Title
Change your Mind: Investigating the Effects of Self-Explanation in the Resolution of Misconceptions

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 37(0)

Authors
Allen, Laura K
McNamara, Danielle S
McCrudden, Mathew T

Publication Date
2015

Peer reviewed

Change your Mind: Investigating the Effects of Self-Explanation in the Resolution of Misconceptions

Laura K. Allen (LauraKAllen@asu.edu)
Danielle S. McNamara (DSMcnama@asu.edu)
Arizona State University, Department of Psychology, P.O. Box 872111
Tempe, AZ 85281 USA

Matthew T. McCrudden (Matt.McCrudden@vuw.ac.nz)
Victoria University of Wellington, School of Education, P.O. Box 17-310
Wellington 6147, New Zealand

Abstract

We investigated the differential effects of self-explaining a refutational text, compared to thinking aloud or rereading. Undergraduate students (n = 105) read a refutational text about natural selection and were asked to either *self-explain, think-aloud,* or *re-read* the text. Then they completed a posttest that assessed general knowledge of natural selection. Students who self-explained the refutational text subsequently outperformed their peers on a test of their knowledge of natural selection. Additionally, the results suggest that both instructional and performance differences were significantly linked to the degree of causal cohesion present within students' natural language responses to the text (i.e., self-explanations and think-alouds).

Keywords: comprehension; conceptual change; computational linguistics; cohesion; self-explanation; strategies

Introduction

Misconceptions emerge from our attempts to understand the world around us (Guzzetti et al., 1993). As a result, they tend to be relatively intuitive and relate to our prior (accurate) knowledge reasonably well. Not surprisingly then, these misconceptions can be difficult to recognize and extremely resistant to change (van den Broek & Kendeou, 2008). Importantly, misconceptions cause interference when we attempt to learn new and related information (Feltovich, Couson, & Spiro, 2001), which can pose serious problems in our academic and everyday lives. Hence, researchers investigate processes involved in resolving misconceptions (*conceptual change*) and means to promote conceptual change most effectively (Vosniadou, 2003).

One method proposed to enhance conceptual change is through the development of specific types of educational texts. In particular, *refutational texts* are commonly employed in classroom and laboratory settings because they encourage students to alter their beliefs about concepts by: (a) explicitly defining common misconceptions of a given topic, (b) stating the inaccuracies in these beliefs, and (c) following these statements with correct explanations of the topic (Dole, 2000; Guzzetti et al., 1993). According to the *co-activation hypothesis*, refutational texts are effective because they promote the simultaneous activation of the correct information in the text and the incorrect information held by the reader (Kendeou & van den Broek, 2007; van den Broek & Kendeou, 2008). The co-activation of both correct and incorrect information presumably increases the likelihood that readers recognize inaccuracies in their understandings and work to revise their misconceptions.

Support for the co-activation hypothesis primarily stems from research investigating the cognitive processes that take place while reading refutational texts (Kendeou, Muis, & Fulton, 2011; Kendeou & van den Broek, 2007; McCrudden & Kendeou, 2014; van den Broek & Kendeou, 2008). Prior studies, for instance, have demonstrated that readers allocate more time to target sentences within refutational texts as opposed to control versions of these texts. Additionally, students who read refutational texts generate think-aloud statements that are more indicative of conceptual change strategies (Kendeou & van den Broek, 2007; Kendeou et al., 2011; van den Broek & Kendeou, 2008).

Despite these online processing differences, research on the efficacy of these specialized texts to promote conceptual change has been mixed. Although some research has shown positive effects of these texts on retention of science knowledge and inference-level performance (Ariasi & Mason, 2011; Diakidoy, Kendeou, & Ioannides, 2003; Mason & Gava, 2007), other studies have reported null results (Kendeou et al., 2011; Kendou & van den Broek, 2007; Palmer, 2003). These mixed findings indicate that conceptual change from refutational texts is not a simple or straightforward process. Rather, this learning process likely depends on a number of other factors, and in particular, the cognitive processes in which readers engage while reading.

