referring specifically to my research because the current study adopts an epistemic beliefs framework. However, when I present a broad review of relevant theoretical perspectives, I use the term personal epistemology to refer generally to the study of individuals' conceptions about knowledge and knowing.

Knowledge representations are means by which information about the world is represented. Mislevy and colleagues (Mislevy et al., 2010) differentiate between internal and external knowledge representations. Internal knowledge representations are the ways in which we represent knowledge in our brains, whereas external knowledge representations are physical or conceptual structures that represent ideas which can be accessed time and again by different individuals or the same individual (Mislevy et al., 2010). In the domain of education, external knowledge representations include textbooks, curricula, and assessments (Haerle & Bendixen, 2008). For the current study, I focus on external knowledge representations in the form of instructional texts used to explain physics concepts.

Rationalism is one of three types of epistemic beliefs proposed in Royce's (1983) framework (which I adopt for the current study). According to Royce, individuals who endorse a rationalist view believe that knowledge is derived and justified through reason and logic. In my research, I use Royce's framework not only to assess and classify individuals' epistemic beliefs, but also to design and characterize the knowledge representations (i.e., instructional texts) with which participants engage. Accordingly, for the current study, "rationalist" knowledge representations are those that emphasize logic and reason in the presentation of pertinent physics concepts (e.g., through the use of theorems and mathematical equations).

Metaphorism is another epistemic belief from Royce's (1983) framework that, along with rationalism, plays an important role in my study. Within the context of Royce's framework, individuals who endorse a metaphorical view believe that knowledge is derived through intuition and justified via universal awareness. Accordingly, the "metaphorical" knowledge representations in this study were designed to appeal to universal insight and awareness by presenting physics concepts through the use of commonplace examples.

Empiricism is the third of three epistemic beliefs from Royce's (1983) framework. Empiricism focuses on the processing of sensory information, and individuals who espouse a predominantly empiricist view believe that knowledge is derived and justified through direct observation and experimentation. Although the effects of this particular epistemic belief on learning have been explored in other studies (e.g., Muis, 2008; Muis & Franco, 2009), empiricism does not feature prominently in the current study due to limitations in the study's design. Nonetheless, the term appears frequently throughout this paper when I refer not only to Royce's (1959; 1978; 1983) work, but also to relevant empirical studies that have adopted Royce's framework.

Conceptual change is defined in this study as the changing of inaccurate or misconceived prior knowledge to "correct" or scientifically-accepted knowledge (Chi, 2008). Specifically, for the conceptual change outcome in this study, I examine changes (from pretest to posttest) in individuals' conceptual knowledge of Newton's First and Third Laws of Motion.

Shallow processing refers to learners' attempts to engage with superficial aspects of the to-be-learned material (Craik & Lockhart, 1972). In my study, I define shallow processing strategies as those that involve memorization of the new material (e.g., rehearsal/repetition), or the activation of prior knowledge without attempting to integrate it with new information (e.g., making associations).

Deep processing involves more vigorous cognitive analysis of the to-be-learned material (Craik & Lockhart, 1972). Following others (e.g., Dole & Sinatra, 1998; Pintrich et al., 1991; Stathopoulou & Vosniadou, 2007a), I identified three types of deep processing strategies in my study: integrating new ideas with their prior knowledge (e.g., elaboration); organizing and summarizing ideas (e.g., paraphrasing); and metacognitive engagement (e.g., monitoring understanding; reflecting on conflicts between prior knowledge and new information in the text).

Metacognitive processing, or thinking about one's thinking (Slavin, 2003), is viewed in this study as a form of deep processing. This shares Dole and Sinatra's (1998) perspective that "significant metacognitive reflection" (p. 121) is a key component of deep levels of engagement with to-be-learned material. In my study, I identify three specific strategies that represent metacognitive processing: self-questioning, monitoring one's understanding, and acknowledging cognitive conflict (i.e., noticing when one's prior knowledge conflicts with ideas presented in the text).

