Adolescents' Epistemic Profiles in the Service of Knowledge Revision

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Abstract

Refutation texts have been previously shown to be effective at promoting knowledge revision. The current study builds on recent trends to gain deeper insights into how this learning advantage can be enhanced and extended to more learners. In particular, we examined whether distinct epistemic profiles can be discerned on the basis of individuals' beliefs about justification for knowing (i.e., justification by authority, personal opinion, or multiple sources) in the natural sciences. Further, we designed refutation texts according to this trichotomous framework of epistemic justification. We tested whether profiles stronger in certain dimensions would attain higher learning scores over others and whether consistency between profiles and texts would confer a learning advantage compared to when these factors were inconsistent. Results showed that distinct epistemic profiles are discernable and a profile with stronger preference for justification by multiple sources, authority, and lower preference for justification by personal opinion in natural science attained higher learning scores. Further, higher learning scores were observed when refutation texts justified by authoritative explanations were consistent with one cluster dominant in preference for justification by authority. Theoretical and instructional design implications are discussed.

Keywords: epistemic cognition; refutation text; knowledge revision; person-centered analysis.

1 Introduction

Revising misconceptions¹ is an important goal of formal education. For a number of concepts encountered in K-12 STEM curricula, such as Newtonian mechanics, students hold understandings that deviate from the scientific consensus (Hestenes, 1998). Such misconceptions impede learning of new information and may delay college and career readiness in STEM fields (Kendeou & van den Broek, 2005; Next Generation Science Standards, Lead States, 2013). In response, researchers and educators have developed and tested instructional interventions to promote the revision of misconceptions. One outcome of these empirical efforts has been to establish that refutation texts, which are texts that identify, refute, and explain common misconceptions, are an effective method to achieve knowledge revision or conceptual change² (Sinatra & Broughton, 2011; Tippet, 2010).

A recent trend in the extant literature has been to gain deeper insights into how refutation texts fit into broader theories of comprehension (Dumas, Alexander, & Grossnickle, 2013) and how their beneficial effects can be enhanced and extended to all learners (Authors, 2016; Poehnl & Bogner, 2013; Trevors, Muis, Pekrun, Sinatra, & Winne, 2016). To this end, researchers have studied the interactions between refutation texts and the characteristics of the individuals reading them (Cordova, Sinatra, Jones, Taasobshirazi, & Lombardi, 2014; Kendeou, Muis, & Fulton, 2011; McCrudden & Kendeou, 2014). The current research builds off this trend by examining

¹ In the current article, we use the term *misconceptions*—as it is frequently used in the research literature on conceptual change—to describe prior knowledge that deviates in structure from that of the scientifically accepted conception. We wanted to recognize definitional similarities with other descriptors in conceptual change and science education research such as *alternative conceptions*, *alternative frameworks*, *intuitive or naïve conceptions*, and *preconceptions*.

² In the current study, we use the term *knowledge revision* to refer to revision of a specific erroneous belief that is amenable to change via a refutation text. In the extant literature, the term *conceptual change* has been used in reference to several different grain-sizes of change, including change in specific beliefs, flawed mental models, and ontological category errors (Chi, 2008). Although in the current study we focus on the change of specific erroneous beliefs, findings from previous research that have used the term *conceptual change* are informative for our current design. However, to prevent the proliferation of terms used in the current article, we used the term knowledge revision throughout.

how one such characteristic relevant to misconceptions – individuals' thinking about knowledge and knowing, referred to as their epistemic cognition (Greene, Sandoval, & Bråten, 2016) – interacts with variations made to the traditional refutation discourse structure to ~~impact~~promote ~~on~~ knowledge revision.

In the first section, we outline recent theoretical and empirical research on refutation texts for knowledge revision, including a proposed framework that explains the theoretical mechanisms for their effectiveness. Next, we review models and empirical evidence for relations between epistemic cognition and knowledge revision. Then we review recent research on the theoretical links and empirical interactions between epistemic cognition and refutation texts on knowledge revision to inform the hypotheses of the current study.

1.1 Refutation Text and Knowledge Revision

Refutation texts are typically comprised of three components: an explicit identification of a common misconception; a statement of the inaccuracy of the misconception; and an explanation or justification for the correct conception (Hynd, 2001). The effectiveness of refutation texts to promote knowledge revision compared to texts without a refutation structure has been extensively documented (Braasch, Goldman, & Wiley, 2013; Broughton, Sinatra, & Nussbaum, 2013; Diakidoy, Mouskounti, Fella, & Ioannides, 2016; Kendeou, Smith, & O'Brien, 2013; Kendeou & van den Broek, 2007; Kendeou, Walsh, Smith, & O'Brien, 2014; Trevors et al., 2016; van den Broek, 2010; van Loon, Dunlosky, van Gog, van Merrienboer, & de Bruin, 2015).

Recently, Kendeou and colleagues (2013, 2014) have proposed a theoretical framework that accounts for how the three components of refutation texts produce these empirical findings. According to the Knowledge Revision Components (KReC) framework (Kendeou & O'Brien,

2014), for prior misconceptions to be revised, a necessary condition is their activation in close proximity to the activation of the correct concepts (Co-activation Principle). Co-activation is a necessary condition because the new, correct knowledge should be integrated in the conceptual network that contains the misconception (Integration Principle) and become dominant in that network. Dominance is achieved as the amount of correct information in this conceptual network increases with the addition of explanations and justifications, which draws more activation to itself at the expense of the misconception (Competing Activation Principle). This competition determines whether knowledge revision will be successful or not.

Indeed, Kendeou and colleagues have empirically identified the explanation component in refutations as a key determinant of their success (Kendeou et al., 2013, 2014). Specifically, in a series of experiments, they found that refutations with explanations were more effective than refutations without explanations at eliminating the activation of incorrect information during reading (Kendeou et al., 2014; Rapp & Kendeou, 2009). Specifically, refutations with strong explanations, defined as multiple sentences that lead to a rich, recursive, and interconnected network of information, resulted in faster reading times of sentences stating the correct conceptions than weaker single-sentence explanations (Kendeou et al., 2014). The authors concluded that refutations with elaborated explanations were more effective than unelaborated explanations to eliminate the disruption to comprehension caused by the refuted information. Thus, the presence and quality of explanations of correct conceptions are a core determinant of the success or failure of the revision process.

However, open questions remain on how individual characteristics interact with refutation texts to affect knowledge revision. One factor theoretically predicted to be relevant in the process of revising knowledge are individuals' beliefs about justification for knowing, which

can be considered an aspect of their epistemic cognition (Greene et al., 2016). In past research, we have applied theories of epistemic cognition to redesign how refutation texts justify correct knowledge as one means to promote knowledge revision (Authors, 2016). To extend and refine this line of inquiry to better understand for whom refutations are most effective, we turn next to research on epistemic cognition and, in particular, how individuals process various forms of knowledge justification.

1.2 Epistemic Cognition and Knowledge Revision

When deciding when something is known, what level of uncertainty about knowledge is tolerable, or who is a trustworthy source of knowledge, individuals' epistemic cognition becomes relevant. Epistemic cognition refers to the cognitive and behavioral manifestation of individuals' beliefs about knowledge and knowing, including beliefs about complexity, certainty, sources, and ways of justifying knowledge (Barzilai & Zohar, 2014; Greene, Sandoval, & Bråten, 2016; Sinatra et al., 2014). Although there are a number different theoretical frameworks of epistemic cognition (Barzilai & Zohar, 2014; Chinn, Rinehart, & Buckland, 2014; Elby & Hammer, 2010; Kuhn, Cheney, & Weinstock 2000; Muis, 2007), in the current research we focus on this latter aspect – beliefs about the justification of knowledge – since we contend that this dimension of epistemic cognition is particularly relevant for learning from refutation texts and knowledge revision (Authors, 2016). In particular, given that the success of refutation texts as an instructional tool derives in large part from the explanations and justifications of correct knowledge (Kendeou et al., 2013, 2014), we draw upon theories that focus on this dimension of epistemic cognition.

1.2.1 Justifications for knowing. Recent theoretical and empirical research presents a trichotomous framework of epistemic justification and shows how this perspective productively

explains relations between epistemic cognition and learning. Ferguson, Bråten, and colleagues (Ferguson, 2015; Ferguson, Bråten, & Strømsø, 2012; Ferguson, Bråten, Strømsø, & Anmarkrud, 2013) describe three positions on epistemic justifications that individuals may take that differ in their focus on what evidence or reasoning is valid to justify a knowledge claim: justification by authority, whereby individuals rely on external authoritative sources (e.g., teachers, textbooks, religious leaders); justification by personal opinion, whereby individuals believe knowledge is justified if it coheres internally with their prior personal opinions and knowledge; and justification by multiple sources, whereby individuals rely on corroboration between multiple sources as a valid way to determine the veracity of knowledge claims.