Text Comprehension Processes

Comprehension of texts is a complex activity that involves knowledge of the language and the domain, as well as interactions among lower and higher-order skills used to process this knowledge. Not surprisingly, then, individuals vary a great deal in the cognitive processes that they employ during comprehension (McNamara, Jacovina, & Allen, in press; McNamara & Magliano, 2009). One explanation for inconsistent results regarding the effects of refutational texts is that, despite reading the same text, students may engage in vastly different processes depending on the particular circumstances (instructions, goals, prior knowledge, etc.).

Deep comprehension relies on a reader's ability to activate prior knowledge and make connections among this prior knowledge and information in a text (McNamara & Magliano, 2009). The result of these processes is the mental representation. Readers develop *coherent* representations of text material to the degree that they establish connections using inferences (Oakhill & Yuill, 1996). Thus, the generation of inferences is key to successfully comprehending text information (McNamara, 2004; McNamara & Magliano, 2009).

Self-explanation is a strategy that has been used to promote these coherence-building processes (McNamara, 2004), which in turn enhances understanding of complex concepts (Chi et al., 1989). In particular, self-explanation fosters the activation of prior knowledge, the generation of inferences, and places a greater focus on *causally* relevant information, rather than *perceptually* relevant information (Chi et al., 1989; Legare & Lombrozo, 2014; Walker et al., 2014). Causal information focuses on mechanistic relations between people or objects (e.g., X *caused* Y to happen), whereas perceptual information refers to the characteristics of those people or objects (e.g., their color or shape).

Our principal claim is that conceptual change may not rely solely on the type of texts presented to students, but also (and more importantly) on the comprehension processes that students employ while reading these texts. In particular, we suggest that refutational texts will be successful to the extent that students generate inferences, which will consequently increase the coherence of their text representations. Thus, instructing students to self-explain will promote coherence-building processes and increase the efficacy of refutational texts to promote conceptual change.

As an initial step, we investigate coherence-building processes while students read refutational texts. We do so by examining both referential and causal *cohesion* in students' responses to the text (i.e., self-explanations and think-alouds). Referential cohesion emerges from cues such as overlap in objects (i.e., nouns) or people, indicating that these referents are the same or different across sentences. Causal cohesion is signaled by overlapping actions (i.e., verbs) and connectives (e.g., *because*, *therefore*), which serve to explicitly describe connections among events, actions, people, and objects.

Although these cohesion indices are not *direct* measures of coherence (e.g., McNamara et al., 2014), studies have shown that cohesion can serve as a *proxy* for coherence, and the cohesion of students' self-explanations is a strong predictor of their ability to comprehend texts (Allen, Snow, & McNamara, 2015; Varner et al., 2013). Thus, we predict that in comparison to normal reading processes reflected in students' think-alouds, instructing students to self-explain text will lead them to place a greater emphasis on *causal relationships*, which will increase the degree to which their text responses are causally cohesive. Additionally, we predict that these cohesion differences will relate to their performance on a posttest knowledge measure.

Current Study

In the current study, we examine whether instructing individuals to *self-explain* a refutational text will differentially affect their understanding of natural selection in comparison to thinking-aloud or rereading. We also examine the extent to which these differences manifest in the cohesion of students' verbal responses while reading the text. Our research questions are listed below:

1) Does self-explanation of a refutational text enhance comprehension of natural selection in comparison to thinking-aloud or rereading the text?
2) Does the cohesion of students' natural language responses vary as a function of instructional condition (i.e., self-explanation vs. think aloud)?
3) Does the cohesion of students' natural language responses predict post-reading performance on a test of natural selection knowledge?

We first hypothesize that students in the experimental conditions will vary in the degree to which they are able to learn from the refutational text. In particular, we hypothesize that students who engage in self-explanation will outperform the students who think-aloud or reread on a post-reading measure of natural selection knowledge.

