Learning and Individual Differences 69 (2019) 108–115

Contents lists available at ScienceDirect

Learning and Individual Differences

journal homepage: www.elsevier.com/locate/lindif

The effects of refutation texts on generating explanations[☆]

Kelsey K. Will[a,*], Andalusia Masad[b], Haley A. Vlach[b], Panayiota Kendeou[a]

[a] University of Minnesota, Department of Educational Psychology, 56 E River Road, Minneapolis, MN 55455, United States of America
[b] University of Wisconsin-Madison, Department of Educational Psychology, 859 Education Sciences Building, 1025 W. Johnson Street, Madison, WI 53706, United States of America

ARTICLE INFO

Keywords:
Explanation
Misconception
Comprehension
Knowledge revision

ABSTRACT

The aim of the present study was to examine the effect of refutation texts on generating explanations and explore individual differences in quality of explanations. Seventy-five undergraduates read refutation and non-refutation texts addressing common scientific misconceptions and completed a two-tier post-test including True/False and open-ended questions. Readers' written post-test explanations were coded on accuracy and quality dimensions. The analysis of these explanations showed less circularity and uncertainty descriptors and more accuracy and causal connections in the refutation than the non-refutation condition. Further, three distinct clusters of readers emerged: coherence-building readers, non-coherence building readers, and promiscuous readers. Results demonstrate examining explanation characteristics can provide a useful tool for revealing how readers' knowledge influences learning from texts.

1. Introduction

When students enter learning environments they may bring along incorrect knowledge about different topics, making it difficult to acquire new related knowledge (e.g., Carey, 2009; Chi, 2005; Clement, 1991; Kendeou, Walsh, Smith, & O'Brien, 2014; Novak, 1988; Posner, Strike, Hewson, & Gertzog, 1982; Trumper, 2001; Vosniadou & Brewer, 1992, 1994). Misconceptions of scientific knowledge occur when one has inaccurate knowledge about phenomena and concepts (Kendeou & van den Broek, 2005). Decades of research have demonstrated such misconceptions are not only prevalent, but also difficult to revise (Sinatra & Broughton, 2011). Revision efforts are important because incorrect knowledge is detrimental to the development of accurate understanding and decision-making (Carey, 1985).

Revision efforts in educational settings have often used refutation texts (Kendeou, Braasch, & Bråten, 2016). These texts promote knowledge revision by explicitly acknowledging common misconceptions, directly refuting them, and providing explanations (Hynd, 2001). To date, a great deal of evidence supports the utility of refutation texts in facilitating knowledge revision (e.g., Ariasi & Mason, 2011; Broughton, Sinatra, & Reynolds, 2010; Chinn & Brewer, 1993; Guzzetti, Snyder, Glass, & Gamas, 1993; Hynd & Alvermann, 1986; Kendeou et al., 2016; Sinatra & Broughton, 2011; Tippett, 2010). However, further research is needed to identify mechanisms that help explain how such texts exert their influence (Rusanen, 2014).

Readers' understanding of material after reading refutation texts is one potential source to determine whether knowledge revision has taken place. Such understanding is often evaluated with the use of researcher developed post-tests; indeed, higher post-test scores after reading refutation texts compared to non-refutation texts have been proposed to be indicative of learning from text and knowledge revision (Braasch, Goldman, & Wiley, 2013; Kendeou & van den Broek, 2007; Mason, Zaccoletti, Carretti, Scrimin, & Diakidoy, 2018). These post-tests often require readers to explain scientific concepts in their own words. Above and beyond their accuracy, the quality of such responses can provide information about readers' reasoning and knowledge.

The aim of the present study was to examine the effect of refutation texts on generating explanations and explore individual differences in the quality of explanations. We draw on the extant literatures of refutation text and explanation (e.g., Chin & Brown, 2000; Kendeou et al., 2014) to understand the role of refutation texts in the generation of *explanations*, and determine the extent to which explanation *quality* can provide information about readers' reasoning and understanding of the text.

1.1. Refutation texts and knowledge revision

One framework that has been proposed to account for knowledge

[☆] No conflicts of interest. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

* Corresponding author.
E-mail address: will3559@umn.edu (K.K. Will).

https://doi.org/10.1016/j.lindif.2018.12.002
Received 11 February 2018; Received in revised form 12 October 2018; Accepted 6 December 2018
1041-6080/

revision in the context of reading refutation texts is the Knowledge Revision Components framework (KReC; Kendeou & O'Brien, 2014). The KReC framework consists of five principles that outline the assumptions and conditions necessary for knowledge revision during reading: encoding, passive activation, co-activation, integration, and competing activation. According to the encoding principle, readers cannot simply erase information that has been encoded into long-term memory. According to the passive activation principle, this previously-encoded information can be passively reactivated during reading. These two assumptions can explain why previously acquired incorrect knowledge has the potential to be reactivated and disrupt reading, thus hindering the learning of new, related information. KReC also outlines three conditions that can facilitate revision. The co-activation principle posits that for the revision to take place, new correct information must make contact with previous, incorrect information in working memory. The integration principle posits that the result of co-activation will be the integration of new information with previous information in readers' memory. Finally, the competing activation determines the success of revision as follows: as the recently encoded correct information gets highly integrated with additional information to support it, it draws most of the activation to itself and away from the previously acquired incorrect information. When this competition results in the reduction of the activation of the previously acquired incorrect information, knowledge revision has taken place.