A notable shift has occurred in the way researchers of epistemic cognition view justifications for knowing. Early conceptualizations of justifying knowledge on the basis of authority held that this was a passive, uncritical, or naïve stance (Hofer & Pintrich, 1997). Contemporary researchers now present a more nuanced perspective and no longer consider use of authoritative sources as inherently passive or uncritical. For instance, Chinn, Buckland, and Samarapungavan (2011) broadened the scope of types of justifications and ~~reconceptualised~~ conceptualized authority as *testimony*. Chinn et al. (2011) conclude that individuals rely ubiquitously on socially-shared testimony from others to justify their knowledge (e.g., via rumors, weather reports, scientific publications) and that a sophisticated epistemic stance is based on knowing which types of justifications are best suited to a particular situation. This reconceptualization implies that individuals are actively evaluating and corroborating multiple interacting justifications to ascertain support for knowledge claims (Chinn et al., 2011). Thus, justification by multiple sources differs from justification by authority in that the latter represents a preference for one authoritative source to justify belief in a particular knowledge

claim whereas the former represents a preference for multiple corroborating sources to perform the same function. These differences also extend to what cognitive processes are entailed, as justification by authority would involve identifying and committing to memory expert testimony whereas justification by multiple sources would involve a critical analysis of claims for the preponderance of evidence from multiple sources of varying authoritativeness. As a counterpoint, a belief in justification by personal opinion suggests a more subjective approach to knowledge and knowing that would entail privileging one's own opinion over others and a potentially reduced motivation to resolve discrepancies between knowledge claims since knowledge is believed to be a question of opinion (Bråten, Britt, Strømsø, & Rouet, 2011; Bråten, Ferguson, Strømsø, & Anmarkrud, 2014c; Ferguson et al., 2012, 2013; Ferguson & Bråten, 2013; Greene, Azevedo, & Torney-Putra, 2008).

In their program of research on justification beliefs, Bråten, Ferguson, and colleagues have found consistent empirical trends. Students' self-reported beliefs in justification by authority was found to be the most valued form of justification when studying science content (Bråten & Ferguson, 2014; Bråten, Ferguson, Anmarkrud, Strømsø, & Brandmo, 2014a; Bråten, Ferguson, Strømsø, & Anmarkrud, 2013) and positively predicted essay citations (Bråten et al., 2014c) and science course grades (Bråten & Ferguson, 2014). Justification by multiple sources positively predicted attending to source information (Bråten et al., 2014c), time spent on objectively reliable internet pages (Kammerer, Amann, & Gerjets, 2015), situational interest and deeper level learning strategies (Bråten, Anmarkrud, Brandmo, & Strømsø, 2014b), and higher quality post-reading argumentative essays (Bråten et al., 2014c). In contrast, personal justification was found to negatively predict readers' abilities to validate inferences across documents and science course grades (Bråten & Ferguson, 2014; Bråten et al., 2013, 2014a). In

related research, a belief that knowledge is a matter of subjective personal opinions negatively related to sourcing behaviors (e.g., connecting text content to its author; Barzilai, Tzadok, & Eshet-Alkalai, 2015) and negatively related to comprehension of complex scientific issues (Barzilai & Eshet-Alkalai, 2015). In sum, reliance on justification based on personal opinion over corroboration of multiple sources or scientific authority may be detrimental to learning in some contexts, as the learner's focus is shifted to internal considerations away from attending to and more deeply processing the information in the texts.

1.2.2 Epistemic justification and knowledge revision. The trichotomous framework of epistemic justification has important theoretical implications for knowledge revision and refutation texts in particular, given their shared focus on justification. Recall that a central mechanism for knowledge revision described by Kendeou and colleagues (2013, 2014) is the richness and dominance of causal explanations or justifications relayed by refutation texts in subsequent mental representations. Beliefs in epistemic justification may act as one set of predictors for the construction of these mental representations. For example, a belief in personal justification may prompt overreliance on prior, erroneous knowledge, thus preventing the encoding and/or integration of new, correct information relayed by the refutation text. In contrast, a belief in justification by authority may promote the construction of a detailed mental representation of what a text is about. However, in the absence of attending to any personal justifications, then a necessary step of knowledge revision – co-activating incorrect, prior knowledge and correct, new knowledge – may fail, reducing the likelihood of activation competition; and thus increasing the probability that knowledge revision may be unsuccessful. Finally, a belief in justification by multiple sources may promote attending to multiple correct pieces of evidence and rationale that enriches the mental representation even more, thus leading

to successful knowledge revision. However, in the absence of attending to any information used to justify prior personal beliefs, similar to justification by authority, a belief in justification by multiple sources may not sufficiently induce co-activation between old and new information necessary for knowledge revision. Thus, a potential advantage may be conferred on individuals with a combination of beliefs on epistemic justifications to varying degrees of strengths. This compels researchers to explore a person-centered [research](#) approach and examine the combined effects [of](#) multidimensional profiles of epistemic cognition on learning rather than the effects of individual dimensions in isolation. Further, refutation texts that emphasize different dimensions of epistemic justification may interact with characteristics of learners and thus have important implications for the success or failure of knowledge revision (Bromme, Pieschl, & Stahl, 2010; Murphy, Alexander, Greene, & Hennessey, 2012).

1.2.3 Interactions between readers' epistemic cognition and refutation texts. Several empirical investigations offer insights into the potential interaction between readers' epistemic cognition and textual characteristics. Specifically, previous research has shown consistent effects of epistemic cognition aligned with a constructivist epistemology on conceptual change (Stathopoulou & Vosniadou, 2007). Individuals with epistemic beliefs more aligned ~~with~~[to](#) a constructivist epistemology (e.g., knowledge is interconnected and evolving) are more likely to be sensitive to conceptual inconsistencies in texts (Trevors, Feyzi-Behnagh, Azevedo, & Bouchet, 2016), construct coherent mental representations (Trevors & Muis, 2015), co-activate competing information and experience cognitive conflict while reading a refutation text (Kendeou, Muis, & Fulton 2011), and engage in higher levels of conceptual change learning (Mason & Gava, 2007; Mason, Gava, & Boldrin, 2008). Further, the strength of individuals' knowledge revision will vary as a function of the epistemic justification presented by refutation

texts. Refutation texts designed to emphasize justification by multiple sources resulted in greater learning than other forms of epistemic justification (by personal opinion or by authority) and more than ~~the a~~ non-refutation control ~~text~~ (Authors, 2016).

Notably, researchers find that the aforementioned effects are often moderated by interactions between epistemic cognition and instructional or text design. Muis and colleagues have explored these interactions in their work on the *consistency hypothesis* (Franco et al., 2012; Muis, 2008; Muis & Franco, 2010; Muis, Kendeou, & Franco, 2011). In particular, these researchers determined that when an individual's epistemic profile was consistent with the underlying epistemology of a learning context, (e.g., rational approaches to epistemic justification when solving a math problem), they engaged in greater self-regulation of cognition and deeper processing of the content (Franco et al., 2012; Muis, 2008; Muis & Franco, 2010; Muis et al., 2011). Muis et al. (2011) argued that individuals will seek out and process to a greater degree information that is consistent with their epistemic profile, and given a context with an abundance of epistemically consistent information (e.g., more rational information available when solving a math problem), individuals will have more opportunity to reflect on and regulate their unfolding comprehension of this information. We sought to extend this line of research to investigate possible learning advantages that may occur when there existed consistency between individuals' epistemic justification beliefs, representational format of texts, and underlying epistemology of the domain. In the current study, where we examined learning about topics in the natural sciences, we *a priori* determined that consistency existed between the domain of the natural sciences and beliefs in justification by authority and multiple sources but not justification by personal opinion, as the use and corroboration of multiple authoritative sources is consistent with the rules of inquiry that characterizes science where ~~as in~~ justification

by personal opinion in contrast is not sufficient to make knowledge claims (Chinn & Malhotra, 2002; Hmelo-Silver, Duncan, & Chinn, 2007; Sandoval, 2014).

Further insights into such critical learning processes have been gained by research that has adopted a person-centered approach. Often, research on epistemic cognition has adopted a variable-centered approach, analyzing differences in variance between aggregated samples of individuals. In contrast, a person-centered approach examines the person as its unit of analysis, investigating differences between subgroups formed based on similarities of important characteristics. Research that has adopted a person-centered approach has found that a subgroup with a combination of constructivist epistemic beliefs attained the highest course grades (Chen, 2012) and profiles of individuals' confidence, interest, self-efficacy, and knowledge could differentiate the degree of conceptual change achieved with a refutation text (Cordova et al., 2014). Recently, Kampa, Neumann, Heitmann, and Kremer (2016) found that epistemic profiles could be discerned across several dimensions of epistemic beliefs and which differentiated among 10th grade students' motivation, self-concept, and achievement in the natural sciences. Notably, the authors concluded that adopting variable-centered analyses would have concealed these differences. Particularly relevant to the current study, Ferguson and Bråten (2013) found that profiles can be generated on the basis of epistemic justification dimensions, in which justification by authority and multiple sources ~~become~~became pronounced after reading multiple conflicting texts. However, open questions remain on the effects of combined epistemic justification profiles on knowledge revision and the potential interactions between these profiles and various designs of the justification component in refutation texts.