Second, we hypothesize that students instructed to self-explain the text will significantly differ from students instructed to think-aloud in their use of *causal* cohesion, but not in their use of *referential* cohesion. This hypothesis follows from the assumption that self-explanation primarily enhances the construction of *causal* connections between events, rather than referential connections among concepts. This hypothesis is in line with previous research that has shown that self-explanation promotes greater processing of causal information (Legare & Lombrozo, 2014; Walker et al., 2014) and promotes more coherent mental representations of text (Allen et al., 2015; McNamara, 2004; McNamara & Magliano, 2009).

Our third hypothesis relates to the link between the cohesion indices and performance on a post-reading test of natural selection. We hypothesize that the cohesion indices that significantly differentiate the self-explanation and think-aloud conditions will also relate to students' test performance. This finding would suggest that the potential benefits of self-explanation are related (at least in part) to the degree to which self-explanation promotes specific cognitive processes during comprehension.

Method

Participants

Participants were 105 introductory psychology students from a university located in the southwestern United States who participated for course credit. The students were predominantly in their first year of college (66.3%); 67.3% were male; 53% were Caucasian, 20% were Hispanic, 18% were Asian, 9% were African American, and 4% reported *other*; 18.3% of participants reported that they were second language speakers of English. Seven participants were excluded from the analyses due to missing data.

Study Procedure

Students first completed a brief demographics questionnaire and then read a refutational text related to natural selection. The text was presented one sentence at a time, with previous text remaining on the screen. Students completed a posttest that assessed general knowledge of natural selection.

Students were randomly assigned to one of three conditions, which related to the instructions they were given for reading the text: *self-explanation condition* (n=33), *think-aloud condition* (n=35), or *reread condition* (n=30). Students in the self-explanation and think-aloud conditions were prompted to generate typed responses on 16 separate occasions throughout the text. The students in the self-explanation condition were asked to *explain* the information in the text that they had just read to themselves, whereas students in the think-aloud conditions were told to state whatever they were thinking. Students in the reread condition did not generate responses while reading. To control for time on task, they read the text twice.

Measures

Refutational Text The text assigned to students (n=716 words; 8 paragraphs) was adapted from an excerpt in Steven Pinker's book, *How the Mind Works* and describes the concept of natural selection and refutes intelligent design. In particular, it explains how the world can appear to be a product of intelligent design, but does not, in reality, have a designer. To make this point, the text uses the example of how the eye evolved. The text was adapted to be refutational, in that it explicitly acknowledged commonly held alternative conceptions about a topic (here, natural selection) and directly refuted them by providing more satisfactory explanations.

Conceptual Inventory of Natural Selection (CINS) Natural selection is a topic for which students commonly have misconceptions. Thus, in this study, we examined students' understanding of this topic. The CINS is a 20-item multiple-choice assessment developed to measure general knowledge of natural selection (Anderson, Fisher, & Norman, 2002). The CINS was specifically developed to capture students' common misconceptions of natural selection. The items address understanding of the five factors and three inferences identified by Mayr (1982) as important for understanding the logic underlying the theory of natural selection. The CINS uses common alternative conceptions as distractors. This assessment is considered to be a valid and reliable measure of knowledge about natural selection (e.g., Nehm & Shonfeld, 2008).

Text Analyses

To prepare the students' natural language responses (i.e., their self-explanations or think-alouds) for text analysis, we aggregated all of the responses provided by each individual student (this aggregation method is discussed in greater detail in Varner et al., 2013). Thus, for each student, one aggregated response file was created, which contained all of the text that they generated while reading. Paragraph breaks were added to each of these aggregated files to preserve the paragraph structure of the text; thus, each file contained eight paragraphs.

Computational Analysis of Text Cohesion Students' aggregated response files were analyzed using Coh-Metrix (McNamara et al., 2014), which calculates linguistic text properties, ranging from lower-level word indices to higher-level indices about coherence and rhetorical language use. For the purposes of the current study, we used Coh-Metrix to measure *referential cohesion* and *causal cohesion.* For each of these groups, three indices were selected.