The revision mechanism proposed in KReC is supported by several studies that used refutation texts. For example, evidence for the co-activation principle has been obtained in studies using a reading time paradigm, suggesting readers experience interference and slow down during the reading of correct information in refutation texts (Ariasi & Mason, 2011; Kendeou et al., 2014; Kendeou & van den Broek, 2007). Some level of knowledge revision occurs if both conceptions are co-activated and the reader experiences cognitive conflict by recognizing the conflicting information (McCrudden & Kendeou, 2014; van den Broek & Kendeou, 2008). Additionally, when readers integrate the explanation component of the refutation text, their representation of the information becomes focused on the accurate information and reduces the impact of inaccurate information (Kendeou et al., 2014; Kendeou, Butterfuss, Van Boekel, & O'Brien, 2017; Kendeou, Smith, & O'Brien, 2013; Van Boekel, Lassonde, O'Brien, & Kendeou, 2017). Indeed, Kendeou et al. (2014) provided evidence that the explanation component in the refutation text's structure ultimately determines knowledge revision. It follows that readers' understanding of the explanations provided in the refutation texts is therefore an important factor to consider. We turn to this issue next.

1.2. Importance and characteristics of explanations

When readers construct their own explanations, they may integrate new knowledge within their existing knowledge base and understanding of the world (Brown & Campione, 1990; Chi, De Leeuw, Chiu, & LaVancher, 1994). Asking readers to explain information they read challenges them to evaluate and elaborate on their understanding, which can positively contribute to their learning of the targeted subject matter. Indeed, the ability to generate responses that are accurate and of good quality to explain phenomena is a critical part of learning (Chin & Brown, 2000; Sandoval & Reiser, 2004). This is particularly true in science given that understanding and explaining the 'how' and the 'why' are overarching objectives of the field. Explanations are not only crucial to our understanding of the world, but they are also the way in which we exchange knowledge with others (Lombrozo, 2006).

Previous literature has determined several quality dimensions of explanations that can be either beneficial or harmful to learning (Callanan & Oakes, 1992; Dagher, 1995; Jarvie & Agassi, 1967; Rips, 2002; Thagard, 1992; for a review, see Vlach & Noll, 2016). These dimensions involve prior knowledge, understanding relationships between concepts, and the ability to make connections beyond the texts themselves. The dimensions positively related to learning include mentioning trustworthiness (e.g., Bråten, Strømsø, & Britt, 2009), using analogies correctly (e.g., Vendetti, Matlen, Richland, & Bunge, 2015), describing causal relationships (e.g., Fender & Crowley, 2007; Sandoval, 2003), utilizing prior knowledge (e.g., Asoko, 2002; Fender & Crowley, 2007; Kendeou & van den Broek, 2005), and describing physical characteristics (e.g., Asoko, 2002; Szechter & Carey, 2009). The dimensions negatively related to learning include using personification (e.g., Kallery & Psillos, 2004; Legare, Lane, & Evans, 2013), describing religious, magic, or mythical forces (e.g., Browne & Woolley, 2004; Canfield & Ganea, 2014), providing circular reasoning (e.g., Baum, Danovitch, & Keil, 2008; Keil, 2006; Kendeou & van den Broek, 2005; Pritchard, 1990; Weisberg, Keil, Goodstein, Rawson, & Gray, 2008), using unnecessary descriptors (e.g., Kendeou & van den Broek, 2005; Mayer & Jackson, 2005; Pritchard, 1990), and using uncertainty descriptors (e.g., Kendeou & van den Broek, 2005; Pritchard, 1990). Utilization of these dimensions indicates one's lack of understanding regarding the evidence that describes causal relationships and reasoning of scientific concepts.

To summarize, the ability to generate responses that are accurate and of good quality to explain concepts is critical for knowledge acquisition and revision (e.g., Chin & Brown, 2000). In turn, examining characteristics of readers' explanations after reading refutation and non-refutation texts can provide a useful tool for revealing their knowledge and understanding of science texts. Even though there is existing evidence supporting the utility of refutation texts in facilitating knowledge revision (Guzzetti et al., 1993; Sinatra & Broughton, 2011; Tippett, 2010), further research can provide valuable insights into the characteristics of explanations readers generate as well as their reasoning after reading these texts (Brown & Campione, 1990).

1.3. Present study

The aim of the present study was to investigate the effects of refutation texts on generating explanations after reading and explore individual differences in the use of quality indicators in explanations. Our work focused on two research questions. First, we wanted to understand the extent to which explanations produced *after* completing reading are influenced by text structure, namely refutation and non-refutation texts. The current analysis focuses on an in-depth coding of secondary data that consisted of post-test responses readers generated after reading refutation and non-refutation texts targeting common misconceptions (Kendeou, Butterfuss, Kim, & Van Boekel, in press). We hypothesized that after completing reading, readers in the refutation condition would provide explanations with high-quality indicators for target concepts compared to readers in the non-refutation condition. Second, we explored individual differences in the *quality* and *accuracy* of explanations generated *after* reading refutation and non-refutation texts. We hypothesized distinct profiles would emerge using the accuracy and quality dimensions.

We approached these questions with both a variable-centered and a person-centered approach. A variable-centered approach allows for the analysis of differences between distinct groups of individuals (Block, 1971; Trevors, Kendeou, Bråten, & Braasch, 2017). In the context of this study, a variable-centered approach allowed for the analysis of differences in quality and accuracy variables between the readers' responses in the refutation and non-refutation conditions. A person-centered approach examines individuals to determine the presence of individual differences and form similar clusters (Bergman, Magnusson, & El-Khouri, 2003; Block, 1971; Trevors et al., 2017). This approach allows for seeing how individuals differ and how variables are related. In the context of this study, a person-centered approach allowed for the examination of individual differences in the quality of explanations and their relation to learning from texts.

Table 1
Accuracy: dimensions, definitions, and examples from post-test explanations.

Dimension	Definition	Example from post-tests
Explanation	The response provided a reason supporting or refuting the belief statement.	"The seasons are caused by the tilt of the Earth's axis." (SN 105)
Overall accuracy	The response was either correct or incorrect when compared to the information provided in the text.	"Seasons are caused by the tilt of the Earth, not its distance from the sun." (SN 212)

2. Method

2.1. Participants

The post-test data of 75 undergraduate students (44 female; M_{age} = 19.76, SD_{age} = 3.50, $\text{Range}_{\text{age}}$: 18–38 years) enrolled in introductory psychology courses were used in the current study. Participants received partial course credit for their participation.