Another consideration of the current study was the relative paucity in research on children's epistemic cognition as it predicts academic achievement. Although there is a long

tradition of research in developmental psychology on children's epistemic cognition, which often examines how educational and life experiences relate to epistemic development (Bendixen, 2016; Burr & Hofer, 2002; Krettenauer, 2005; Hallett, Chandler, & Krettenauer, 2002; Kuhn, Cheney, & Weinstock, 2000; Moshman, 2015), relatively fewer investigations have been conducted on children's epistemic cognition using an educational psychology research paradigm, in which epistemic cognition is examined as it relates and predicts relevant learning outcomes (Hofer, 2004). Related to beliefs about how knowledge is justified, the period of adolescence in particular marks a shift away from realism as the singular form of justification (i.e., knowledge is objective and a direct copy of reality) towards differentiation of other forms of justification, including subjective skepticism, dogmatic reliance on authority, or appeals to rationality (Greene et al., 2008). Therefore, in the current study we focus on how adolescents variously justify knowledge in the natural sciences with the intent to shed light on academically relevant epistemic profiles during this consequential developmental period.

1.3 The Present Study

Central to the current study is the exploration of interactions between readers' epistemic cognition and refutation texts. Given the integral role of justification to the design of refutation texts and knowledge revision, we designed three types of refutation texts that were aligned with the trichotomous justification for knowing framework (i.e., justification by personal opinion, authority, or multiple sources) and compared the effectiveness of these designs against a non-refutation control. Further, given profiles of combined epistemic justifications varying in strength may confer a learning advantage not observable when examining dimensions in isolation, we adopted a person-centered approach and explored the presence and implications of specific epistemic cognition profiles. Last, given the potential for advantageous interactions

when epistemic cognition is consistent with the underlying epistemology of refutation texts and academic domains, we also explored this possibility. Specifically, based on theoretical and empirical considerations from Kendeou et al. (2013, 2014), Bråten and Ferguson and colleagues (Bråten et al., 2014b, 2014c; Bråten & Ferguson, 2014; Ferguson & Bråten, 2013), and Muis et al. (2011) we tested two hypotheses:

Hypothesis 1A: Distinct epistemic profiles can be discerned on the basis of adolescents' beliefs about justification for knowing.

Hypothesis 1B: Epistemic profiles that are relatively high on justification by multiple sources (JMS) and justification by authority (JA) will outperform profiles relatively low on these dimensions and outperform profiles high on justification by personal opinion (JPO) on post-tests measures of learning.

Hypothesis 2: Epistemic profiles and refutation texts will interact, such that profiles relatively high in JMS and/or JA will attain higher learning scores after reading a refutation text with an epistemic justification component that was consistent with their epistemic profile than when these factors were inconsistent.

A summary of these hypotheses is presented in Table 1. We tested these hypotheses in the current study with a mixed factorial, within- and between- subjects design. In particular, we collected adolescents' self-reported beliefs about justification for knowing in the natural sciences and applied cluster analysis to determine person-centered epistemic profiles.- We designed three

refutation texts conditions (plus a non-refutation control) based on three forms of epistemic justification that identified common misconceptions in the natural sciences, refuted them, and explained the correct concept with justification that appealed to authority, multiple sources, or personal opinion. The use of person-centered analysis reflects a potentially more ecologically valid approach to investigations into individuals' epistemic beliefs. Rather than text designs that were fully consistent with epistemic profiles, refutation texts were designed to focus on one epistemic dimension at a time given that clusters cannot be prefigured and justifications in texts are binary and cannot reflect variations in continuous epistemic dimensions. All participants read each type of refutation text and effects and interactions with epistemic profiles were analyzed with both pre- to post-test comparisons as well as a near-transfer test of learning and physics course grades to bolster our conclusions.

2 Method

2.1 Participants

Participants in the study were 246 Greek-Cypriot children who volunteered from 24 classes from 6 public secondary schools in Cyprus.³ The sample included 147 girls and 99 boys with an overall mean age of 14.09 years ($SD = 0.29$). All participants were white, native Greek speakers, and had no reported history of speech, attention, neurological, or sensory difficulties. Parental consent was obtained and participation was anonymous. The study employed a within- and between-subjects design and random assignment to four material sets that are described in detail below.

2.2 Materials

³ Participants took part in conditions within a larger study described in Authors (2016). Thus, all students in the current study completed all individual difference, evaluation, and comprehension measures following the same procedure of the Authors (2016) study, while also completing the epistemic cognition measure (described below). Only materials and procedures pertaining to the current set of analyses will be presented here.

2.2.1 Topic knowledge test. We developed an eight-item test that was administered before and after reading the refutation texts to assess topic knowledge. Each item addressed a common misconception in Newtonian Mechanics (e.g., Heavier objects fall faster) that was also addressed by one of eight experimental texts used in the current study. Misconceptions were selected from the taxonomy of misconceptions reported in the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992). Each test item had two-tiers (Tan, Goh, Chia, & Treagust, 2001; Treagust, 1988). The first tier was a typical True/False question, whereas the second tier required participants to provide an explanation for their response. On the True/False question, participants were awarded one point for the correct answer and zero points for an incorrect answer. On the explanation question, participants were awarded three points for the correct explanation, one point for an incomplete or partially correct explanation, and zero points for an incorrect explanation. The possible range of scores was 0-4 on each question. Two raters scored all tests independently and any disagreements (3.3%) were resolved through discussion. The reliability of the scores on the test was high ($\alpha = .82$). The topic knowledge test was administered twice: once before reading and again after reading to assess learning.

2.2.2 Epistemic cognition measure. To assess beliefs about justification for knowing, we used the Justification for Knowing Questionnaire (JFK-Q) developed by Ferguson et al. (2013). This is an 18-item questionnaire based on the multidimensional conceptualization of justification for knowing by Greene et al. (2008), with items written to capture justification of knowledge claims by means of different types of sources. Specifically, the JFK-Q is intended to capture separate dimensions concerning justification by personal opinion (JPO; e.g., “What is a fact in natural science depends on one’s personal views”), justification by authority (JA; e.g., “When I read something about natural science that is based on scientific investigations, then I

believe that it is correct”), and justification by multiple sources (JMS; e.g., “To detect incorrect claims in texts about natural science, it is important to check several information sources”), with all items pertaining to the domain of science. The questionnaire was translated from English in Greek following a double translation approach. Participants rated each item on a 10-point anchored scale (1 disagree completely, 10 agree completely). Results from factor analysis of this measure are reported in the Results section.

2.2.3 Texts. ~~The Eight textual texts materials~~ were written in Greek ~~and consisted of 8 passages, and~~ each addressed ~~ing~~ a separate misconception in Newtonian Mechanics. The ~~passages-texts~~ were narrative-informational (Duke, 2000), that is, narrative texts that convey information about the natural world. Each ~~passage-text~~ included an Introduction (100 words), a Refutation section (45 words), an Explanation section (110 words), and a Closing section (20 words). The Introduction served to establish the story line of the ~~passage-text~~ (e.g., *Tom was hanging out with one of his friends this afternoon. They were planning to go see a movie and they were very enthusiastic about it. While getting ready, they started talking about their homework and specifically about a physics problem that was due the next day. It was a problem that involved two balls that were exactly the same size and shape, but one weighted twice as much as the other. The problem has assumed that the two balls would be dropped from a house roof at the same time*). This was followed by an acknowledgement of the misconception (e.g., *Tom had initially believed that if two objects were the exact same shape and size, but one was heavier, the heavier object would fall faster*) and one of the three refutation-plus-explanation conditions: refutation with justification by authority (RJA), refutation with justification by multiple sources (RJMS), and refutation with justification by personal opinion (RJPO). A fourth condition that included no refutation (NR) served as the control. The ~~RJA~~ text refuted and

explained a common misconception based on an authority (e.g., *His science teacher explained in class earlier that day that this idea was incorrect*). The RJMS text was based on converging evidence from two authoritative sources (e.g., *A scientific article and an encyclopedia Tom read explained that this idea was incorrect*), whereas the RJPO was based on the story character's own opinion (e.g., *He always trusted his opinion, so he self-explained why his initial idea was incorrect*). The non-refutation (NR) control condition simply continued the storyline without stating the misconception, refuting, or explaining it. Texts were equated on length (275 words each). This was accomplished for non-refutation text by adding information that simply continued the storyline but that did not explain or justify the correct concept. Texts were also equated on readability as indexed by the Automated Readability Index (ARI). The ARI indices of the texts ranged between 13.44 – 14.61, suggesting their appropriateness for the target age group. A sample text in each of the four conditions is included in the Appendix (please note that the sample text has been translated from Greek to English and thus the length of each section is not the same).