The referential cohesion indices included: *argument overlap*, *stem overlap*, and *content word overlap*. Argument overlap refers to the degree to which sentences in the text contain overlapping nouns and pronouns. Stem overlap is similar to argument overlap, but it matches all words with similar stems. Thus, overlapping stems will be counted even if one is a noun and the other is an adjective. Finally, content word overlap refers to the *proportion* of explicit content words that overlap between two sentences. Therefore, this variable helps to control for the varying lengths of sentences in a text.

The causal cohesion indices included: *causal ratio*, *explicit verb overlap,* and *semantic verb overlap*. The causal ratio is assessed by calculating the ratio of causal verbs to causal particles within a text. The causal verb measure is based on the frequency of main causal verbs in a text (as identified by WordNet; Felbaum, 1998) and the causal particle count is based on a pre-defined set of causal particles (e.g., *because*, *as a result*). This index reflects the degree to which students are explicitly explaining causal events by expressing the directionality of cause-effect relationships. Verb overlap is also calculated with WordNet, and measures the degree to which verbs (which have strong links to actions, events, and states) are repeated in the text. Verb cohesion indicates the degree to which a text makes explicit connections among events (rather than objects). Semantic verb overlap is calculated using Latent Semantic Analysis and refers to the degree to which sentences in a text contain verbs that have similar semantic meaning.

Results

Statistical analyses were conducted to examine whether self-explanation of a refutational text enhanced students' performance on a post-reading measure of natural selection knowledge, as well as whether the cohesion of their typed responses played a role in this effect.

CINS Performance As predicted, students in the self-explanation condition (*M*=51.36%, *SD*=20.13%) significantly outperformed students in both the think-aloud

(*M*=41.43%, *SD*=15.93%), and reread (*M*=41.50%, *SD*=20.09%) conditions, $F(1,95)=43.17$, $p<.001$ (see Figure 1). Hence, self-explanation enhanced students' knowledge of natural selection in comparison to thinking aloud or rereading the text.

Figure 1: Conceptual Inventory of Natural Selection Scores as a Function of Condition

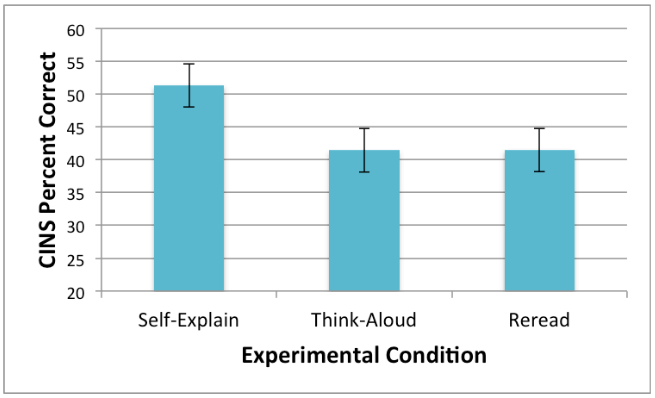

Table 1: Descriptive Statistics [(Means and (SD)] for Referential and Causal Cohesion

Index	Self-Explanation	Think-Aloud
Referential Cohesion		
Argument overlap	0.31 (0.13)	0.26 (0.18)
Stem overlap	0.03 (0.17)	0.02 (0.02)
Content word overlap	0.06 (0.02)	0.06 (0.03)
Causal Cohesion		
Causal ratio	1.00 (0.53)	0.69 (0.40)
Explicit verb overlap	0.58 (0.09)	0.48 (0.11)
Semantic verb overlap	0.13 (0.03)	0.10 (0.04)

Cohesion Indices Our second research question regarded whether students in the self-explanation and think-aloud conditions differed in their use of referential and causal cohesion within their verbal responses. A MANOVA analysis was first conducted to investigate whether **referential** cohesion differed for students in the two conditions (see Table 1 for descriptive statistics). This analysis yielded a non-significant multivariate model, $F(3,64)=2.21$, $p=.10$, with none of the indices demonstrating significant effects. A similar MANOVA analysis was conducted to examine whether **causal** cohesion differed for the two conditions. This analysis yielded a significant model, $F(3,64)=10.10$, $p<.001$, with all of the indices demonstrating significant effects: causal ratio $F(1,66)=7.58$, $p<.01$, explicit verb overlap $F(1,66)=16.65$, $p<.01$, and semantic verb overlap $F(1,66)=11.25$, $p=.001$.