"Double-track approach" refers to a contemporary approach to epistemic beliefs research advocated by Bromme and colleagues (Bromme et al., 2010). This approach emphasizes the need to move away from decontextualized studies of students' epistemic beliefs and instead focus on the ways in which epistemic beliefs interact with various aspects of an individual's learning environment. Specifically, the authors (Bromme et al., 2010) suggest that, when formulating predictions and interpretations regarding the effects of students' epistemic beliefs on learning, epistemic beliefs researchers should analyze the learning content with which students engage. The current study adopts a double-track approach.

Self-regulated learning is defined in this study as "learning that results from students' self-generated thoughts and behaviors that are systematically oriented toward the attainment of their learning goals" (Schunk, 2001, p. 125). In recent years, researchers have identified important theoretical (e.g., Muis, 2007) and empirical (e.g., Bråten & Strømsø, 2010; Muis, 2008) relations between epistemic beliefs and self-regulated learning. Results from the current study have implications for these relations, as noted in the discussion section of this paper.

APPENDIX C

DEMOGRAPHICS QUESTIONNAIRE

(Note: This questionnaire was completed in an online survey environment)

1. Name: ____________________________
2. Age (in years): ____________________________
3. Sex: Male / Female / Other
4. Academic Major: ____________________________
5. Academic Minor: ____________________________
6. Grade Point Average (in all *secondary* studies): ____________________________
7. Grade Point Average (in all *post-secondary* studies): ____________________
8. I am studying at the _______________________ level[16]:
    - ○ Undergraduate
    - ○ Graduate

[16] Only undergraduate students were eligible to participate in the study. This item was included to verify that each participant met this criteria.

APPENDIX D

PSYCHO-EPISTEMOLOGICAL PROFILE SCALE (PEP)[17]

For each of the following statements, you are to indicate your personal agreement or disagreement on the scale provided next to each statement. If you **completely disagree** with the statement, please circle (**1**) next to the statement. If you **completely agree** with the statement, please circle a (**5**) next to the statement. If you neither completely disagree or completely agree with the statement, circle the number in between 1 and 5 that best describes your agreement. Use the following scale to rate your agreement: *(Note: Number column has been removed.)*

1 = Completely Disagree
2 = Moderately Disagree
3 = Neutral
4 = Moderately Agree
5 = Completely Agree

1. A good teacher is primarily one who has a sparking entertaining delivery.

2. The thing most responsible for a child's fear of the dark is thinking of all sorts of things that could be "out there".

3. Most people who read a lot, know a lot because they come to know of the nature and function of the world around them.

4. Higher education should place a greater emphasis on fine arts and literature.

5. I would like to be a philosopher.

6. A subject I would like to study is biology.

7. In choosing a job I would look for one which offered opportunity for experimentation and observation.

8. The Bible is still a best seller today because it provides meaningful accounts of several important eras in religious history.

9. Our understanding of the meaning of life has been furthered most by art and literature.

10. More people are in church today than ever before because they want to see and hear

[17] Reprinted with permission from Dr. Leendert Mos (personal communication, 5 October 2011).

for themselves what ministers have to say.

11. It is of primary importance for parents to be consistent in their ideas and plans regarding their children.

12. I would choose the following topic for an essay: The Artist in an Age of Science.

13. I feel most at home in a culture in which people can freely discuss their philosophy of life.

14. Responsibility among people requires an honest appraisal of situations where irresponsibility has transpired.

15. A good driver is observant.

16. When people are arguing a question from two different points of view, I would say that the argument should be resolved by actual observation of the debated situation.