Four material sets were constructed so that students could receive in a counterbalanced order 8 texts, two in each of the four text conditions. Following this design, all participants read 8 passage texts, all four text-refutation conditions (within-subjects design), and all texts appeared in all four conditions across participants. Participants were randomly assigned to one of the four material sets. Thus, material set served as a blocking variable and was included in the analyses to remove any variability associated with it.

2.2.4 Transfer problem test. To assess learning after reading, we developed a near transfer problem test was developed to further assess learning after reading. The test was considered near transfer because it required the use of knowledge acquired in each of the texts

applied in a different narrative context during the same session (Barnett & Ceci, 2002). The test included 8 scenario problems. Each scenario problem addressed the misconception that was targeted in each text the following way. In each scenario, two friends were presented expressing both the correct and the incorrect conception. For example, the scenario problem addressing the misconception that *if two objects were the exact same shape and size but one was heavier, the heavier object would fall faster* started with two friends, Jean and Mary walking, spotting a brick and a plastic solid box that had the same size. “*Jean bet Mary that if they threw them both at the same time over the side of the bridge into the river, the brick would hit the water first. Mary argued that they would both hit the water at the same time.*” Following the scenario, participants were presented with two questions. The first question asked participants to resolve the disagreement, and answer which girl was correct. The second question asked participants to explain in detail why they thought she was correct. On the first question, participants were awarded one point for the correct answer and zero points for an incorrect answer. On the second question, following the same rationale described in the Topic Knowledge test above, participants were awarded three points for the correct explanation, one point for an incomplete or partially correct explanation, and zero points for an incorrect explanation. The possible range of scores was thus 0-4 on each question. Two raters scored all tests independently and any disagreements were resolved through discussion. The reliability of the scores was high ($\alpha = .85$).

2.2.5 Physics course grades. Final exam physics grades were self-reported by the students on a scale from 0-20. Schools follow the exact same curriculum and textbooks as per the Ministry of Education and Culture policy. In this context, a course grade reflects a student’s overall performance (including class participation and exam performance) as evaluated by their teacher.

2.3 Procedure

Data for the study were collected in two separate sessions by six graduate research assistants. In the first, 40-min session the epistemic beliefs questionnaire, and the topic knowledge test were group-administered in participants' classrooms. Participants were instructed to read each question carefully and answer to the best of their knowledge. One week after the first session, each participant read the eight texts in Newtonian Mechanics and responded to the topic knowledge test again and the transfer test during an 80-min session that also took place in participants' classrooms. Participants did not have access to the texts while completing the topic knowledge post-test or the transfer test.

3 Results

3.1 Preliminary Analysis

A significant correlation between total topic knowledge post-test scores and transfer test scores showed evidence of convergent construct validity, $r(246) = .70, p < .001$.

We elected to conduct an exploratory factor analysis given that, to our knowledge, no other research has administered the JFK-Q with adolescents in Greek. Thus, we wanted evidence of the nature of the factors that were produced in this new context. Principal components analysis⁴ with oblique rotation was conducted using IBM SPSS v24.0 to assess the underlying factor structure for the 18 items of the JFK-Q. Oblique rotation was used because the factors were expected to be correlated (Ferguson et al., 2013). Three factors were requested, based on the fact that the items were designed to index three constructs: justification by personal opinion (JPO), justification by authority (JA), and justification by multiple sources (JMS). The mean

⁴ Principal components analysis (PCA) was currently used as the extraction method consistent with previous research with the JFK-Q (Ferguson et al., 2013). An alternative extraction method to PCA is principal axis factoring (PAF), however, both are commonly used in epistemic cognition research (Buehl, 2008) and often produce similar results (Meyers, Gamst, & Guarino, 2013; Widaman, 2007). Indeed, a re-analysis with PAF selected as the extraction method lead to all items mapping onto the same factors.

Kaiser-Meyer-Olkin measure of sampling adequacy was .75, indicating the data were suitable to principal components analysis. Similarly, the Bartlett's test of sphericity was significant ($\chi^2 = 941.70$, $df = 153$, $p < .001$). The three extracted factors accounted for 44% of the total variance in the measure and were consistent with theory and previous research (Ferguson 2015; Ferguson et al., 2012, 2013; Ferguson & Bråten, 2013). The rotated solution showed three factors had satisfactory pattern coefficients with six items that loaded onto each of factors and no item significantly and equally loaded on two or more factors (pattern and structure coefficients can be found in a supplementary appendix). Thus, the average of the six items for each of the three factors was calculated and used in the subsequent cluster analysis. The reliability estimates for average scores on the factors of JPO, JA, and JMS, respectively, were $\alpha = 0.63$, $\alpha = 0.73$, and $\alpha = 0.75$.

3.2 Cluster Analysis

To test Hypothesis 1A, we examined whether profiles could be formed using the means for each of the three justification for knowledge factor dimensions (i.e., JPO, JA, JMS). Given that these data were on the same scale and normally distributed, no weighing or transformations were conducted. Epistemic justification dimensions were analyzed by the *k*-means cluster procedure of IBM SPSS v24.0. A variety of different methods was used to determine the appropriate number of clusters; we evaluated two-, three-, four-, and five-cluster solutions for distinct, non-redundant, profiles with adequate number of participants in each (Pastor, 2010).

Univariate ANOVA indicated that the two-cluster solution did not significantly differentiate among the three justification dimensions, ($p > .05$ for JPO). Results from ANOVA for the three-cluster solution showed acceptable differentiation among the three justification dimensions (all $ps < .001$). Further, the three-cluster solution showed distinct, non-redundant

profiles. Cases for Cluster 1 appeared to be relatively moderate on all three justification dimensions. Cases in Cluster 2 were highest overall on all dimensions. Cases in Cluster 3 appeared to be relatively high on JMS and JA, and lowest overall on JPO. There were an adequate number of cases in each cluster (22-40% of total sample).

Results from ANOVA for four- and five-cluster solutions showed acceptable differentiation among the three justification dimensions (all $ps < .001$). However, these solutions did not produce distinct, non-redundant profiles: cases in Cluster 1 and Cluster 3 in the four-cluster solution and cases in Cluster 1 and Cluster 5 in the five-cluster solution were all relatively moderate across the justification dimensions. Thus, the three-cluster solution was determined to produce the most interpretable and distinct profiles.⁵ The means for the justification dimensions across the three-cluster solution are reported in Table 2 and depicted in Figure 1. Follow-up pairwise comparisons confirmed that all three justification dimensions significantly differed between the three clusters (all $ps < .05$).

To further validate the cluster solution, ANOVA with post-hoc comparisons using Bonferroni correction was conducted with cluster group as the independent variable, and physics grade, a variable not used in the cluster analysis, as the dependent variable. Results showed a significant difference between epistemic profiles, $F(2, 243) = 10.84, p < .001, \eta^2 = .08$. Follow-up Bonferroni-corrected pairwise t tests showed that Cluster 3 (high JA/JMS, lowest JPO; $M = 16.46, SE = .33$) attained significantly higher physics grades than Cluster 1 (moderate on all dimensions; $M = 14.31, SE = .32$), $t(191) = 4.63, p < .001$, Cohen's $d = .67$. The difference between Cluster 1 (moderate on all dimensions; $M = 14.31, SE = .32$) and Cluster 2 (highest on all dimensions; $M = 15.62, SE = .44$) ~~approached~~ did not reach statistical significance ~~yet the~~

⁵ Sample size did not permit splitting nor was a second sample available to test the replicability of the final cluster solution, therefore caution is recommended in considering the generalizability of findings. However, we describe additional steps taken to externally validate the current clusters.

practical significance indicates a difference that warrants further attention, $t(150) = 2.39$, $p = .053$, Cohen's $d = .41$. No significant difference was obtained between Clusters 2 and 3, $t(145) = 1.51$, $p > .3$ Cohen's $d = .26$.

3.3 Post-Test Learning

To test Hypotheses 1B and 2, namely that JMS and JA dominant epistemic profiles, designed refutation texts, and consistency between these factors would confer a learning advantage, a mixed factorial $3 \times 4 \times 2$ repeated measures ANOVA was conducted. Cluster profile (1, 2, or 3) was entered as the between-subject variable and topic knowledge test items addressed by each text type (RJA, RJMS, RJPO, and NR) and by time of test (pre-test and post-test) were entered as within-subject variables. Material set was entered as a blocking variable. Results showed a main effect of time, a main effect of cluster, and a three-way interaction between time $\times$ text type $\times$ cluster. The material set variable did not account for any variance, $F(1, 242) = 1.45$, $p > .05$. Means are presented in Table 3 and inferential statistics are presented in Table 4.