2.2. Materials

2.2.1. Texts

Participants read 10 narrative-informational texts (Duke, 2000), each addressing a common misconception that had been identified as highly prevalent in the population from which the current sample was drawn (e.g., Van Boekel et al., 2017). Narrative-informational texts were chosen because they allow opportunities to refute and explain common misconceptions in a friendlier context for the reader to comprehend (Kendeou et al., 2014). Appendix A lists the 10 common misconceptions. Appendix B contains sample texts.

The refutation texts included a refutation-plus-elaboration section that explicitly stated and refuted the target misconception. The refutation was immediately followed by an explanation that provided extra information supporting the refutation. The non-refutation text included a non-refutation-plus-non-elaboration section followed the same structure of the refutation section. However, the text in this section progressed the story, making no mention of either the misconception or the refutation. Both texts included a correct outcome (target) sentence that stated the correct information. Each passage ended with a comprehension question that did not address information concerning the misconception but was included to ensure understanding.

Two material sets were constructed and each contained 10 texts, half in each of the two experimental conditions. Across the two sets, each text occurred once in each condition. Participants were randomly assigned to a set.

2.2.2. Post-test

The test included 10 two-tiered questions (Tan, Goh, & Chia, 2001; Treagust, 1988) corresponding to the 10 misconceptions targeted in the texts. The first tier was a True/False question, followed by the second tier asking readers to provide an explanation for their True/False response. The two-tiered questions afforded the opportunity to assess the readers' knowledge. For instance, an incorrect answer to the first-tier item and an incorrect explanation illustrates the existence of incorrect knowledge. A correct answer to the first-tier item and an incorrect explanation also illustrates the presence of incorrect knowledge. Conversely, a correct answer to the first-tier item and a correct explanation illustrates correct knowledge.

2.3. Procedure

All procedures, including the informed consent and the recruitment of participants, were reviewed and approved by the University's Institutional Review Board (IRB). Participants were tested individually in a single session. They were informed they were going to read texts for general understanding. Approximately half of the participants were asked to think-aloud as they read, and the remaining half were asked to read silently (for detailed methods see Kendeou et al., in press). When the participants finished reading all texts, they were asked to complete the post-test. To address the aims of this study, we performed an elaborate coding of the post-test responses.

2.3.1. Coding post-test responses

Each written response readers generated on the post-test was coded with respect to accuracy and quality dimensions. The unit of analysis was the participant's entire written response. The dimensions for each response were coded independently of one another in terms of presence (code = 1) or absence (code = 0) in each response. Two raters independently coded all post-tests. To determine inter-rater reliability, 20% of the post-tests were compared. Disagreements were resolved through discussion. Inter-rater reliability was high (96.9%).

Drawing on the extant literature, 13 coding dimensions were selected that reflected the accuracy and quality characteristics of a response. Table 1 lists each *accuracy* dimension, the corresponding definition, and an example from the written post-test responses. Table 2 lists each *quality* dimension, the corresponding definition, and an example from the written post-test responses.

Two *accuracy* dimensions evaluated whether each response was an explanation (code = 1) or not (code = 0), and the accuracy of the response was in comparison to the information in the text (Chin & Brown, 2000; Lombrozo, 2006). Codes for the scientific accuracy of the response quantified the level at which the reader understood the correct reason for why the belief statement was true or false, either based on text information or prior knowledge (Kendeou & van den Broek, 2005; Pritchard, 1990; Ruiz-Primo, Li, Tsai, & Schneider, 2010). The response was coded as accurate (2 points) or inaccurate (0 points).

The *quality* of readers' responses was assessed using 11 dimensions previous literature has determined are either beneficial or harmful to learning science (Callanan & Oakes, 1992; Dagher, 1995; Jarvie & Agassi, 1967; Rips, 2002; Thagard, 1992; Vlach & Noll, 2016).

3. Results

Before performing any analyses to address the main research questions, we examined if there were differences between the think-aloud and silent reading groups in each of the dependent variables. A series of mixed ANOVAs showed no differences in any of the dependent variables (all Fs < 1). Thus, data from both groups were combined for subsequent analyses.

3.1. Research question 1

3.1.1. Quality

First, we wanted to understand the extent to which explanations generated after reading were influenced by text structure, namely refutation and non-refutation texts. Results showed, on average, significantly more explanations were generated in the refutation (M = 4.60, SD = 0.90) than the non-refutation condition (M = 3.81, SD = 1.21), $t(74)$ = 5.62, $p < .001$, d = 0.74. Also, accuracy of responses was significantly higher in the refutation (M = 6.96, SD = 3.07) than the non-refutation condition (M = 3.09, SD = 2.62), $t(74)$ = 9.03, $p < .001$, d = 1.36. Causality was significantly higher in the refutation than the non-refutation condition. Circularity and

Table 2
Quality: dimensions, definitions, and examples from post-test explanations.