17. I would like to visit a library.

18. If I were visiting India, I would primarily be interested in understanding the basis for their way of life.

19. Human morality is molded primarily by an individual's conscious analysis of right and wrong.

20. A good indicator of decay in a nation is a decline of interest in the arts.

21. My intellect has been developed most by learning methods of observation and experimentation.

22. The prime function of a university is to teach principles of research and discovery.

23. A good driver is even tempered.

24. If I am in a contest, I try to win by following a pre-determined plan.

25. I would like to have been Shakespeare.

26. Our understanding of the meaning of life has been furthered most by mathematics.

27. I like to think of myself as a considerate person.

28. I would very much like to have written Darwin's "The Origin of Species".

29. When visiting a new area, I first try to see as much as I possibly can.

30. My intellect has been developed most by gaining insightful self-knowledge.

31. I would be very disturbed if accused of being insensitive to the needs of others.

32. The kind of reading which interests me most is that which creates new insights.

33. The greatest evil inherent in a totalitarian regime is alienation of human relationships.

34. Most atheists are disturbed by the absence of factual proof of the existence of God.

35. In choosing a job I would look for one which offered the opportunity to use imagination.

36. In my leisure I would most often like to enjoy some form of art, music, or literature.

37. The kind of reading which interests me most is that which stimulates critical thought.

38. I prefer to associate with people who are spontaneous.

39. In my leisure I would like to play chess or bridge.

40. Most people who read a lot, know a lot because they develop an awareness and sensitivity through their reading.

41. When visiting a new area, I first pause to try to get a “feel” for the place.

42. Many TV programs lack sensitivity.

43. I like to think of myself as observant.

44. Happiness is largely due to sensitivity.

45. I would be very disturbed if accused of being inaccurate or biased in my observations.

46. A good teacher is primarily one who helps his or her students develop their powers of reasoning.

47. I would like to be a novelist.

48. The greatest evils inherent in a totalitarian regime are restrictions of thought and criticism.

49. More people are in church today than ever before because theologians are beginning to meet the minds of the educated people.

50. The most valuable person on a scientific research team is one who is gifted at critical

analysis.

51. Many TV programs lack organization and coherence.

52. I like country living because it gives you a chance to see nature first hand.

53. Upon election to Parliament I would endorse steps to encourage an interest in the arts.

54. It is important for parents to be familiar with theories of child psychology.

55. The prime function of a university is to train the minds of the capable.

56. I would like to have written Hamlet.

57. Higher education should place a greater emphasis on mathematics and logic.

58. The kind of reading which interests me most is that which is essentially true to life.

59. A subject I would like to study is art.

60. I feel most at home in a culture in which realism and objectivity are highly valued.

61. The prime function of a university is to develop a sensitivity to life.

62. When playing bridge or similar games I try to think my strategy through before playing.

63. If I were visiting India, I would be primarily interested in noting the actual evidence of cultural change.

64. When buying new clothes I look for the best possible buy.

65. I would like to visit an art gallery.

66. When a child is seriously ill, a good parent will remain calm and reasonable.

67. I prefer to associate with people who stay in close contact with the facts of life.

68. Many TV programs are based on inadequate background research.

69. Higher education should place greater emphasis on natural science.

70. I like to think of myself as logical.

71. When people are arguing a question from two different points of view, I would say that each should endeavor to assess honestly his or her own attitude and bias before arguing further.

72. When reading an historical novel, I am most interested in the factual accuracy found in the novel.

73. The greatest evil inherent in a totalitarian regime is distortion of the facts.

74. A good driver is considerate.

75. Our understanding of the meaning of life has been furthered most by biology.

76. I would have liked to be Galileo.

77. My children must posses the characteristics of sensitivity.

78. I would like to be a Geologist.

79. A good indicator of decay in a nation is an increase in the sale of movie magazines over news publications.

80. I would be very disturbed if accused of being illogical in my beliefs.

81. Most great scientific discoveries came about by thinking about a phenomenon in a new way.

82. I feel most at home in a culture in which the expression of creative talent is encouraged.

83. In choosing a job I would look for one which offered a specific intellectual challenge.

84. When visiting a new area, I first plan a course of action to guide my visit.

85. A good teacher is primarily one who is able to discover what works in class and is able to use it.

86. Most great scientific discoveries come about by careful observation of the phenomena in question.

87. Most people who read a lot, know a lot because they acquire an intellectual proficiency through sifting of ideas.

88. I would like to visit a botanical garden or zoo.

89. When reading an historical novel, I am most interested in the subtleties of the personalities described.

90. When playing bridge or similar games I play the game by following spontaneous cues.

APPENDIX E

RATIONAL INSTRUCTIONAL TEXT FOR NEWTON'S FIRST LAW

(Note: Text was presented to participants on cue cards, one line at a time.)