On the main effect of test time, given that there were only two time points (pre-test and post-test) an examination of means showed that participants scored significantly higher overall at post-test ($M = 2.16$, $SE = .114$)⁶ compared to pre-test ($M = 1.56$, $SE = .091$).

On the main effect of cluster and the interaction between time, text type, and cluster, two sets of post-hoc analyses were conducted. First, Bonferroni-corrected pairwise t tests were calculated on topic knowledge test scores (pre-test and post-test) for items addressed by each text type (RJA, RJMS, RJPO, and NR). Second, Bonferroni-corrected independent t tests were conducted between each of the three clusters for-on post-test items addressed by each text type controlling for its associated pre-test score. Post hoc analyses are presented in Table 5.

⁶ Means reported in post-hoc analyses were adjusted for the material set covariate.

Pairwise t test results showed that Cluster 1 (moderate on all epistemic dimensions) scored significantly higher on all post-test items addressed by refutations, specifically, refutations justified by authority ($M = 1.46$, $SE = .15$), refutations justified by personal opinion ($M = 1.68$, $SE = .17$), and marginally higher for refutations justified by multiple sources ($M = 1.65$, $SE = .16$) compared to their pre-test scores on these same items (RJA: $M = 1.09$, $SE = .13$; JPO: $M = 1.08$, $SE = .15$; RJMS: $M = 1.18$, $SE = .15$). No significant differences between pre-test and post-test items addressed by non-refutation texts for Cluster 1 were found ($p > .9$).

Cluster 2 (highest on all epistemic dimensions) significantly improved on their post-test scores only on items addressed by refutations justified by multiple sources ($M = 2.54$, $SE = .31$) compared to their pre-test scores on these same items ($M = 1.45$, $SE = .23$). No other significant differences for Cluster 2 were found ($ps > .2$).

Cluster 3 (high JA/JMS, lowest JPO) significantly improved on their post-test scores on items addressed by refutations justified by authority ($M = 2.73$, $SE = .27$) and refutations justified by personal opinion ($M = 2.68$, $SE = .25$) compared to their pre-test scores on these same items (RJA: $M = 1.57$, $SE = .21$; JPO: $M = 1.72$, $SE = .21$). No other significant differences for Cluster 3 were found ($ps > .1$).

Independent samples t tests indicated that Cluster 3 (high JA/JMS, lowest JPO; $M = 2.60$, $SE = .18$) scored significantly higher than Cluster 1 (moderate on all epistemic dimensions; $M = 1.68$, $SE = .17$) on the post-test items addressed by refutations with justification by authority. No other significant differences were observed ($ps > .1$). A conceptual summary of the findings is presented in Table 6.

3.4 Transfer Learning

To further test our hypotheses that JMS and JA dominant profiles, designed refutation

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texts, and consistency between these factors would confer an advantage for transfer learning, a mixed factorial 3×4 repeated measures ANOVA was conducted. Cluster profile (1, 2, or 3) was entered as the between-subject variable, transfer test item scores by text type (RJA, RJMS, RJPO, and NR) was entered as the within-subject variable. Topic knowledge pretest scores (calculated as the overall mean of the eight items targeted in the texts) was entered as a covariate and material set was entered as a blocking variable. There was no significant interaction between text type and the [material set](#) covariate, suggesting that the homogeneity of slopes assumption was met, $F(3, 239) = 2.12, p > .05$. Mauchly's test showed that the sphericity assumption was not met. Therefore, the Greenhouse–Geisser correction was used to adjust the degrees of freedom in these analyses. Results showed a main effect of refutation text type, and a main effect of epistemic profile clusters, but no interaction between refutation text and epistemic profile clusters was found. Topic knowledge pretest was a significant covariate, $F(1, 241) = 99.73, p < .001, \eta^2 = .29$. The material set variable did not account for any variance, $F(1, 241) < 1, p > .05$. Means are presented in Table 3, inferential statistics are presented in Table 4, and post hoc analyses are presented in Table 5.

On the main effect of refutation texts, Bonferroni-corrected pairwise t tests indicated that participants scored significantly higher on transfer test items addressed by JMS refutations ($M = 3.32, SE = .15$)⁷ compared to items addressed by the non-refutation control ($M = 2.77, SE = .15$). No other significant differences between refutation texts were observed on transfer scores ($ps > .1$).

On the main effect of epistemic profiles, Bonferroni-corrected independent t tests indicated that Cluster 3 (high JA/JMS, lowest JPO; $M = 3.42, SE = .16$) scored significantly higher than Cluster 1 (moderate on all dimensions; $M = 2.57, SE = .16$) on the near transfer test.

⁷ Means reported in post-hoc analyses were adjusted for prior knowledge and material set covariates.

No other significant differences were observed ($ps > .1$). A conceptual summary of the current findings is presented in Table 6.

3.5 Interpretation

In sum, analysis of raw post-test scores in relation to pre-test scores showed that clusters differentially learned from the various types of refutational justifications presented ~~within-by~~ texts. Participants in Cluster 1 (moderate on all dimensions) increased their post-test scores from pre-test baseline for all items addressed by refutational justification types, suggesting a broad-based benefit from refutation texts. In contrast, Clusters 2 (highest on all dimensions) and Cluster 3 (high JA/JMS, lowest JPO) increased in their post-test scores relative to pre-test baseline for items addressed by fewer types of refutational justifications (i.e., RJA and RJMS), however, the effect sizes of these increases were larger than for the increases observed in Cluster 1. ~~Although only one significant difference was obtained between clusters on post-test scores (described below), the numerical differences in magnitude between the effect sizes of learning suggests~~ ~~suggesting that more attention is warranted to determine that whether participants in Clusters 2 and 3 with profiles relatively higher in JA/JMS benefitted~~ more strongly from some forms of refutation texts.

Indeed, across both dependent learning variables analyzed, results showed support for Hypothesis 1B in that Cluster 3 (high JA/JMS, lowest on JPO) performed better than Cluster 1 (moderate on all dimensions) on overall transfer learning and in particular on some post-test items (i.e., items addressed by RJA texts). However, only ~~partial-limited~~ support was found for Hypothesis 2 in that a consistency advantage appeared ~~limited-restricted~~ to RJA items and not extended to include other items consistent with the dominant epistemic dimensions in Cluster 3's profile (i.e., JMS) ~~nor to Cluster 2, with the highest reported preference for JA.~~

4 Discussion

The current study sought to explore the main effects and interactions between refutation texts designed according to different dimensions of epistemic justification and readers' related epistemic cognition. Findings from the current research offer ~~only~~ partial support for our hypotheses on the benefits of justifications by authority and multiple sources and the epistemic consistency between refutation texts and individuals. Specifically, we were able to discern distinct epistemic profiles on the basis of adolescents' beliefs about justification for knowing (Hypothesis 1A). Further, adolescents who reported stronger preference for justification by multiple sources (JMS) and justification by authority (JA) and the least preference for justifications based on personal opinion (JPO; Cluster 3) performed ~~higher~~ better on the transfer test compared to students who reported relatively equal and moderate preference across all epistemic justification dimensions (Cluster 1; Hypothesis 1B). Additionally, we found that refutation texts that included justification by multiple sources (JMS) resulted in more transfer learning than non-refutation texts. ~~and that~~ Clusters 1, 2, and 3 also differentially improved upon their pre-test scores. Last, text type and epistemic profile interacted on topic knowledge post-test scores such that Cluster 3 again outperformed Cluster 1 on test items that were based on RJA refutation texts, which ~~partially demonstrated limited~~ support ~~for~~ Hypothesis 2. Overall, the findings are among the first to show complex effects and interactions between adolescents' epistemic profiles and novel refutation text designs. The conclusions from the current study may also contribute to the goal of gaining deeper insights into how the benefits of refutation texts can be enhanced and extended to young learners with diverse profiles. We address each point in turn and conclude with a discussion of the limitations of the study and directions for future research.