Dimension	Definition	Example from post-tests
Trust	The response addressed trust of the text.	"Only information I have on this topic is from the reading so I'm trusting that [the belief statement is] false." (SN 116)
Analogy	The response used a "like" or "as" comparison.	No examples in the responses.
Causal relationships	The response described a cause and effect relationship to explain the belief statement.	"They change due to their emotions rather than surroundings." (SN 114)
Prior knowledge	The response mentioned information the reader recognized from the text or reader's prior experiences.	"Based off the story and my previous knowledge of physics this seems true." (SN 217)
Physical characteristics	The response described physical traits or objects that were not described in the belief statement.	"There are certain enzymes that break down turkey and cause the person to become sleepy." (SN 114)
Mistrust	The response addressed mistrust of the text.	"I don't believe what I read in the flashcards." (SN 213)
Personification	The response gave a human quality to an object or idea that was not human.	"Lightning strikes the tallest buildings multiple times a year." (SN 210)
Religion/magic	The response included religious or magic information.	No examples in the responses.
Circularity	The response restated the belief statement or circled around the belief statement.	"I'm pretty sure lightning never strikes the same place twice." (SN 106)
Unnecessary descriptors	The response included description words unnecessary for comprehension.	"The human brain is very complex and many different parts are used when different tasks are being completed." (SN 204)
Uncertainty descriptors	The response included phrases showing uncertainty about the information.	"I'm not sure if he was or wasn't." (SN 104)

Table 3
Results of *t*-tests for explanation accuracy and quality dimensions by condition.

Dimension	Condition		*t*	*p*
	Refutation	Non-refutation		
	M (*SD*)	*M* (*SD*)		
Explanation	4.60 (0.90)	3.81 (1.22)	5.62	.000*
Overall accuracy	6.96 (3.07)	3.09 (2.62)	9.025	.000*
Trust	0.07 (0.34)	0.08 (0.32)	−0.33	.741
Analogy	0.00 (0.00)	0.00 (0.00)	–	–
Causality	2.49 (1.19)	1.80 (1.34)	3.57	.001*
Prior knowledge	4.96 (0.20)	4.92 (0.27)	1.00	.321
Physical characteristics	0.55 (0.95)	0.59 (1.01)	−0.36	.717
Mistrust	0.11 (0.42)	0.12 (0.33)	−0.24	.810
Personification	0.43 (0.72)	0.29 (0.51)	1.64	.105
Religious/magical	0.00 (0.00)	0.00 (0.00)	–	–
Circularity	0.43 (0.76)	1.05 (1.13)	−4.59	.000*
Unnecessary descriptors	0.43 (0.95)	0.45 (0.92)	−0.29	.770
Uncertainty descriptors	0.37 (0.78)	0.60 (0.89)	−2.09	.040*

Note.
* Indicates $p < .05$.

uncertainty descriptors were significantly higher in the non-refutation than the refutation condition. No other effects were significant. Table 3 depicts differences by condition.

3.2. Research question 2

3.2.1. Profiles analysis

Second, we wanted to explore if there were individual differences in *quality* and *accuracy* of explanations generated after reading refutation and non-refutation texts. In doing so, we used cluster analysis. To determine the appropriate number of clusters, we evaluated two-, three-, and four-cluster solutions for distinct profiles with adequate numbers of participants (Pastor, 2010). The dimensions of analogy and religious/magical were not included in the analyses since they had zero frequency. The ANOVA results for the two-cluster solution did not significantly differentiate among the nine quality dimensions (all *ps* > .05 for trust, mistrust, causality, prior knowledge, and circularity). The ANOVA results for the three-cluster solution showed acceptable differentiation among the nine quality dimensions (all *ps* < .10). The ANOVA results for the four-cluster solution did not significantly differentiate among the nine quality dimensions (all *ps* > .05). Thus, the three-cluster solution was determined to produce the most distinct profiles. Profiles are presented in Table 4, along with the results from

Table 4
Profiles analysis.

Dimension	Cluster 1 Coherence building readers	Cluster 2 Non-coherence building readers	Cluster 3 Promiscuous readers	
	(*n* = 46)	(*n* = 26)	(*n* = 3)	
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*p*
Trust	0.00 (0.00)	0.19 (0.57)	0.00 (0.00)	.055
Mistrust	0.02 (0.15)	0.23 (0.65)	0.33 (0.58)	.038*
Causality	3.13 (0.86)	1.31 (0.74)	3.00 (1.00)	.000*
Prior knowledge	5.00 (0.00)	4.88 (0.33)	5.00 (0.00)	.055
Physical characteristics	0.43 (0.91)	0.50 (0.76)	2.67 (0.58)	.003*
Personification	0.43 (0.69)	0.19 (0.40)	2.33 (0.58)	.001*
Circularity	0.13 (0.40)	0.96 (0.96)	0.33 (0.58)	.000*
Unnecessary descriptors	0.26 (0.49)	0.27 (0.45)	4.33 (1.15)	.001*
Uncertainty descriptors	0.07 (0.25)	0.62 (0.75)	3.00 (1.00)	.000*

Note. Results from Kruskal-Wallis test.
* Indicates $p < .05$.

Kruskal-Wallis analyses. Follow-up non-parametric analyses confirmed all quality dimensions differed between clusters.

3.2.2. Clusters

Cluster 1 was identified as *coherence-building readers* because their explanations reflected several high-quality indicators. Specifically, Cluster 1 (*n* = 46) used significantly more causality ($p < .001$) and prior knowledge ($p < .001$) than Cluster 2. Cluster 1, also used significantly less trust ($p = .019$), mistrust ($p = .034$), circularity ($p < .001$), and uncertainty descriptors ($p < .001$) than Clusters 2 and 3. There were no significant differences between Clusters 1 and 2, for physical characteristics, personification, and unnecessary descriptors (all *ps* > .05).

Cluster 2 was identified as *non-coherence building readers* because their explanations reflected several low-quality indicators. In turn, Cluster 2 (*n* = 26) used significantly less causality ($p = .013$), physical characteristics ($p = .002$), personification ($p = .001$), unnecessary descriptors ($p = .001$), and uncertainty descriptors ($p = .002$) than Cluster 3. There were no significant differences between Cluster 2 and Cluster 3 for trust, mistrust, prior knowledge, and circularity (all

$ps > .05$).

