Examining the influences of epistemic beliefs and knowledge representations on cognitive processing and conceptual change when learning physics

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A B S T R A C T

The purpose of this study was to investigate the role of epistemic beliefs and knowledge representations in cognitive and metacognitive processing when learning about physics concepts through text. Specifically, we 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. Results revealed that when individuals' epistemic beliefs were consistent with the knowledge representations in their assigned texts, they performed better on various measures of learning (use of processing strategies, text recall, and changes in misconceptions) than when their epistemic beliefs were inconsistent with the knowledge representations. These results have implications for how researchers conceptualize epistemic beliefs and support contemporary views regarding the context sensitivity of individuals' epistemic beliefs.

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1. Introduction

"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, Couse, & 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 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). The current study responds to these calls by examining the role of students’ epistemic beliefs and knowledge representations in cognitive and metacognitive processing in the context of learning about physics. Specifically, we 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, we address researchers’ calls to combine quantitative approaches with qualitative, 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. Specifically, we examine the online processes that occur while students read new material, as well as offline products that occur after reading. For online measure of learning, we explore 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), we define deep processing strategies as those that involve learners’ attempts to integrate new ideas with their 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). We 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).

In addition to exploring deep and shallow processing strategies, we also investigate two offline products of learning: text recall and conceptual change. Broadly speaking, conceptual change involves changing inaccurate or misconceived prior knowledge to “correct” or scientifically accepted knowledge (Chi, 2008). In the current study, we measure conceptual change by examining whether students changed their misconceptions1 about 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 our study is to add to the conceptual change literature. Across several models of knowledge and belief change, a combination of learner and text characteristics are 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, Muis, & Fulton, 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, our study investigates 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 our study, we first describe the theoretical perspectives and empirical research that informed our work. We then introduce our research questions, followed by our hypotheses.

1.1. Theoretical perspectives

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. Generally speaking, the different approaches to conceptualizing individuals’ beliefs about knowledge and knowing can be clustered into four categories: 1) developmental models (e.g., Belenky, Clinchy, Goldberger, & Tarule, 1986; King & Kitchener, 1994; Kuhn, Cheney, & Weinstock, 2000; Perry, 1970); 2) multidimensional views (e.g., Hammer & Elby, 2002; Hofer & Pintrich, 1997; Royce, 1959; Schommer, 1990); 3) metacognitive perspectives (e.g., Bromme et al., 2010; Hofer, 2004; Kitchener, 1983; Kuhn, 1999a, 1999b); and 4) integrated frameworks (e.g., Greene, Azevedo, & Torney-Purta, 2008; Muis et al., 2006). Although a comprehensive review of these various approaches is beyond the scope of this paper, we adopt the second approach—multidimensional views—for the current study.

In Schommer’s (1990) oft-cited 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. For example, for the structure dimension, certain knowledge, respectively, the continuum ranges from a belief that knowledge is simple and certain (typically considered to be a more “naive,” or less constructivist, view) to a belief that knowledge is complex and tentative (typically considered to be a more “sophisticated” or constructivist view).

In addition to further refinements of Schommer’s (1990) initial framework (e.g., Schommer, 1994; Schommer-Aikins, 2002), several other multidimensional frameworks can be 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, and are described as “largely tacit, crude, disconnected bits of cognitive machinery” (p. 144) that are activated in specific contexts (Elby, 2009, p. 144).

Multidimensional frameworks also differ with regard to the number and type of dimensions proposed. For example, in their “theories” framework, Hofer and Pintrich (1997) propose two core dimensions—1) nature of knowledge, and 2) nature of knowing—each of which 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 vs. 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 the current study, we adopt Royce’s (1959) multidimensional framework, which proposes two dimensions of beliefs about knowing: beliefs about how knowledge is derived, and beliefs about how knowledge is justified. These dimensions overlap with the “nature of knowing” dimension of Hofer and Pintrich’s (1997) framework; that is, beliefs about how knowledge is derived and

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1 In the conceptual change literature, these have alternately been referred to as preservice misconceptions (Chinn & Brewer, 1993), alternative conceptions (Tyson, Venville, Harrison, & Treagust, 1997), alternative frameworks (Caravita & Hallén, 1994), and naïve theories (Vosniadou, 2007), to name a few. For simplicity, we use the term “misconceptions” throughout this paper to refer to prior knowledge that is inconsistent with scientifically accepted ideas within a domain of study, such as physics (Murphy & Mason, 2006; Pines & West, 1983).
justified (Royce, 1959) are comparable to beliefs about the source of knowledge and justification for knowing, respectively (Hofer & Pintrich, 1997). In the context of his model, Royce (1978) proposed that individuals’ beliefs about how knowledge is derived and justified can be combined to reflect three basic approaches to knowing: 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, whereby individuals believe knowledge is derived via intuition and justified via universality.