1	The focus in this text is Newton's first law, sometimes referred to as the "law of inertia":
2	Every material object continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.
3	There are two key words mentioned in this law.
4	The first is *continues*.
5	An object continues to do whatever it happens to be doing unless a force is exerted upon it.
6	If it is at rest, it continues to be in a state of rest.
7	If it is moving, it continues to move without turning or changing its speed.
8	The second key word is *change*.
9	Objects do not resist motion but rather they resist a change in their existing motion.
10	Object's resistance to a change in its state of motion is what we call *inertia*.
11	The properties of inertia can be represented by the equation $\sum \vec{F}=0$ which states that when the vector sum of all forces acting on an object is zero, the object remains in its current state (in motion or in rest).
12	What does the phrase "vector sum" mean?
13	A *vector* is a mathematical quantity, which has both a magnitude (numerical value) and a direction.
14	The *vector sum* $\sum \vec{F}$ refers to the sum of all forces that push or pull on an object, taking into account both the magnitude and direction of each force.
15	The vector sum of all forces is also called the *net force*.
16	If there is no net force on an object, the object will not change its state of motion.
17	Likewise, if an object is in a state of rest, then there is no net force acting on it.
18	"No net force" can mean: 1) There are no forces pushing or pulling on the object, or 2) The forces that push or pull on the object cancel each other out.
19	Many students have difficulty understanding Newton's first law because it is in direct opposition to a very popular conception about motion.
20	This incorrect conception is the idea that objects have an innate force that keeps them moving.
21	Newton reasoned that objects do not need an innate force to keep them moving; rather, objects in motion tends to stay in motion, and objects in rest tend to remain at rest.
22	Another difficult idea for students to understand is that, when no net force is acting on them, objects do not naturally come to a stop.

23	Do objects have a natural tendency to come to a stop?
24	No!
25	Objects have a natural tendency to remain in their state, but they require an external net force to change this state.
26	That is, an object will not stop, speed up, or change its direction unless there is an external net force pushing or pulling on it.
27	For example, suppose a force of $\overrightarrow{10\text{N}}$ is applied on an object.
28	Now suppose a second force of equal magnitude is applied to the object in the opposite direction: $\overleftarrow{-10\text{N}}$
29	These two forces cancel each other and their vector sum is zero: $$\sum \vec{F} = \overrightarrow{10\text{N}} + - \overleftarrow{10\text{N}} = 0$$
30	Because the vector sum (net force) is zero, the object will not slow down, speed up, or change its direction.
31	However, suppose the second force is of greater magnitude than the first force: $\overleftarrow{-30\text{N}}$
32	In this case, the vector sum of all forces pushing or pulling on the object yields an unbalanced net force: $$\sum \vec{F} = \overrightarrow{10\text{N}} + - \overleftarrow{30\text{N}} = \overleftarrow{-20\text{N}}$$
33	Consequently, the object's motion will change because of the external net force acting on it, not because of an innate force.

APPENDIX F

METAPHORICAL INSTRUCTIONAL TEXT FOR NEWTON'S FIRST LAW

(Note: Text was presented to participants on cue cards, one line at a time.)

1	The focus in this text is Newton's first law, sometimes referred to as the "law of inertia":
2	Every material object continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.
3	There are two key words mentioned in this law.
4	The first is *continues*.
5	An object continues to do whatever it happens to be doing unless a force is exerted upon it.
6	If it is at rest, it continues to be in a state of rest.
7	If it is moving, it continues to move without turning or changing its speed.
8	The second key word is *change*.
9	Objects do not resist motion but rather they resist a change in their existing motion.
10	Object's resistance to a change in its state of motion is what we call *inertia*.
11	Demonstrations of inertia are when we stamp our feet to remove snow from them, shake a garment to remove dust, or tighten the loose head of a hammer by slamming the hammer handle-side-down on a firm surface.
12	Many students have difficulty understanding Newton's first law because it is in direct opposition to a very popular conception about motion.
13	This incorrect conception is the idea that objects have the natural tendency to come to a stop unless a force keeps them moving.
14	Imagine a situation where we slide a book across the table and we watch it slide to a rest.
15	The book does not come to a rest position because we stopped pushing it.
16	Rather, the book comes to a rest because of the presence of the force of friction.
17	In a frictionless environment, the book would continue moving.
18	Another difficulty in understanding Newton's law is the idea that objects have an innate force that keeps them moving.
19	This commonsense belief contradicts Newton's first law in several ways.
20	Imagine a person holding a stone at shoulder height while walking forward at a brisk pace.
21	What will happen when the person drops the stone?
22	What kind of path will the stone follow and why?