Finally, Cluster 3 was identified as *promiscuous readers* because their explanations included both high- and low-quality indicators. This cluster included three exceptional cases. Cluster 3 ($n = 3$) used significantly more physical characteristics ($p = .003$), personification ($p = .001$), unnecessary descriptors ($p < .001$), and uncertainty descriptors ($p < .001$) than Cluster 1. There were no significant differences between Cluster 3 and Cluster 1 for trust, mistrust, causality, prior knowledge, and circularity (all $ps > .05$).

3.2.3. Cluster validation

To validate the three clusters, additional analyses were performed. First, a Kruskal-Wallis analysis was conducted with cluster membership as the independent variable and accuracy scores, a variable not used in the cluster analysis, as the dependent variable. Results showed a significant difference between the three clusters ($p < .001$). Follow-up post-hoc comparisons using Mann-Whitney showed Cluster 1 had higher accuracy scores than Cluster 2 ($p < .001$) and Cluster 2 had higher accuracy scores than Cluster 3 ($p < .05$). Cluster 1 also had higher accuracy scores than Cluster 3 ($p < .001$). These differences are consistent with the characteristics of each cluster.

Second, a Kruskal-Wallis analysis was conducted with cluster membership as the independent variable and explanation scores, another variable not used in the cluster analysis, as the dependent variable. The explanation score refers to the dimension which assessed if the response was an explanation. Results showed a significant difference between the three clusters ($p < .001$). Follow-up by post-hoc comparisons using Mann-Whitney showed Cluster 1 generated more explanations than Cluster 2 ($p = .045$) and Cluster 2 generated more explanations than Cluster 3 ($p = .017$).

4. Discussion

The aim of the present study was to examine the effects of refutation texts on explanation quality and explore potential individual differences. To achieve this aim we sought to answer two specific research questions. First, we examined the extent to which explanations produced after completing reading were influenced by text structure, namely refutation and non-refutation texts. We hypothesized that after reading was completed, readers in the refutation condition would provide explanations with high-quality indicators for target concepts compared to readers in the non-refutation condition. Indeed, readers in the refutation condition provided significantly more explanations and used causality, a high-quality indicator, more than readers in the non-refutation condition. Conversely, the explanations from readers in the non-refutation condition contained significantly more circular phrases and uncertainty descriptors than readers in the refutation condition.

Second, we explored whether there were individual differences in *quality* and *accuracy* of explanations generated after reading refutation and non-refutation texts. We hypothesized distinct profiles would emerge using the quality dimensions and accuracy. Indeed, a three-cluster solution demonstrated three types of readers: *coherence-building readers*, *non-coherence building readers*, and cases of *promiscuous readers*, each negotiating the reading task differently and establishing different levels of accuracy and understanding. The *coherence-building readers* were distinguished by their high use of causality and high post-test scores suggesting success in learning from texts. The *non-coherence building readers* were distinguished by their high use of circularity and low post-test scores suggesting less success in learning. The *promiscuous readers* were special cases distinguished by their use of both low-quality (personification, unnecessary descriptors, uncertainty descriptors) and high-quality indicators (physical characteristics) and the lowest post-test scores, suggesting low levels of learning.

There is precedent in the literature identifying similar clusters or profiles of readers across development. Thus, these profiles may represent relatively stable individual differences (Gernsbacher, 1997). For example, Bohn-Gettler and Kendeou (2014) identified clusters of coherence-building and non-coherence-building processes in a sample of adult readers. The extent to which readers engaged in coherence or non-coherence building depended on individual differences in working memory capacity. Importantly, coherence-building processes were associated with high levels of comprehension, whereas non-coherence building processes were associated with low levels of comprehension. This pattern of results is consistent with the coherence and non-coherence building readers identified in the present study. Related, McMaster and colleagues (McMaster et al., 2012; Rapp, van den Broek, McMaster, Kendeou, & Espin, 2007) identified several clusters of young readers in grade 4, including a group of struggling readers who appeared to engage in activities much as good readers did. However, these activities were frequently unsuccessful and also drew on inappropriate knowledge. This pattern of results is consistent with the promiscuous readers identified in the present study, who frequently used both high- and low-quality indicators in their explanations, resulting in low overall post-test performance.

Taken together, the results suggest readers in the refutation condition reached a better understanding of causal relationships, and generated more accurate responses with less circularity and uncertainty, than the non-refutation condition. One explanation for these findings is that refutation texts may have helped readers to break the "cycle of circularity"; readers may have gained an understanding of the direct causal pathways of the conception and thus relied less on circular misconceptions. Consequently, the refutation texts then supported the generation of explanations with quality dimensions, which in turn facilitated comprehension, articulation, and perhaps also knowledge revision. Indeed, this study suggests refutation texts may engender shifts in the directionality of thought, from circular to causal pathways, which is an important milestone in scientific understanding (McNeill, Lizotte, Krajcik, & Marx, 2006; Zohar & Nemet, 2002). Future research should target these thought processes as they may be the foundation for knowledge revision.

It is important to note that the refutation texts in the present study addressed misconceptions that were conceived at the individual belief level (Chi, 2008). Previous research has shown that such misconceptions are possible to revise after reading refutation texts (Braasch et al., 2013; Kendeou & van den Broek, 2007; Mason et al., 2018), whereas other types of misconceptions that are more complex are less likely to be revised (Chi, 2013). Even though we cannot be certain that knowledge revision has taken place in this study given the absence of a pretest, it is very likely that it did. Indeed, if we integrate both process (e.g., think-aloud protocols, reading times; Kendeou et al., in press) and outcome measures, there is convergence for knowledge revision. The present analysis, however, focused exclusively on outcome measures, thus we refrain from making strong claims about revision.