These three approaches to knowing are considered to be 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 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).

1.2. Empirical studies

1.2.1. Epistemic beliefs and cognitive processing strategies

Within a multidimensional framework of epistemic beliefs, a number of researchers have examined relations between students’ beliefs and their use of cognitive processing strategies. 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.

Results from this study and others (e.g., Cano, 2005; Dahl, Bals, & Turi, 2005; Kardash & Howell, 2000; 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 student 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 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.

1.2.2. Epistemic beliefs and conceptual change

Although results from previous studies (e.g., Kardash & Howell, 2000; Muis, 2008; Schommer et al., 1992) have shown that epistemic beliefs are related to learning processes (e.g., strategies) and achievement related outcomes, few have examined relations between epistemic beliefs and other learning outcomes like conceptual change. In particular, researchers have called for more studies to examine these relations (Alexander & Sinatra, 2007; Murphy & Mason, 2006; Pintrich, 1999) and, to date, there is increasing evidence that epistemic beliefs have both direct (Qian & Alvermann, 1995) and indirect (Stathopoulou & Vosniadou, 2007a) influences on conceptual change. For example, in a study by Qian and Alvermann (1995), 212 high school students completed a prior knowledge test and a questionnaire designed to measure four dimensions of epistemic and learning beliefs proposed in Schommer’s (1990) model: 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, 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.

1.3. Beyond students’ epistemic beliefs: 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 constructivist view of knowledge being linked to better learning outcomes than a less 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, Kiehnnes, & Stahl, 2008; Elby & Hammer, 2001; Schommer-Akins, 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 et al. (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 et al.’s (2010) notion of a double-track approach. In one such study, Windschitl and Andre (1998) explored the interaction of 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. 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, 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 (1959) model), 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; Triadafilidis, 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 in which similar results were found within a different domain of study (Muis & Franco, 2010), Muis referred to this phenomenon as the consistency hypothesis, which suggests that during learning, an individual will focus more on aspects of the content that are consonant with that individual’s epistemic beliefs.

1.4. 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, we examined the role of epistemic beliefs and knowledge representations in cognitive and metacognitive learning strategies in the context of learning physics. We used Royce’s (1959) multidimensional model as a framework for characterizing both participants’ epistemic beliefs and the knowledge representations (i.e., physics texts) with which participants in our study engaged. Specifically, undergraduate students in our study 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, our study asks: Do individuals’ epistemic beliefs interact with knowledge representations to facilitate or constrain learning about physics concepts? Stated in more specific terms, our 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 do epistemic beliefs and knowledge representations interact to facilitate or constrain changes in individuals’ misconceptions about Newtonian mechanics?

Taking into account the literature reviewed above, we present two plausible sets of hypotheses. 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) consistency hypothesis, we predict a main effect for epistemic beliefs across all research questions (i.e., the main effect position), such 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, if we take 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, then we would not expect our results to reveal that one type of belief is superior to another with regard to the learning outcomes of interest. Rather, we would 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, we 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, we predict that there will be no differences in students’ use of shallow processing strategies as a function of congruency or incongruency (Hypothesis 2b).

Our study aims to contribute to the epistemic beliefs literature in two important ways. First, by examining the interaction between epistemic beliefs and knowledge representations, we 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 in our study, we 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, our 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.

2. Method

2.1. Participants

Seventy-five undergraduate students2 (N = 56 females) enrolled in various courses and majoring in several different disciplines participated in the study. 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 was 21.80 (SD = 4.03). The majority of students were of North American descent (mainly Caucasian, N = 59), and the remaining students were from Eastern countries (N = 14) or of European descent (N = 2).

2.2. Materials

2.2.1. Demographics questionnaire

A demographics questionnaire was used to collect conventional demographic information such as age, gender, year in university, undergraduate major, and first language spoken.

2.2.2. The Force Concept Inventory

The Force Concept Inventory (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 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

2 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.
of Newtonian concepts such that students’ grasp of the concepts is “insufficient for effective problem solving” (p. 151). The PCl has been used as a tool for measuring students’ misconceptions in a number of students of physics-related conceptual change (e.g., Kendeou et al., 2010; Savinainen, Scott, & Viiri, 2005). For this sample, Cronbach’s alpha was .83.

2.2.3. The Psycho-Epistemological Profile

The Psycho-Epistemological Profile (PEP; Royce & Mos, 1980) was used to measure participants’ epistemic beliefs. In accordance with Royce’s (1959) multidimensional model, 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 endeavor 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 scores met this criterion.

2.2.4. 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, in contrast to straightforward expository text, identifies common misconceptions about a topic and deconstructs those misconceptions through the presentation of contradictory evidence and correct explanations (Alvermann & Hague, 1989; Chambliss, 2002; Guzzetti, Snyder, Glass, & Gamas, 1993). According to Hynd (2001), a refutational format 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))³.