A follow-up Discriminant Function Analysis (DFA) was next calculated to investigate whether the three significant causal indices (i.e., causal ratio, explicit verb overlap, semantic verb overlap) accurately classified the students according to whether they were asked to self-explain (SE) or think-aloud (TA). A DFA model was first developed for the entire set of students and this model was then used to predict group membership of the students using leave-one-out-cross-validation (LOOCV) in order to ensure that the model was stable across the dataset.

The stepwise DFA retained all three variables related to causality. The results revealed that the DFA using these two indices correctly allocated 50 of the 68 students in the total set, $\chi2$ (df=3, n=68)=25.00 p<.001, for an accuracy of 73.5% (chance level for this analysis is 50%). The reported Cohen's Kappa was .473, indicating a moderate agreement. For the LOOCV analysis, the DFA allocated 47 of the 68 students for an accuracy of 69.1% (see the confusion matrix reported in Table 2). The results of these analyses confirm our second hypothesis and indicate that students in the self-explanation condition generated text responses that were more causally cohesive, but exhibited no differences in terms of referential cohesion.

Table 2: Confusion Matrix for DFA classifying Task Instructions

		SE	TA
Whole Set	SE	**25**	8
	TA	10	**25**

		SE	TA
LOOCV	SE	**23**	10
	TA	11	**24**

Performance Differences Related to Causal Cohesion We last examined the degree to which the indices of causal cohesion that significantly differed according to experimental condition also related to students' performance on the CINS test. Pearson correlations were calculated between these causal cohesion indices and students' scores on the CINS. This analysis revealed that one of the three causal cohesion indices was significantly correlated with scores: explicit verb overlap ($r=.36$, $p<.01$).

A final DFA analysis was calculated to investigate whether this measure of verb overlap accurately classified the students according to their CINS performance group. A median split was calculated on students' CINS scores to produce two groups: *Low Score* (*M*=6.26, *SD*=1.25) and *High Score* (*M*=12.42, *SD*=2.69). The results of the DFA revealed that the model correctly allocated 50 of the 68 students in the total set, $\chi2$ (df=1,n=68)=15.832 p< .001, for an accuracy of 73.5% (the chance level for this analysis is 50%). The reported Cohen's Kappa was .471, indicating a moderate agreement. For the LOOCV analysis, the DFA also allocated 50 of the 68 students for an accuracy of 73.5% (see the confusion matrix reported in Table 3). These results partially confirm our final hypothesis that the degree of causal cohesion in students' text responses was related to their performance on the CINS test. Specifically, students with higher verb overlap in their responses also had higher scores on the CINS test. This suggests that the benefits of self-explanation may be attributable (at least in part) to its promotion of text processes that emphasize developing connections among actions and events.

Table 3: Confusion Matrix for DFA classifying CINS Performance

		Low Score	High Score
Whole Set	Low Score	**25**	10
	High Score	8	**25**

		Low Score	High Score
LOOCV	Low Score	**25**	10
	High Score	8	**25**

Discussion

In the current study, we investigated the differential effects of *self-explaining* a refutational text, over *thinking aloud* or *rereading*. Students who self-explained the refutational text subsequently outperformed their peers on a test of natural selection knowledge. Additionally, both instructional and performance differences were significantly linked to the degree of causal cohesion present within students' natural language responses to the text.