23	Many people to whom this problem is presented answer that the stone will fall straight down onto the ground exactly under the point it was released.
24	Some people even think that the stone will travel backward and fall behind its point of release.
25	In reality, the stone will move forward landing a few feet ahead of the point of its release.
26	According to Newton's law, when the stone is dropped it will continue to move forward at the same speed as the walking person if no force acts to change its horizontal velocity.
27	This is not what we observe in real life though.
28	Rather, we observe the stone slowing its forward motion and falling downward at the same time.
29	How can we explain the stone's motion?
30	First, the stone continues to move forward because it was moving forward to begin with and not because of an innate force that keeps it moving!
31	Second, the stone is slowing its forward motion because of air resistance and is falling downward at the same time because of gravity.
32	Thus, the stone's motion changes because other forces, air resistance and gravity, act upon it.
33	Thus, the idea that objects need an innate force to keep them moving is incorrect.

APPENDIX G

RATIONAL INSTRUCTIONAL TEXT FOR NEWTON'S THIRD LAW

(Note: Text was presented to participants on cue cards, one line at a time.)

1	The focus in this text is Newton's third law.
2	Newton's third law differs from his first and second laws.
3	Newton's first and second laws tell us what forces do; Newton's third law tells us the nature of those forces.
4	So, what is a force?
5	A force is a push or pull on an object, which results from its interaction with another object.
6	In every interaction, forces always occur in pairs.
7	In other words, there is no such thing as a single, isolated force.
8	The third law is as follows: "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first."
9	The mathematical formula for Newton's third law is a vector relationship: $$\vec{F}_{AB} = - \vec{F}_{BA}$$ (F = force; AB = Object A on Object B; BA = Object B on Object A)
10	One force is called the action force and the other is called the reaction force.
11	These two forces are co-parts of an interaction and neither force exists without the other.
12	Some students have difficulty with the term interaction.
13	They understand interaction to mean a struggle between opposing forces where the most "forceful" exerts greater force.
14	For example, some students wonder: "If forces are always equal and opposite, then how do two objects of different size get different accelerations in the same interaction?"
15	In other words, when two objects collide, how can they experience different consequences?
16	Does one object exert a greater force than the other?
17	No!

18	In every interaction, the pair of forces is always equal in size; the belief that there is a greater force is incorrect.
19	So how do we explain the different consequences, or accelerations?
20	Newton reasoned that the same force acting on objects of different mass will produce different accelerations because force is a function of an object's mass and acceleration.
21	The relationship between force, mass, and acceleration is described in Newton's second law, which is written as: $$F_{net} = ma$$ (F_{net} = net force; m = mass; a = acceleration)
22	Expressed differently, acceleration is the ratio of force to mass: $$F_{net} / m = a$$
23	Two objects differing in size, or mass, can experience different accelerations in an interaction, even though the forces exerted on both objects are equal: Object A (larger mass): $F_{net} / \mathbf{M} = \scriptstyle a$ Object B (smaller mass): $F_{net} / \scriptstyle m \displaystyle = \mathbf{A}$
24	The term interaction is not the only source of confusion for students; some are also confused by the terms action and reaction.
25	This is because the words action and reaction often suggest a specific sequence – i.e., "First an action, then a reaction."
26	However, this is not the case in Newton's third law.
27	There is no particular sequence!
28	The action and reaction forces occur at the same time.
29	The pair of forces is equal in size and time.
30	It doesn't matter which force is called the action force, and which is called the reaction force.
31	The important thing is that they are co-parts of one interaction and that neither force

	exists without the other.
32	Another difficulty for students is whether inanimate, motionless objects still exert forces.
33	Do they?
34	Yes!
35	The term “normal force” describes the support force exerted on an object when it is in contact with another stable object.
36	The direction of both normal forces is always perpendicular to the surface of the stable object.
37	That is, when Object A is resting on Object B, the direction of the normal forces on Object A is perpendicular to the surface of Object B.
38	In other words, objects that are not in motion still exert forces.
39	The idea that only animate objects can exert forces is incorrect.