4.1 Refutation Text, Epistemic Justification, and Knowledge Revision

The current study found that all forms of refutation texts resulted in significant increases in topic knowledge test scores that varied by cluster, whereas non-refutation texts uniformly did not. Further, refutation texts that explained and epistemically justified correct concepts by using with multiple corroborating sources as epistemic justification resulted in significantly higher transfer learning scores compared to non-refutation texts. These findings are important as non-refutation texts are considered typical for natural science textbooks, implicating that practical benefits may be obtained with modifications to text-based instructional content. The findings are also consistent with a substantial body of evidence that shows learning benefits that result from refutation texts (Braasch et al., 2013; Broughton et al., 2013; Diakidoy et al., 2016; Kendeou et al., 2013, 2014; Trevors et al., 2016; van den Broek, 2010; van Loon et al., 2015). Previous research has further shown learning advantages conferred to individuals who prefer epistemic justification by multiple sources and science authorities over those who prefer to justify knowledge based on personal opinions (Bråten et al., 2013, 2014a; Bråten & Ferguson, 2014; Ferguson & Bråten, 2013). The current findings indicate that this advantage also extends to curriculum designs in knowledge revision in particular. According to Kendeou and colleagues (2013, 2014), the success or failure of knowledge revision is determined by the richness and dominance of correct information in forming a subsequent mental representation. Traditionally, refutation texts achieve this via their explanatory component (Kendeou et al., 2013, 2014), likely accounting for their effectiveness (Braasch et al., 2013; Broughton et al., 2013; Diakidoy et al., 2016; van den Broek, 2010; van Loon et al., 2015). Redesigning this component to highlight multiple sources of justification may have promoted attending to multiple correct pieces of evidence and rationale that enriched the mental representation and may have accounted for its current success. Future work should investigate such cognitive processes to better understand

how to design refutation texts to optimize learning benefits. The findings that refutations justified by authority and personal opinion were statistically indistinguishable from non-refutation texts in terms of transfer scores may also suggest that efforts to revise instructional texts should emphasize other forms of justification, such as multiple corroborating sources, to promote transfer learning.

4.2 Epistemic Profiles and Knowledge Revision

To examine how these benefits may be moderated by the epistemic beliefs profiles adolescents bring to bear, the current study adopted a person-centered approach to study the effects and interactions of complex individual profiles. We predicted that an advantage ~~may~~ would be conferred on individuals with a combination of beliefs on epistemic justifications to varying degrees of strengths. We proposed that profiles characterized by stronger beliefs in JA and JMS ~~may-would~~ promote a larger benefit for successful knowledge revision than either dimension in isolation. In particular, we theorized that adolescents who believed that knowledge is justified by authorities would give a great deal of attention to instructional texts and those who believed that knowledge is justified by multiple sources would engage in critical analysis of corroborating information. Thus, we theorized stronger beliefs in both epistemic dimensions ~~may~~ would result in greater attentiveness to information relayed by science texts and lead to detailed and rich mental representations and thus greater knowledge revision. In contrast, those with profiles conveying relatively stronger beliefs in JPO were predicted to over-rely on prior, erroneous knowledge and prevent new, correct information to become dominant in the mental network, thus impeding knowledge revision.

The current findings partially supported these predictions stemming from the theorization above. Individuals in Cluster 1 (moderate on all dimension) increased their post-test topic

knowledge from pre-test baseline for items addressed by refutations with all types of justification, suggesting these individuals broadly benefited from refutation texts, regardless of justification. In contrast, Clusters 2 (highest on all dimensions) and Cluster 3 (high on JA/JMS, lowest on JPO) increased in their post-test scores relative to pre-test baseline for a more limited set of items addressed by refutations with justifications (i.e., RJA and RJMS). However, the effect sizes of the increases for Clusters 2 (highest on all dimensions) and 3 (high on JA/JMS, lowest on JPO) were numerically larger than for the increases observed in Cluster 1 (moderate on all dimension), which may suggesting that individuals in Clusters 2 and 3 benefited more strongly from some forms of refutation texts. Indeed, individuals who reported moderate preference across the three epistemic dimensions (Cluster 1) scored significantly lower overall on the transfer test and some post-test items compared to individuals who reported relatively stronger preference for JMS and JA and lowest preference for JPO (Cluster 3). Mean scores for individuals in Cluster 2, which reported the highest preference across the three epistemic dimensions, ~~was~~ were ~~intermediate~~ between Clusters 1 and 3 but did not statistically differ from either.

Based on the formation of the three clusters (Figure 1), we can attempt to deduce and isolate the epistemic dimensions responsible for this pattern of results. The commonality of epistemic dimensions between Cluster 2 and 3 are that they both are relatively high on JMS and JA compared to Cluster 1, whereas these clusters differ on JPO. The commonality between Cluster 1 and 2 are that they are both relatively high on JPO compared to Cluster 3; they differ on JMS and JA. From these differences and commonalities, we can conclude that higher achievement is associated with higher JMS and JA and/or lower JPO. This conclusion is aligned with previous research on the trichotomous framework that finds higher levels of attainment are

associated with beliefs in knowledge justified by multiple sources and authority and lower attainment associated with a belief in knowledge justified by personal opinion (Bråten et al., 2011, 2013, 2014a; Bråten & Ferguson, 2014; Ferguson & Bråten, 2013). It may be possible that it is this combination of epistemic beliefs ~~to~~in varying degrees of strengths that was mirrored by individuals in Cluster 3 – both stronger preference for JMS and JA and least preference for JPO – provided an advantage for knowledge revision and accounted for their higher test scores. Further, it may be that stronger preference for JMS and JA while studying topics in the natural sciences might mitigate or protect against potential detrimental effects related to preferences for JPO. Future research can test these conjectures and specifically whether promoting preference for epistemic justification from external sources (multiple authoritative sources) leads to higher achievement in science versus preference for internal sources (personal opinion) and whether such benefits are extended to other domains (e.g., history, literature). Notably, this result would not have been observed without the current use of a person-centered approach, which demonstrates the utility of profile analysis for researchers who seek to understand the complex relations between individual characteristics and learning tasks.

4.3 Interaction Between Texts and Profiles

Beyond the main effects of refutation text designs and adolescents' epistemic profiles, we also observed a significant interaction between these variables. We had predicted that individuals with an epistemic profile relatively high in JMS and/or JA would achieve higher learning scores after reading a refutation text with epistemic justification component that was consistent with their epistemic profile than when these factors were inconsistent. We did not predict a similar advantage for consistency between text and belief related to JPO as preference on this dimension is inconsistent with the underlying epistemology of the natural sciences (Chinn & Malhotra,

2002; Sandoval, 2014). The evidence from the current study presents ~~eds partial-limited~~ support for this hypothesis. Specifically, participants in Cluster 3 high in belief about knowledge justified by authority (JA) attained the highest proportional learning gains on content from RJA refutation texts compared to participants in Cluster 1 lowest in JA. This result is partially consistent with Muis and colleagues (Franco et al., 2012; Muis, 2008; Muis et al., 2011; Muis & Franco, 2010) research on the consistency hypothesis, which found that when an individual's epistemic profile was consistent with the underlying epistemology of a learning context they engaged in greater self-regulation of cognition and deeper processing of the content. We speculate that the mechanisms that account for the current findings are possibly due to individuals who believed that knowledge in the natural sciences is justified by authority and who engaged in greater self-regulation and deeper processing of refutation texts that presented explanations justified by authoritative characters. Chinn et al. (2011) argued that individuals commonly use authoritative testimony to justify knowledge, which may be advantageous in some contexts. Indeed, Bråten, Ferguson and colleagues (Bråten et al., 2014a; Bråten & Ferguson, 2014; Ferguson & Bråten, 2013) have shown empirically the importance of justification by authority when learning science content. However, it should be noted that significant interactions for other dimensions were not observed (i.e., JMS), and that Cluster 2, with the highest reported preference for JA, did not also obtain ~~a higher learning gain~~ post-test scores for items on consistent with RJA texts. The lack of this interaction may be attributable to the fact that Cluster 2 was also highest on JPO, which may have impeded learning of this science content. Overall, more research is needed to test these hypotheses.

4.4. Unique Contributions of the Current Study

The current findings advance our knowledge on epistemic cognition and knowledge revision in several ways. First, these findings reveal important boundary conditions in epistemic cognition that are predictive of knowledge revision success. Namely, although strong beliefs in JA and JMS have been previously linked to advantageous learning outcomes, this learning benefit appeared to be only conferred in the current study when a belief in JPO was simultaneously low. These findings give novel insights on the conditional limits of potential benefits and drawbacks of various epistemic belief dimensions, which may have important implications for future research and instructional designs. Second, our focus on adolescence represents a particularly unique but under-examined context for the development of epistemic cognition (Krettenauer, 2005; Hallett, Chandler, & Krettenauer, 2002; Muis, Trevors, Duffy, Ranellucci, & Foy, 2016). In particular, researchers expect that adolescence marks a shift away from a singular form of justification – that of absolutism/realism – towards differentiation and awareness of other forms of justification, including subjective skepticism, dogmatic reliance on authority, or appeals to rationality (Greene et al., 2008). By investigating how adolescents variously justify knowledge in the natural sciences, the current study sheds light on academically relevant profiles during this consequential developmental period. Third, the use of person-centered analysis resulted in several novel extensions to previous research. This approach uncovered meaningful relations between multiple learner characteristics and academic achievement likely not observable with traditional variable-centered analysis. Person-centered analysis was also a potentially more ecologically valid assessment of individuals. A recurring issue in the epistemic cognition literature is the risk of false dichotomization of individuals' beliefs forced by Likert designs (Greene & Yu, 2014; Sinatra, 2016). The current study offers one remedy to this with its use of person-centered analysis to show how individuals are

epistemically multifaceted. Given these considerations, its current use may further aid to bridge learning theory to instructional practice since person-centered analysis herein considered how actual individuals, not variables, interacted with instructional designs. We contend that the field of epistemic cognition has sufficiently matured to allow for specific instructional design recommendations to be made on how to adapt instruction to account for various epistemic profiles, several that we detail next.