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 \( \sum F = 0 \) 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).

\[
\sum F = 0
\]

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:

\[
\sum F = 10N - 10N = 0
\]

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. 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.

³ Although Royce’s (1978) multidimensional model includes three dimensions (rationalism, metaphorism, and empiricism), we chose to focus only on rational vs. 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. We also felt more confident in our ability to approximate Royce’s definitions of rationalism and metaphorism in our presentation of pertinent Newtonian concepts.
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.

### 2.2.5. 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 labeled “elaboration,” “paraphrase,” and “metacognitive comments,” respectively (see Table 3 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.

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 labeled “repetition/rehearsal” and “association,” respectively (see Table 4 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.

Transcripts were coded independently by two research assistants who did not have knowledge of participants' epistemic beliefs while coding. Agreement between the two raters was calculated for each type of strategy (elaboration, paraphrase, metacognitive comments, repetition/rehearsal, and association) and found to be acceptable, ranging from $K = .53$ to $K = 1$. Disagreements were resolved through discussion.

#### 2.2.6. Text recall

To answer the third research question, we measured recall of text material 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., Kardas & Howell, 2000) meaning that recalled statements and 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 ($K = .84$, $p < .01$), and any disagreements were resolved through discussion.
2.2.7. 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 (i.e., the content that was covered in the physics texts). Each correct response was given one point, and each incorrect response is given a zero, with a maximum score of 5 points per law.

2.3. 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 tornadoes. 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 written texts and respond to the “treatment fidelity” question described above. The entire session took approximately 1 h and 30 min 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.

3. Results

3.1. Preliminary analyses

First, to ensure the knowledge representations were developed as intended, we explored participants’ ratings for each of the texts. For each of the four texts, the majority of participants perceived the

<table>
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<tr>
<th>Table 3</th>
<th>Descriptions and examples of deep processing strategies.</th>
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<tr>
<td>Type of strategy</td>
<td>Description</td>
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<tr>
<td>Deep processing</td>
<td>Elaboration</td>
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<tr>
<td></td>
<td>Paraphrase</td>
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<tr>
<td>Metacognitive comments</td>
<td>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).</td>
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<table>
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<tr>
<th>Table 4</th>
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<td>Type of strategy</td>
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</tr>
<tr>
<td>Shallow processing</td>
<td>Repetition/rehearsal</td>
</tr>
<tr>
<td>Association</td>
<td>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.</td>
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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 Royce’s (1978; Royce & Mos, 1980) definition of metaphorism; for the rational version of the first law, 84.3% of the participants perceived it as rational; for Newton’s Third Law in metaphorical form, 68.4% perceived it as metaphorical; and for the rational version of the third law, 70.3% perceived it as rational. Accordingly, we were 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 –6.3 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 5 for the PEP subscales as a function of predominant epistemic belief.

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.

### 3.2. Cognitive processing strategies

#### 3.2.1. 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. Means and standard deviations are presented in Table 6 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 Fig. 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.

#### 3.2.2. 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 6 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 \( p > .05 \)).

#### 3.3. Text recall

Our 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 7 for recall of text material across text type as a function of epistemic beliefs. Specifically, as shown in Fig. 2, students in our study 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 ($p > .05$).

3.4. Conceptual change

To answer our fourth research question, we conducted two types of analyses of participants’ responses to relevant FCI pretest and posttest items. First, we conducted a repeated measures ANOVA with epistemic beliefs (rational, metaphorical) and congruency (congruent, incongruent) as between-subjects variables, and changes over time in scores from pretest to posttest as the within-subjects variable. Results revealed a significant main effect for time ($F = 2.83, p = .03, \eta^2 = .04$), and a significant belief $\times$ congruency $\times$ time interaction ($F = 2.78, p = .04, \eta^2 = .04$). As shown in Figs. 3–6, post hoc comparisons revealed that for Newton’s First Law and for both epistemic groups, when the representational format of the text was congruent with students’ epistemic beliefs, they changed more misconceptions than when the text was incongruent, $t(26) = -4.32, p = .0001$ for the rational group, and $t(47) = -7.65, p = .0001$ for the metaphorical group. For Newton’s Third Law, the same pattern of results was found; students changed their misconceptions more under congruent beliefs to text conditions than incongruent beliefs to text conditions, $t(26) = -2.12, p = .01$ for the rational group, and $t(47) = -2.70, p = .01$ for the metaphorical group.

Second, for each of the items for each law, we calculated the number and percentage of participants who correctly changed their misconception on that item from pretest to posttest to explore specifically which misconceptions they changed or did not change. In Table 8 (first law) and 9 (third law), we 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 8), 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 concatenation 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.

For Newton’s Third Law items (Table 9), 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 214). Moreover, for three of the items (4, 15, 28), more than 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.