From a methodological point of view, the present study demonstrates how variable-centered and person-centered approaches can be integrated to produce new insights into readers' learning from text. A variable-centered approach allowed for the identifications of differences between explanations produced as a result of reading refutation and non-refutation texts, highlighting the importance of text structure. A person-centered approach allowed for the identification of individual differences in the quality of the explanations produced, highlighting the presence of clusters or profiles of readers (Bohn-Gettler & Kendeou, 2014; McMaster et al., 2012; Rapp et al., 2007; Trevors et al., 2017). Thus, the combination of both variable-centered and person-centered approaches produced new insights into how text structure influences learning from text and how individuals respond to different text structures.

Despite these contributions, this study also has its limitations. As we noted above, one limitation is the lack of a pre-test of misconceptions for the specific sample. Even though previous research found that the targeted misconceptions are prevalent in the population from which the current sample has been drawn (e.g., Kendeou et al., 2014; Van Boekel et al., 2017), it is very likely that there was variability in readers' pre-existing beliefs. In future research, a pre-test should be incorporated to confirm the presence and strength of misconceptions prior to engaging with refutation and non-refutation texts. The challenge of including a pre-test is determining how it could be incorporated in this context without drawing attention to the target misconceptions or activating them before reading and thus potentially influencing post-test outcomes. Future research should also consider the inclusion of a delayed post-test measure to provide insight into whether readers retained the correct knowledge and maintained the reported learning gains long-term. Additionally, continued work is necessary to understand the negative relation between trust as a quality indicator and accuracy. This was a surprising finding and may be due, in part, to the low frequency of this dimension in student responses.

4.1. Conclusions

The current results add to the growing body of work showing that refutation texts are a powerful tool for learning (Ariasi & Mason, 2011; Broughton et al., 2010; Chinn & Brewer, 1993; Danielson, Sinatra, & Kendeou, 2016; Guzzetti et al., 1993; Hynd & Alvermann, 1986; Kendeou et al., 2016; Sinatra & Broughton, 2011; Tippett, 2010). This work also demonstrates that examining characteristics of explanations is a useful method for revealing how learners' reasoning influences their understanding of and learning from texts. In this context, refutation texts may facilitate shifts from circular to causal reasoning pathways that, in turn, may be foundational for knowledge revision.

Appendix A

A.1. Targeted common misconceptions

1. Seasons are caused by the Earth being closer to the Sun in the summer than in the winter.
2. Meteors that land on Earth are hot.
3. Napoleon Bonaparte was very short.
4. Chameleons change color to match their surroundings.
5. People only use 10% of their brains.
6. If you drop two balls of the same size but one weighs twice as much, the heavier ball will hit the ground first.
7. Reading in dim light causes nearsightedness (myopia).
8. Eating turkey makes people especially drowsy.
9. Ostriches bury their heads in the sand.
10. Lightning never strikes the same place twice.

Appendix B

B.1. Sample refutation text

Introduction

After a busy day at work, Kate was out for her nightly run. About halfway through the run, she stopped at a corner to rest and stretch. Kate looked up at the clear night sky while she took a sip from her water bottle. She saw a meteor falling beyond the trees and she watched until it hit the ground. She quickly ran about 400 yards to the site where the meteor landed. When she arrived there were already several people there. She noticed that her neighbor Jerry had also come down the street to see what was going on.

Refutation

Kate warned everyone not to touch the meteor because it would be hot and they could get burned. However, Jerry said that they should not worry because it actually should not be hot.

Elaboration

He explained that the high speed of the meteor when it enters the atmosphere causes it to melt or vaporize its outermost layer. The hot molten layer quickly blows off and the inside of the meteor does not have time to heat up again before passing through the atmosphere. This is because meteors are poor conductors of heat. Jerry told the crowd that many meteors that make it to Earth are actually found covered in frost. Despite this information, they all decided it was still a good idea not to touch it.

Filler

Kate continued to stare at the meteor. She had never seen anything like this in person before, and figured that would be true of many people here. What if a television crew came to interview witnesses? She could be on TV! She had to come across as smart if she was interviewed. She listened carefully as Jerry assured everyone that…

Correct outcome

Meteors landing on Earth are always cold.

Closing

Police cars were now starting to arrive. The police told the crowd they had to go home because they needed to block off the area. Kate decided to sprint home to tell her family about the news.

B.2. Sample non-refutation text

Introduction

After a busy day at work, Kate was out for her nightly run. About halfway through the run, she stopped at a corner to rest and stretch. Kate looked up at the clear night sky while she took a sip from her water bottle. She saw a meteor falling beyond the trees and she watched until it hit the ground. She quickly ran about 400 yards to the site where the meteor landed. When she arrived there were already several people there. She noticed that her neighbor Jerry had also come down the street to see what was going on.

Nonrefutation

Kate was excited and curious because she had never seen a meteor on the ground before. Jerry said that he could look up more about meteors in the astrophysics book that he had.

Nonelaboration

He told them that he had always been very interested in space and had read many articles about the research that they have been conducting in the space program. Jerry was known for offering up facts and information to anyone that would listen to him. He was sure that his book will have all sorts of facts about meteors. He walked across the street to get the book from his house while more people gathered around the meteor. They could not believe a meteor landed in their very own town.

Filler

Kate continued to stare at the meteor. She had never seen anything like this in person before, and figured that would be true of many people here. What if a television crew came to interview witnesses? She could be on TV! She had to come across as smart if she was interviewed. She listened carefully as Jerry assured everyone that…

Correct outcome

Meteors landing on Earth are always cold.

Closing

Police cars were now starting to arrive. The police told the crowd they had to go home because they needed to block off the area. Kate decided to sprint home to tell her family about the news.