4.5 Limitations and Future Directions

The conclusions of the current study are limited in several ways but also present new directions for future research. First, although we obtained a significant main effect of refutation texts on transfer scores this pattern was not mirrored with topic knowledge test scores. We speculate that perhaps this is due to the topic knowledge test lacking sensitivity as a dependent variable to detect knowledge revision given that this effect was apparent in the transfer test scores. Further, given the age of our sample, an alternative explanation is that adolescents are less experienced processing varying forms of epistemic justification in the natural sciences, which thus lead to greater variance in responses that obscured an effect. Second, in reference to the consistency hypothesis (Franco et al., 2012; Muis, 2008; Muis & Franco, 2010; Muis et al., 2011), we found one significant interaction that supported our hypothesis and several non-significant results that failed to support our hypothesis. Thus, a possible alternative explanation to this prediction is that in this context an adaptive epistemic profile (high on [JMSJA/JA-JMS](#), low on JPO) possesses a global learning advantage that positions these individuals to successfully learn from a range of content and justification types rather than narrow preference for one type over another. This was apparent in the results for both current dependent learning variables used in the current study (i.e., topic knowledge post-test and transfer test scores).

However, we recommend a cautious approach in speculating on non-significant results. Rather, we intend to offer additional considerations that may be useful for researchers when they are designing new studies and alternative hypotheses that may be potentially fruitful avenues for future investigations. Third, another limitation is that ~~stems from~~ the current factor solution of the JFK-Q, ~~which only~~ accounted for only 44% of the variance in the measure and that factor reliability estimates, although acceptable, were relatively low.

In reference to the current materials, the design of refutation texts may also have been a limitation. Refutation texts were in the format of informational narratives so that those that were designed to align with justification by personal opinion presented characters' personal opinions. It may be possible that participants in this study may process and learn from justifications of knowledge based on characters' ~~personal~~ opinions differently from justification based on their own personal opinions if these opinions differ. For example, a reader may find their personal opinions (based on their life experiences) about projectile motion more compelling than the opinions described by a character in a narrative, ~~and even more so if the opinions of the reader and character differ.~~ Future research could examine the possibility and impact of such processing and learning differences by contrasting the current refutation texts (with characters' opinions) against other texts that present refutations justified by personal beliefs, attitudes, or opinions that are consistent with the participant's own.

Last, in terms of research designs, future research can employ process methodologies to examine processes and mechanisms of learning that account for the differences between refutation text designs and epistemic profiles observed in the current study. Employing process methods and designs such as eye-tracking, think-aloud protocols, and reading time paradigms may shed light on how preferences for JMS and JA beneficially impact and JPO impinge on

knowledge revision. Further, it will be valuable to investigate the generalizability of epistemic clusters with different samples characteristics and how cluster membership may impact learning and/or change under interventions that target multiple aspects of instructional designs, including pedagogical approaches (e.g., constructivism), representations of authority in classrooms, a wider array of curricula materials, evaluation methods, and instructional scaffolds (Ferguson & Bråten, 2013; Muis, Trevors, & Chevrier, 2016).

4.6 Conclusions

Overall, the current findings underscore the importance of epistemic justification for knowledge revision. Refutation texts on misconceptions in the natural sciences can be adaptively redesigned to emphasize correct knowledge that is justified by multiple sources and authorities, which represent new trends in epistemic cognition research. Further, adopting a person-centered approach revealed complex effects and interactions between epistemic profiles and learning from refutation texts. Individuals with epistemic profiles that privileged justification by multiple sources and authority and least preferred justification by personal opinion were best positioned to take advantage and learn from such instructional texts. Promoting epistemic change towards this profile and refining the design of refutation texts may lead to further success in revising knowledge misconceptions in the natural sciences. In sum, researchers should continue to build on this line of inquiry to uncover the conditions under which the benefits of refutation texts may be enhanced and extended to more learners.

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Table 1

Hypothesized Effects and Interactions Between Refutation Text Type and Epistemic Profiles on the Level of Learning Achievement in the Natural Sciences

Refutation text type	Epistemic profile	
	+JMS and/or +JA	+JPO
RJPO	Moderate	Low
RJA	High	Low
RJMS	High	Low

Note. + denotes a profile high on an epistemic dimension relative to other possible profiles. JMS = Justification by Multiple Sources; JA = Justification by Authority; JPO = Justification by Personal Opinion; RJA = Refutation with Justification by Authority; RJMS = Refutation with Justification by Multiple Sources; RJPO = Refutation with Justification by Personal Opinion; NR = Non-Refutation.

Table 2
Descriptive Statistics of Epistemic Justification Dimensions Across the Final Three-Cluster Solution.

Variable	Cluster 1 <i>n</i> = 99		Cluster 2 <i>n</i> = 53		Cluster 3 <i>n</i> = 94	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Justification by authority	5.19 ^a	1.20	7.98 ^b	1.32	6.92 ^c	1.28
Justification by multiple sources	5.77 ^a	1.36	8.49 ^b	.94	8.04 ^c	1.18
Justification by personal opinion	4.84 ^a	1.24	6.47 ^b	1.34	3.57 ^c	1.59

Notes. Data based on a 1-10 Likert scale. Superscript letters that differ in the same row indicate statistically significant differences in means at $p < .05$.

Table 3
Descriptive Statistics of Learning Variables by Text Type and Cluster

	RJA		RJMS		RJPO		NR		Total	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Pre-test score overall ^a	1.39	1.80	1.66	1.97	1.46	1.81	1.66	1.86	-	-
Cluster 1	1.09	1.25	1.18	1.49	1.08	1.50	1.28	1.59	4.64	4.49
Cluster 2	1.62	2.16	1.45	1.70	1.72	1.85	1.68	1.95	6.47	6.10
Cluster 3	1.57	2.01	2.28	2.37	1.72	2.01	2.04	1.99	7.62	5.99
Post-test score overall ^a	2.08	2.20	2.29	2.15	2.17	2.17	2.02	2.00	-	-
Cluster 1	1.46	1.49	1.65	1.58	1.68	1.71	1.57	1.52	6.30	5.06
Cluster 2	2.06	2.16	2.55	2.28	2.17	2.20	2.08	2.27	8.71	7.73
Cluster 3	2.73	2.64	2.83	2.42	2.68	2.47	2.47	2.20	10.59	7.03
Transfer score overall ^a	3.00	2.46	3.29	2.56	2.95	2.40	2.76	2.39	-	-
Cluster 1	2.38	2.17	2.44	2.10	2.13	1.94	2.18	1.99	2.29	1.55
Cluster 2	3.13	2.31	3.42	2.76	3.08	2.42	2.86	2.45	3.12	2.00
Cluster 3	3.57	2.69	4.11	2.63	3.74	2.57	3.32	2.62	3.69	2.07
Physics grade overall ^b	-	-	-	-	-	-	-	-	-	-
Cluster 1	-	-	-	-	-	-	-	-	14.31	3.08
Cluster 2	-	-	-	-	-	-	-	-	15.62	3.19
Cluster 3	-	-	-	-	-	-	-	-	16.46	3.35

Notes. Abbreviations: RJA = Refutation with Justification by Authority; RJMS = Refutation with Justification by Multiple Sources; RJPO = Refutation with Justification by Personal Opinion; NR = Non-Refutation.

^a Possible range of scores: 0 – 8.

^b Possible range of scores: 0 – 20.

Table 4
Mixed Factorial Repeated Measures ANOVA

Variable	<i>df</i>	<i>F</i>	η^2	<i>p</i>
Topic knowledge test scores				
Time	1	7.01**	.028	.009
Text type	3	.79	.003	.497
Cluster	2	9.82***	.075	< .001
Time x Text type	3	1.96	.008	.118
Time x Cluster	2	2.03	.016	.134
Text type x Cluster	6	.47	.004	.834
Time x Text type x Cluster	6	2.08[†]	.017	.054
Transfer scores				
Text type	2.79	14.64***	.057	< .001
Cluster	2	6.73***	.053	.001
Text type x Cluster	5.59	.62	.005	.715

Note. Bolded values denote statistical significance.