APPENDIX H

METAPHORICAL INSTRUCTIONAL TEXT FOR NEWTON'S THIRD LAW

(Note: Text was presented to participants on cue cards, one line at a time.)

1	The focus in this text is Newton's third law.
2	Consider, for example, the interaction between a hammer and a stake.
3	The hammer exerts a force on a stake and drives it into the ground.
4	But this force is only half the story, for there must be a force to halt the hammer in the process.
5	What exerts this force?
6	The stake!
7	Newton reasoned that while the hammer exerts a force on the stake, the stake exerts a force on the hammer.
8	So in the interaction between the hammer and the stake there is a pair of forces - one acting on the stake and the other acting on the hammer.
9	Such observations led Newton to his third law-the law of action and reaction.
10	The third law is stated as follows: "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first."
11	One force is called the action force and the other force is called the reaction force.
12	These two forces are co-parts of a single interaction and neither force exists without the other.
13	They are equal in strength and opposite in direction.
14	Thus, Newton's third law is often stated "For every action there is an opposite and equal reaction."
15	In every interaction, the forces always occur in pairs.
16	The action and reaction pair of forces makes up the interaction between two things.
17	Some students have difficulty with the term interaction.
18	They perceive interaction as a struggle between opposing forces where the most 'forceful' exerts greater force.
19	More forceful in students' mind can also mean bigger, greater mass, or more active.
20	Let us take for instance a rifle that is fired.
21	There is an interaction between the rifle and the bullet.
22	A pair of forces acts on both the rifle and the bullet.

23	The force exerted on the bullet is as great as the reaction force exerted on the rifle, hence the rifle kicks.
24	Given that the forces are equal in magnitude, why doesn't the rifle recoil with the same speed as the bullet?
25	Because the rifle has greater mass than the bullet, and acceleration is the ratio of force to mass, the rifle has less acceleration.
26	The acceleration of the bullet is huge because the same force is divided by a small mass.
27	Another example that also refutes the idea that massive objects exert greater forces is that of earth and moon.
28	The earth and moon are attracted to each other by gravitational forces.
29	Does the more massive earth pull harder on the moon?
30	No, no, no!
31	Both earth and moon pull each other in a single interaction with equal and opposite in direction forces.
32	Another idea that is difficult for students to understand is that objects that are not in motion still exert forces.
33	For instance, obstacles to motion like chairs or walls do exert forces; they do not just get in the way.
34	Consider a book lying on a table.
35	The book pushes downward on the table.
36	The magnitude of this downward force equals the book's weight.
37	The table also exerts an upward support force on the book that is equal to the book's weight.
38	Thus, the idea that only animate, moving objects can exert forces is incorrect.
39	There are still forces acting on inanimate, motionless objects.

APPENDIX I

INSTRUCTIONS TO PARTICIPANTS

1. ***Demographics questionnaire, pretest FCI, PEP:***

   "You will begin by completing a series of questionnaires. Please be sure to read all instructions carefully, as they will vary depending on the questionnaire. When you have completed this portion of the study, please let me know."

2. ***Think-aloud component:***

   a) *Demonstration and practice text:*

      "Now we are going to read some texts and think out loud after each sentence. First, I will demonstrate how to read and think aloud, and then I will give you a chance to try it. Let's practice."

      After the researcher completes the demonstration, the participant is given the remainder of the practice text with the following instructions:

      "Now I want you to read the sentence on each card out loud and talk aloud about your thoughts. Tell me everything that you are thinking – whatever comes to your mind – even if it is not relevant.

      Think about each sentence carefully, and make sure you understand what you read. Once you have turned to a new card, you will not be allowed to look back at any of the previous cards.

      Try to remember what you have read, because I will ask you some questions about this text later on."

   b) *After the practice think aloud is complete, the participant is given the first of two experimental texts, along with the following instructions:*

      "Please read the sentence on each card aloud and tell me everything that you are thinking. Then turn to the next card and do the same thing. Make sure that you understand what you read, and try to remember it, because I will ask you some questions about this text later on."