We interpret these results to indicate that self-explanation promotes specific coherence-building processes that are more conducive to conceptual change than other processes. All students in this study were randomly assigned to an experimental condition and were exposed to the same refutational text. The only manipulation in the study was whether students were asked to *explain* the information in the text to themselves, *state* what they were thinking at the moment, or read the text twice. However, despite this relatively minor manipulation, students in the self-explanation condition significantly outperformed their peers on a test of general natural selection knowledge. Importantly, the CINS did not simply measure students' comprehension of the specific text context (i.e., it was a general measure of natural selection knowledge). Thus, self-explanation of this refutational text enhanced students' understanding of natural selection more broadly, perhaps by changing their prior misconceptions about the topic.

Beyond these performance differences, the results from the current study also provide more fine-grained information about the online cognitive processes underlying these conditional differences. In this study, we demonstrated that causal cohesion was a significant predictor of students' experimental condition as well as their performance on the CINS test. These results indicate that instructing students to self-explain the information in the text led them to engage in more *causal* and *coherence-building* text processing, which ultimately impacted their performance on the CINS test. Importantly, these results suggest that simply generating responses while reading will not necessarily promote increased understanding of the text. Rather, students need to be given explicit instructions on how to engage with the text in order to benefit from this generation process.

The results from the current study are important because they indicate that self-explanation can promote beneficial comprehension processes that can help to increase students' comprehension of complex science concepts. In particular, this study suggests that students may not be able to resolve deep misconceptions by simply reading specific types of texts (as predicted by the co-activation hypothesis). Rather, they likely need to be provided explicit instructions that encourage the generation of inferences and other coherence-building processes while they read refutational texts. Previous research indicates that self-explanation can enhance students' understanding of complex concepts (e.g., Chi et al., 1989; McNamara, 2004). However, and somewhat interestingly, there are no previous studies to our knowledge that directly compare self-explanation to think-aloud. Hence, this study furthers our understanding of how self-explanation relates to other comprehension processes (i.e., thinking-aloud and rereading), as well as in examining the associated online processes at a more fine-grained level.

This study is, of course, only a first step in answering our questions. First, additional studies will be necessary to examine conceptual change more directly by including knowledge assessments both before and after reading the text. In the current study, we did not use a pretest-posttest design and, consequently, we are unable to make inferences about conceptual change at the level of individual student. Second, further research is needed to examine the generality of these effects across different types of texts and different types of misconceptions.

A final avenue for future research relates to the efficacy of self-explanation in enhancing conceptual change, and whether these effects depend on differences in students' abilities, such as prior knowledge or reading ability. Although we see here that self-explanation led to more effective comprehension processes, previous research suggests that some students struggle to generate coherent self-explanations (McNamara, 2004). We expect that such students would need training to use comprehension strategies in conjunction with self-explanation (McNamara, 2004; Jackson & McNamara, 2013).

Overall, the results of this study are promising and point to the efficacy of self-explanation to promote conceptual change. By using a multi-method approach, combining behavioral methods with computational linguistics, this study also contributes to a better understanding of why self-explanation enhances learning, and potentially increases conceptual change. Misconceptions can pose large impediments to comprehension and learning. Hence, better understanding the conceptual change process, and developing methods to promote conceptual change are crucial areas of research.

Acknowledgments

This research was supported in part by the Institute for Educational Sciences (IES R305A130124) and National

Science Foundation (NSF REC0241144; IIS-0735682). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the IES or NSF.

References

Allen, L. K., Snow, E. L., & McNamara, D. S. (2015). Are you reading my mind? Modeling students' reading comprehension skills with natural language processing techniques. In P. Nlikdyrin, A. Merceron, & G. Siemens (Eds.), *Proceedings of the fifth annual international learning analytics and knowledge conference* (pp. 246-254). Poughkeepsie, NY.

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching, 39,* 952-978.

Ariasi, N. & Mason, L. (2011). Uncovering the effect of text structure in learning from a science text: An eye-tracking study. *Instructional Science, 39*, 581-601.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, R., & Glaser, R. (1989). Self-explanation: How students study and use examples in learning to solve problems. *Cognitive Science, 13,* 145–182.