References

Ariasi, N., & Mason, L. (2011). Uncovering the effect of text structure in learning from a science text: An eye-tracking study. *Instructional Science, 39*(5), 581–601.
Asoko, H. (2002). Developing conceptual understanding in primary science. *Cambridge Journal of Education, 32*, 153–164.
Baum, L. A., Danovitch, J. H., & Keil, F. C. (2008). Children's sensitivity to circular explanations. *Journal of Experimental Child Psychology, 100*(2), 146–155.
Bergman, L. R., Magnusson, D., & El-Khouri, B. M. (2003). *Studying individual development in an interindividual context: A person-oriented approach.* Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
Block, J. (1971). *Lives through time.* Berkeley, CA: Bancroft Books.
Bohn-Gettler, C. M., & Kendeou, P. (2014). The interplay of reader goals, working memory, and text structure during reading. *Contemporary Educational Psychology, 39*, 206–219.
Braasch, J. L. G., Goldman, S. R., & Wiley, J. (2013). The influences of text and reader characteristics on learning from refutations in science texts. *Journal of Educational Psychology, 105*, 561–578.
Bråten, I., Strømsø, H. I., & Britt, M. A. (2009). Trust matters: Examining the role of source evaluation in students' construction of meaning within and across multiple texts. *Reading Research Quarterly, 44*(1), 6–28.
Broughton, S. H., Sinatra, G. M., & Reynolds, R. E. (2010). The nature of the refutation text effect: An investigation of attention allocation. *The Journal of Educational Research, 103*(6), 407–423.
Brown, A. L., & Campione, J. C. (1990). Interactive learning environments and the teaching of science and mathematics. In M. Gardner, J. G. Greeno, R. Reif, A. H. Schoenfeld, A. diSessa, & E. Stage (Eds.). *Toward a scientific practice of science education* (pp. 111–139). Hillsdale, NJ: Lawrence Erlbaum.
Browne, C. A., & Woolley, J. D. (2004). Preschoolers' magical explanations for violations of physical, social, and mental laws. *Journal of Cognition and Development, 5*(2), 239–260.
Callanan, M. A., & Oakes, L. M. (1992). Preschoolers' questions and parents' explanations: Causal thinking in everyday activity. *Cognitive Development, 7*, 213–233.
Canfield, C. F., & Ganea, P. A. (2014). "You could call it magic": What parents and siblings tell preschoolers about unobservable entities. *Journal of Cognition and Development, 15*, 269–286.
Carey, S. (1985). *Conceptual change in childhood.* Cambridge: MIT Press.
Carey, S. (2009). *The origin of concepts.* Oxford, UK: Oxford University Press.
Chi, M. T. H. (2005). Commonsense concepts of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14*, 161–199.
Chi, M. T. H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.). *International handbook of research on conceptual change* (pp. 61–82). New York, NY: Routledge.
Chi, M. T. H. (2013). Two kinds and four sub-types of misconceived knowledge, ways to change it, and the learning outcomes. In S. Vosniadou (Ed.). *International handbook of research on conceptual change* (pp. 49–70). New York, NY: Routledge.
Chi, M. T. H., De Leeuw, N., Chiu, M.-H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*, 439–477.
Chin, C., & Brown, D. E. (2000). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching, 37*, 109–138.
Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*, 1–49.
Clement, J. (1991). Non-formal reasoning in science: The use of analogies, extreme cases, and physical intuition. In J. Voss, D. Perkins, & J. Segal (Eds.). *Informal reasoning and education*. Hillsdale, NJ: Lawrence Erlbaum Associates.
Dagher, Z. R. (1995). Review of studies on the effectiveness of instructional analogies in science education. *Science Education, 79*(3), 295–312.
Danielson, R. W., Sinatra, G. M., & Kendeou, P. (2016). Augmenting the refutation text effect with analogies and graphics. *Discourse Processes, 53*(5–6), 392–414.
Duke, N. K. (2000). 3.6 minutes per day: The scarcity of informational texts in first grade. *Reading Research Quarterly, 35*, 202–224.
Fender, J. G., & Crowley, K. (2007). How parent explanation changes what children learn from everyday scientific thinking. *Journal of Applied Developmental Psychology, 28*, 189–210.
Gernsbacher, M. A. (1997). Two decades of structure building. *Discourse Processes, 23*, 265–304.
Guzzetti, B. J., Snyder, T. E., Glass, G. V., & Gamas, W. S. (1993). Promoting conceptual change in science: A comparative meta-analysis of instructional interventions from reading education and science education. *Reading Research Quarterly, 28*, 117–159.
Hynd, C. R. (2001). Refutational texts and the change process. *International Journal of Educational Research, 35*(7–8), 699–714.
Hynd, C. R., & Alvermann, D. E. (1986). The role of refutation text in overcoming difficulty with science concepts. *Journal of Reading, 29*(5), 440–446.
Jarvie, I. C., & Agassi, J. (1967). The problem of the rationality of magic. *The British Journal of Sociology, 18*, 55–74.
Kallery, M., & Psillos, D. (2004). Anthropomorphism and animism in early years science: Why teachers use them, how they conceptualise them and what are their views on their use. *Research in Science Education, 34*, 291–311.
Keil, F. C. (2006). Explanation and understanding. *Annual Review of Psychology, 57*, 227–254.
Kendeou, P., Braasch, J. L. G., & Bråten, I. (2016). Optimizing conditions for learning: Situating refutations in epistemic cognition. *Journal of Experimental Education, 84*(2), 245–263.
Kendeou, P., Butterfuss, R., Kim, J., & Van Boekel, M. (2018). Knowledge revision through the lenses of the three-pronged approach. *Memory & Cognition*. https://doi.org/10.3758/s13421-018-0848-y.
Kendeou, P., Butterfuss, R., Van Boekel, M., & O'Brien, E. (2017). Integrating relations reasoning and knowledge revision during reading. *Educational Psychology Review, 29*, 27–39.