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. Figs. 7 and 8 present the percent of participants who successfully changed their misconceptions on Newton’s First and Third Law items, respectively.

4 Interestingly, this item is actually more relevant to Newton’s 2nd Law than Newton’s 3rd Law, but we included it in the third law subset to ensure equivalent numbers of posttest items for the two laws, and because our third law texts briefly discuss the relationship between force, mass, and acceleration (which is the focus of Newton’s 2nd Law).

4. Discussion

The purpose of this study was to investigate the role of epistemic beliefs and knowledge representations in cognitive and metacognitive processes in the context of learning physics. We used Royce’s (1959) 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 qualitative, dynamic process-oriented designs (e.g., Pintrich, 2002), we included several measures of learning in our study: 1) cognitive processing strategies (deep and shallow), 2) text recall, and 3) changes in misconceptions. Broadly speaking, we asked: Do individuals’ epistemic beliefs interact with knowledge representations to facilitate or constrain learning about physics concepts? Results from our 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 in our study: 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. We discuss the implications of these findings below, focusing in particular on their relevance to both the epistemic beliefs and conceptual change literatures.

4.1. Implications

4.1.1. 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 processes and outcomes — e.g., deeper approaches to learning, mastery-oriented goals, higher achievement scores — 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. For example, Elby and Hammer (2001) argue that epistemological sophistication “does not consist of a blanket generalizations that apply to all knowledge in all disciplines and contexts. It incorporates contextual dependencies and judgments” (p. 565) that take into account the discipline, the type of knowledge under discussion, and the intended use of the knowledge. 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.

Our 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 our study

| Table 8 |
| 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. |

| Table 9 |
| 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. |
show that there isn’t one type of epistemic belief that is superior to another with regard to facilitating the particular learning outcomes we measured (cognitive and metacognitive 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 the more significant factor. In our 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, and challenge Muis’ (2008) consistency hypothesis. In particular, it appears that the consistency is not between the underlying epistemic nature of the domain; rather, it is the epistemic nature of the text. Accordingly, in line with Bromme et al. (2010), we 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 their relations with individuals’ epistemic beliefs.

4.1.2. Conceptual change

The study of conceptual change 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, theorists have proposed several factors that influence the extent to which knowledge restructuring occurs (Alexander & Sinatra, 2007; Murphy & Mason, 2006; Sinatra & Pintrich, 2003) and numerous studies have explored whether these factors help or hinder conceptual change (e.g., Mason et al., 2008; Qian & Alvermann, 1995; Sinatra, Southerland, McConaughy, & Demestas, 2003). Contemporary frameworks of conceptual change reflect the view that change is complex, dynamic, and multifaceted (Murphy & Mason, 2006; Sinatra & Mason, 2008), involving the interaction of various factors related to the learner, and the to-be-learned material (e.g., a new conception (Posner, Strike, Hewson, & Gertzog, 1982), message (Dole & Sinatra, 1998), or text). Our study adds to this literature by investigating the role of epistemic beliefs (a learner characteristic) and knowledge representations (a text characteristic) in conceptual change in physics.

In previous 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 — often characterizing texts as refutational versus “traditional” (or expository), and exploring 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). Our study extends previous work by focusing on a more fine-grained text characteristic than has here-tofore been investigated. Specifically, we 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 our study provide preliminary evidence that conceptual change may be influenced by these finer-grained characteristics of texts. Although we only examined conceptual change immediately following the experimental manipulation, we found 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.

Of particular interest for conceptual change theory, results from our study provide tentative support for Dole and Sinatra’s (1998) Cognitive Reconstruction of Knowledge Model (CRKM). 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). 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 take priority in the model. In sum, 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. Although our study did not directly test this proposition, our 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).

4.1.3. General discussion

Our results arouse curiosity about why consistency between individuals’ epistemic beliefs and various knowledge representations may facilitate learning. Although our study did not explore this question specifically, we 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, we 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.

We 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 our 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.

4.2. Limitations

Several important limitations need to be acknowledged for the current study. First, our 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 we 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), we must also acknowledge the possibility that the texts might not accurately reflect the epistemic characteristics that we 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 limit the ecological validity of our findings and may have influenced outcomes in unintended ways. We appreciate the think-aloud methodology as a tool for capturing “online” data but suggest that future studies could enhance the validity of these data by incorporating additional online methodologies such as reading times or eye tracking devices.

Third, the design of our study did not include any delayed measures of learning, as both the recall task and posttest FCI questions were administered directly after participants finished reading their assigned texts. This issue is especially relevant to the conceptual change outcome in our 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.

Finally, our 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, Marx, & Boyle, 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) 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 our 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. We 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.

5. Conclusion

The aforementioned limitations notwithstanding, we submit that our study makes several important contributions. For example, our 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, our 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.

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