Diakidoy, I. N., Kendeou, P., & Ioannides, C. (2003). Reading about energy: The effects of text structure in science learning and conceptual change. *Contemporary Educational Psychology, 28*, 335-356.

Dole, J. A. (2000). Readers, texts and conceptual change learning. *Reading & Writing Quarterly, 16*, 99-118.

Fellbaum, C. (1998). WordNet: An electronic lexical database. Cambridge, MA: MIT Press.

Feltovich, P., Coulson, R., & Spiro, R. (2001). Learners' (mis)understanding of important and difficult concepts: A challenge to smart machines in education. In K. D. Forbus, & P. J. Feltovich (Eds.), *Smart machines in education*. MenloPark, CA: AAAI/MIT Press.

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*, 116-159.

Jackson, G. T., & McNamara, D. S. (2013). Motivation and performance in a game-based intelligent tutoring system. Journal of Educational Psychology, 105, 1036-1049.

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

Kendeou, P., & van den Broek, P. (2007). Interactions between priork knowledge and text structure during the comprehension of scientific texts. *Memory and Cognition, 35,* 1567-1577.

Legare, C. H., & Lombrozo, T. (2014). Selective effects of explanation on learning during early childhood. *Journal of Experimental Child Psychology, 126,* 198-212.

Mason, L. & Gava, M. (2007). Effects of epistemological beliefs and learning text structure on conceptual change. In S. Vosniadou, A. Baltas, & X. Vamvakoussi (Eds.), *Reframing the conceptual change approach in learning and instruction*. Elsevier.

Mayr, E. (1982). *The growth of biological thought. Diversity, evolution and inheritance*. Cambridge, MA: The Belknap Press of Harvard University Press

McCrudden, M. T., & Kendeou, P. (2014). Exploring the link between cognitive processes and learning from refutational text. *Journal of Research in Reading, 37,* 116-140.

McNamara, D.S. (2004). SERT: Self-explanation reading training. *Discourse Processes, 38*, 1-30.

McNamara, D. S., Graesser, A. C., McCarthy, P., & Cai, Z. (2014). *Automated evaluation of text and discourse with Coh-Metrix.* Cambridge: Cambridge University Press.

McNamara, D. S., Jacovina, M. E., & Allen, L. K. (in press). Higher order thinking in comprehension. In P. Afflerbach (Ed.), *Handbook of individual differences in reading: Text and context.*

McNamara, D. S. & Magliano, J. P. (2009). Towards a comprehensive model of comprehension. In B. Ross (Ed.), *The psychology of learning and motivation.* New York, NY: Elsevier Science.

Nehm, R. H., & Schonfeld, I. S. (2008). Measuring knowledge of natural selection: A comparison of the CINS, an open-response instrument, and an oral interview. *Journal of Research in Science Teaching, 45,* 1131–1160.

Oakhill, J., & Yuill, N. (1996). Higher order factors in comprehension disability: Processes and remediation. In C. Cornaldi & J. Oakhill (Eds.), Reading comprehension difficulties: Processes and intervention. Mahwah, NJ: Erlbaum.

Palmer, D. H. (2003). Investigating the relationship between refutational texts and conceptual change. *Science Education, 87*, 663-684.

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.

Varner, L. K., Jackson, G. T., Snow, E. L., & McNamara, D. S. (2013). Does size matter? Investigating user input at a larger bandwidth. In C. Boonthum-Denecke & G. M. Youngblood (Eds.), Proceedings of the 26th Annual Flordia Artificial Intelligence Research Society (FLAIRS) Conference (pp. 546-549). Menlo Park, CA: The AAAI Press.

Vosniadou, S. (2003). Exploring the relationships between conceptual change and intentional learning. In Sinatra, G. M., & Pintrich, P. R. (Eds.), Intentional conceptual change. Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Walker, C. M., Lombrozo, T., Legare, C. H., & Gopnik, A. (2014). Explaining prompts children to privilege inductively rich properties. *Cognition, 133* 343-357.