[†] $p \leq .06$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 5
Post Hoc Analyses of Significant Main Effects and Interactions With Bonferroni-Corrected Independent and Paired Samples T Tests

Dependent Variable	df	t	d	p
Topic knowledge test				
Within-subjects variance				
Cluster 1 (<u>moderate on all dimensions</u>):				
Post – Pre				
RJA	98	3.14*	.63	.02
RJMS	98	2.86 [†]	.58	.06
RJPO	98	3.23*	.65	.02
NR	98	1.76	.36	> .9
Cluster 2 (<u>highest on all dimensions</u>):				
Post – Pre				
RJA	52	1.59	.44	> .9
RJMS	52	3.43*	.95	.01
RJPO	52	2.44	.68	.22
NR	52	2.03	.56	.56
Cluster 3 (<u>high on JA/JMS, lowest on JPO</u>):				
Post – Pre				
RJA	93	5.17**	1.07	< .01
RJMS	93	2.49	.51	.18
RJPO	93	4.07**	.84	< .01
NR	93	2.11	.44	.46
Between-subjects variance				
Cluster 1 – Cluster 2				
RJA	150	-.72	.12	> .9
RJMS	150	-2.44	.40	.18
RJPO	150	-.30	.05	> .9
NR	150	-.94	.15	> .9
Cluster 1 – Cluster 3				
RJA	191	-3.70**	.54	< .01
RJMS	191	-2.16	.31	.38
RJPO	191	-2.27	.33	.29
NR	191	-1.79	.26	.9
Cluster 2 – Cluster 3				
RJA	145	-2.41	.40	.20
RJMS	145	.54	.09	> .9
RJPO	145	-1.62	.27	> .9
NR	145	-.58	.10	> .9
Transfer test				
Within-subjects variance				
RJA – RJMS	244	-2.13	.27	.20
RJA – RJPO	244	.46	.06	> .9
RJA – NR	244	1.60	.20	.67
RJMS – RJPO	244	2.29	.29	.14
RJMS – NR	244	3.17*	.41	.01
RJPO – NR	244	1.29	.17	.60
Between-subjects variance				
Cluster 1 – Cluster 2				
	150	-1.87	.31	.19

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Cluster 1 – Cluster 3	191	-3.65**	.53	< .01
Cluster 2 – Cluster 3	145	-1.28	.21	.61

Note. Bolded values denote statistical significance.

† $p \leq .06$

* $p < .05$

** $p < .01$

Table 6

Conceptual Summary of Current Findings on the Effects and Interactions Between Refutation Text Type and Epistemic Profiles on Learning Achievement in the Natural Sciences

Epistemic belief	Epistemic profiles			Refutation text
	Cluster 1	Cluster 2	Cluster 3	
JA	lowest	highest	high	-
JMS	lowest	highest	high	-
JPO	low	highest	lowest	-
Topic knowledge	ns	ns	ns	-
post-test				
RJA	> pre-test < Cluster 3	ns	> pre-test > Cluster 1	ns
RJMS	> pre-test	> pre-test	ns	ns
RJPO	> pre-test	ns	> pre-test	ns
NR	ns	ns	ns	ns
Transfer test	< Cluster 3	ns	> Cluster 1	-
RJA	ns	ns	ns	ns
RJMS	ns	ns	ns	> NR
RJPO	ns	ns	ns	ns
NR	ns	ns	ns	< RJMS

Note. JA = Justification by Authority; JMS = Justification by Multiple Sources; JPO = Justification by Personal Opinion; RJA = Refutation with Justification by Authority; RJMS = Refutation with Justification by Multiple Sources; RJPO = Refutation with Justification by Personal Opinion; NR = Non-Refutation; ns = Non-Significant difference.

Figure 1. Formation of epistemic cognition profiles from cluster analysis. Figure depicts mean differences on beliefs in justification by authority (JA), justification by multiple sources (JMS), and justification by personal opinion (JPO). Error bars represent 95% confidence intervals.

Appendix

Sample Text in Each Condition

(Translated to English from Greek – length was controlled in Greek)

[Introduction – All Conditions]

Tom was hanging out with one of his friends this afternoon. They were planning to go see a movie and they were very enthusiastic about it. While getting ready they started talking about their homework and specifically about a physics problem that was due the next day. It was a problem that involved two balls that were exactly the same size and shape but one weighed twice as much as the other. The problem assumed that the two balls would be dropped from a house roof at the same time.

[Justification by Authority]

Tom had initially believed that if two objects were the exact same shape and size but one was heavier, the heavier object would fall faster. His science teacher explained in class earlier that day that this idea was incorrect. Tom's science teacher, Mrs. James, was one of the best science teachers in the country. She explained that when you drop two identically shaped objects that have different masses, the two objects will experience the exact same acceleration due to gravity. This is because gravity acts on all objects in exactly the same manner and this occurs regardless of their mass. It does not make a difference if one of the objects weighs more than the other object. That is to say, gravity will exert the same pull on both of them. Therefore the balls will fall at exactly the same rate. Indeed, Tom confirmed with his teacher that the balls hit the ground at the same time.

[Justification by Multiple Sources]

Tom had initially believed that if two objects were the exact same shape and size but one was heavier, the heavier object would fall faster. However, a scientific article and an encyclopedia Tom read explained that this idea was incorrect. Tom read in a scientific article and in an encyclopedia that when you drop two identically shaped objects that have different masses, the two objects will experience the exact same acceleration due to gravity. This is because gravity acts on all objects in exactly the same manner and this occurs regardless of their mass. It does not make a difference if one of the objects weighs more than the other object. That is to say, gravity will exert the same pull on both of them. Therefore the balls will fall at exactly the same rate. Indeed, Tom confirmed in several textbooks that the balls will hit the ground at the same time.

[Justification by Personal Opinion]

Tom had initially believed that if two objects were the exact same shape and size but one was heavier, the heavier object would fall faster. He always trusted his opinion, so he self-explained why his initial idea was incorrect. Tom decided that when you drop two identically shaped objects that have different masses, the two objects will experience the exact same acceleration due to gravity. This is because gravity acts on all objects in exactly the same manner and this occurs regardless of their mass. It does not make a difference if one of the objects weighs more than the other object. That is to say, gravity will exert the same pull on both of them. Therefore the balls will fall at exactly the same rate. Indeed, Tom was absolutely sure of his own opinion that the balls will hit the ground at the same time.

[Control]

Tom and his friend wanted to solve the problem before going to the movie. They started working on it hoping that it would not take them long to do. Tom took the lead reading the problem out loud to his friend. The problem assumed that two identically shaped balls that have different masses would be dropped from a house roof at the same time. When you drop two identically shaped objects that have different masses, the two objects will experience the exact same acceleration due to gravity. This is because gravity acts on all objects in exactly the same manner and this occurs regardless of their mass. That is to say, gravity will exert the same pull on both of them. Therefore the balls will fall at exactly the same rate and hit the ground at the same time. Tom wrote down his explanation while explaining it to his friend.

[Closing – All Conditions]

The two friends were ready to leave the house. They left excited to go see the movie.

Supplementary Appendix

Table S1
Pattern Coefficients from Exploratory Factor Analysis of the Justification for Knowing Questionnaire

Variables	Component		
	JMS	JPO	JA
JFK1	.703		
JFK2	.690		
JFK3	.658		
JFK4	.658		
JFK5	.653		
JFK6	.458		
Justification by Multiple Sources Eigenvalue = 3.91			
JFK7		.763	
JFK8		.717	
JFK9		.634	
JFK10		.602	
JFK11		.446	
JFK12		.366	
Justification by Personal Opinion Eigenvalue = 2.24			
JFK13			.783
JFK14			.707
JFK15			.676
JFK16			.642
JFK17			.535
JFK18			.347
Justification by Authority Eigenvalue = 1.77			

Notes. JA = Justification by Authority; JMS = Justification by Multiple Sources; JPO = Justification by Personal Opinion. For clarity of presentation, coefficients < .35 are suppressed.

Table S2
*Structure Coefficients from Exploratory Factor Analysis of the Justification for
 Knowing Questionnaire*

Variables	Component		
	JMS	JPO	JA
JFK1	.717		
JFK2	.689		
JFK3	.682		
JFK4	.656		
JFK5	.653		
JFK6	.527		.421
JFK7		.755	
JFK8		.703	
JFK9		.648	
JFK10		.613	
JFK11		.452	
JFK12		.372	
JFK13			.742
JFK14			.714
JFK15			.688
JFK16			.674
JFK17	.386		.603
JFK18			.401

Notes. JA = Justification by Authority; JMS = Justification by Multiple Sources; JPO = Justification by Personal Opinion. For clarity of presentation, coefficients < .35 are suppressed.