Kendeou, P., & O'Brien, E. J. (2014). The Knowledge Revision Components (KReC) framework: Processes and mechanisms. In D. N. Rapp, & J. L. G. Braasch (Eds.). *Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences* (pp. 353–377). Cambridge, MA: MIT Press.
Kendeou, P., Smith, E. R., & O'Brien, E. J. (2013). Updating during reading comprehension: Why causality matters. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*, 854–865.
Kendeou, P., & van den Broek, P. (2005). The effects of readers' misconceptions on comprehension of scientific text. *Journal of Educational Psychology, 97*, 235–245.
Kendeou, P., & van den Broek, P. (2007). The effects of prior knowledge and text structure on comprehension processes during reading of scientific texts. *Memory & Cognition, 35*(7), 1567–1577.
Kendeou, P., Walsh, E. K., Smith, E. R., & O'Brien, E. J. (2014). Knowledge revision processes in refutation texts. *Discourse Processes, 51*, 374–397.
Legare, C. H., Lane, J. D., & Evans, E. M. (2013). Anthropomorphizing science: How does it affect the development of evolutionary concepts? *Merrill-Palmer Quarterly, 59*, 168–197.
Lombrozo, T. (2006). The structure and function of explanations. *Trends in Cognitive Sciences, 10*, 464–470.
Mason, L., Zaccoletti, S., Carretti, B., Scrimin, S., & Diakidoy, I. N. (2018). The role of inhibition in conceptual learning from refutation and standard expository tests. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-017-9874-7.
Mayer, R. E., & Jackson, J. (2005). The case for coherence in scientific explanations: Quantitative details can hurt qualitative understanding. *Journal of Experimental Psychology: Applied, 11*, 13–18.
McCrudden, M. T., & Kendeou, P. (2014). Exploring the link between cognitive processes and learning from refutational text. *Journal of Research in Reading, 37*(S1), S116–S140.
McMaster, K., van den Broek, P., Espin, C., White, M., Rapp, D. N., Kendeou, P., ... Carlson, S. (2012). Making the right connections: Differential effects of reading intervention for subgroups of comprehenders. *Learning and Individual Differences, 22*, 100–111.
McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences, 15*, 153–191.
Novak, J. D. (1988). Learning science and the science of learning. *Studies in Science Education, 15*, 77–101.
Pastor, D. A. (2010). Cluster analysis. In G. R. Hancock, & R. O. Mueller (Eds.). *The reviewer's guide to quantitative methods in the social sciences* (pp. 41–54). New York, NY: Routledge.
Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211–227.
Pritchard, R. (1990). The effects of cultural schemata on reading processing strategies. *Reading Research Quarterly, 24*, 273–295.
Rapp, D. N., van den Broek, P., McMaster, K. L., Kendeou, P., & Espin, C. A. (2007). Higher-order comprehension processes in struggling readers: A perspective for research and intervention. *Scientific Studies of Reading, 11*, 289–312.
Rips, L. J. (2002). Circular reasoning. *Cognitive Science, 26*, 767–795.
Ruiz-Primo, M. A., Li, M., Tsai, S.-P., & Schneider, J. (2010). Testing one premise of scientific inquiry in science classrooms: Examining students' scientific explanations and student learning. *Journal of Research in Science Teaching, 47*, 583–608.
Rusanen, A. M. (2014). Towards to an explanation for conceptual change: A mechanistic alternative. *Science & Education, 23*, 1413–1425.
Sandoval, W. A. (2003). Conceptual and epistemic aspects of students' scientific explanations. *Journal of the Learning Sciences, 12*, 5–51.
Sandoval, W. A., & Reiser, B. J. (2004). Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education, 88*, 345–372.
Sinatra, G. M., & Broughton, S. H. (2011). Bridging reading comprehension and conceptual change in science education: The promise of refutation text. *Reading Research Quarterly, 46*, 374–393.
Szechter, L. E., & Carey, E. J. (2009). Gravitating toward science: Parent-child interactions at a gravitational-wave observatory. *Science Education, 93*, 846–858.
Tan, K. C. D., Goh, N. K., & Chia, L. S. (2001). Secondary students' perceptions about learning qualitative analysis in inorganic chemistry. *Research in Science & Technological Education, 19*, 223–234.
Thagard, P. (1992). Analogy, explanation, and education. *Journal of Research in Science Teaching, 29*, 537–544.
Tippett, C. D. (2010). Refutation text in science education: A review of two decades of research. *International Journal of Science and Mathematics Education, 8*, 951–970.
Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education, 10*, 159–169.
Trevors, G. J., Kendeou, P., Bråten, I., & Braasch, J. L. G. (2017). Adolescents' epistemic profiles in the service of knowledge revision. *Contemporary Educational Psychology, 49*, 107–120.
Trumper, R. (2001). A cross-age study of senior high school students' conceptions of basic astronomy concepts. *Research in Science & Technological Education, 19*, 97–109.
Van Boekel, M., Lassonde, K. A., O'Brien, E. J., & Kendeou, P. (2017). Source credibility and the processing of refutation texts. *Memory & Cognition, 45*, 168–181.
van den Broek, P., & Kendeou, P. (2008). Cognitive processes in comprehension of science

texts: The role of co-activation in confronting misconceptions. *Applied Cognitive Psychology, 22*, 335–351.
Vendetti, M. S., Matlen, B. J., Richland, L. E., & Bunge, S. A. (2015). Analogical reasoning in the classroom: Insights from cognitive science. *Mind, Brain, and Education, 9*, 100–106.
Vlach, H. A., & Noll, N. (2016). Talking to children about science is harder than we think: Characteristics and metacognitive judgements of explanations provided to children and adults. *Metacognition and Learning, 11*, 317–338.
Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24*, 535–585.
Vosniadou, S., & Brewer, W. F. (1994). Mental models of the day/night cycle. *Cognitive Science, 18*, 123–183.
Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The seductive allure of neuroscience explanations. *Journal of Cognitive Neuroscience, 20*, 470–477.
Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35–62.