3. ***Distracter worksheet (to prevent rehearsal prior to recall task):***

   "Now I'd like you to spend a few minutes working these problems. No calculators are allowed."

4. ***Recall task:***

   "Now please type everything you remember from the text you just read, as closely as you can remember."

5. ***Posttest FCI Questions:***

   "Please read each question carefully and select the correct answer to the best of your knowledge."

6. ***Repeat steps 2b – 5, with second experimental text and corresponding posttest FCI questions.***

7. ***Question for treatment validity:***

   Participant is provided with a paper copy of the two experimental texts s/he read during the course of the study. Instructions state:

   "Please review the texts and respond to the brief questionnaire provided."

APPENDIX J

DISTRACTER WORKSHEETS

Worksheet A	Worksheet B
1. 464 + 763 =	1. 565 + 367 =
2. 453 x 564 =	2. 345 x 456 =
3. 80 / 4 =	3. 60 / 3 =
4. 1357 + 246 =	4. 1234 + 456 =
5. 678 – 567 =	5. 789 – 456 =
6. 160 / 4 =	6. 120 / 4 =
7. 56 x 35 =	7. 35 x 46 =
8. 1540 x 5 =	8. 1620 x 5 =
9. 1345 – 899 =	9. 1625 – 899 =
10. 367 x 6 =	10. 325 x 4 =

APPENDIX K

QUESTION FOR TREATMENT VALIDITY

Note: For this portion of the study (which occurred at the very end of the session), participants were provided with a copy of the two instructional texts they had read during the course of the study. At the bottom of each text, the following question appeared.

Which of the following statements best describes the text:

a. The text focuses on universal insight or awareness to teach the concepts of Newton's First Law.

b. The text focuses on logic and mathematics to teach the concepts of Newton's First Law.

c. The text focuses on observation and sensory experiences to teach the concepts of Newton's First Law.

APPENDIX L

COMPLETE TABLE OF CONCEPTUAL CHANGE SCORES

Total Instances of Conceptual Change for Each Participant, Presented as a Function of Congruent or Incongruent Text Conditions.

Participant #	Congruent	Incongruent	Total
1	0	0	0
2	1	0	1
3	0	0	0
4	1	0	1
5	4	1	5
6	0	0	0
7	0	0	0
8	3	0	3
9	0	0	0
10	4	1	5
11	4	0	4
12	4	0	4
13	4	1	5
14	4	2	6
15	0	0	0
16	0	1	1
17	3	3	6
18	0	0	0

Total Instances of Conceptual Change for Each Participant, Presented as a Function of Congruent or Incongruent Text Conditions.

Participant #	Congruent	Incongruent	Total
19	1	1	2
20	0	1	1
21	0	4	4
22	1	1	2
23	0	4	4
24	1	2	3
25	0	0	0
26	1	0	1
27	2	3	5
28	3	1	4
29	4	2	6
30	3	0	3
31	2	0	2
32	4	0	4
33	2	0	2
34	1	0	1
35	3	0	3
36	5	1	6
37	4	0	4
38	4	0	4

Total Instances of Conceptual Change for Each Participant, Presented as a Function of Congruent or Incongruent Text Conditions.

Participant #	Congruent	Incongruent	Total
39	3	0	3
40	0	2	2
41	4	1	5
42	3	0	3
43	1	1	2
44	1	0	1
45	0	0	0
46	1	0	1
47	0	0	0
48	3	0	3
49	1	0	1
50	3	2	5
51	2	2	4
52	2	3	5
53	0	1	1
54	0	0	0
55	0	2	2
56	1	3	4
57	0	3	3
58	0	4	4

Total Instances of Conceptual Change for Each Participant, Presented as a Function of Congruent or Incongruent Text Conditions.

Participant #	Congruent	Incongruent	Total
59	0	3	3
60	0	4	4
61	1	0	1
62	1	3	4
63	2	3	5
64	0	0	0
65	3	4	7
66	1	2	3
67	1	3	4
68	1	1	2
69	0	0	0
70	0	0	0
71	0	0	0
72	1	3	4
73	1	1	2
74	0	4	4
75	1	2	3
Total	111	86	197