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Abstract

Example-based instruction with text involves introducing readers to domain principles (e.g., principles of natural selection), followed by several examples that illustrate those principles. It is unclear how bridging inferences contribute to example-based learning. Participants did think-aloud while reading four short texts: one about principles and three about examples of those principles. The main finding was that bridging inferences to the principles and bridging inferences to examples were predictive of learning, whereas other processes were not.

Keywords: bridging inferences, text processing, transfer

Bridging Inferences from Examples to Principles Support Near Transfer

One way to promote knowledge of principles is through example-based instruction (Renkl, 2014). When this approach is used with text, readers are introduced to domain principles (e.g., principles of natural selection in biology), followed by several examples that illustrate those principles. The approach is effective because readers engage in various processes that produce a coherent mental representation of the text. Specifically, readers purportedly use the domain principles to explain the provided examples (Roelle et al., 2017). However, it is unclear to what extent readers construct (a) bridging inferences between the examples and the principles, and (b) bridging inferences between the examples, and how these inferences contribute to readers' ability to apply these principles to similar contexts (e.g., near transfer).

The aim of this study was to investigate the contribution of these types of inferences and other cognitive processes on example-based learning about principles of natural selection in biology. Participants read four short texts: one introduced five principles of natural and three were examples that illustrated those principles (e.g., why the Artic hare has white fur). Participants did a pre-reading knowledge measure, a think-aloud task while reading, and a post-reading knowledge measure. Our research questions were:

1) Do bridging inferences from examples to the principles predict near transfer?
2) Do bridging inferences between examples predict near transfer?
3) Do other cognitive processes (e.g., elaborations) predict near transfer?

Method

Participants

Participants were 95 undergraduates (n = 86 female; one participant did not identify their gender) located at a large public university in the northeastern part of the United States. The

mean age was 19.2 years. Participants were recruited from an introductory educational psychology course and received course credit for their participation. Participants' self-identified ethnicity was 90.7% white/Caucasian, 4.4% Hispanic, 3.3% Asian/Filipina, and 2.2% African American. Data from an additional 15 participants were not included in the final data due to failure to follow instructions.

Materials

Knowledge items. We developed four items, based on the materials from Shtulman et al. (2016), to assess participants' knowledge of the five principles of natural selection described in the principles text. The items asked participants to apply principles of natural selection (e.g., Katydids have leaf-like wings. Their ancestors—who lived long, long ago—did not have leaf-like wings. How would a biologist explain how katydids with leaf-like wings came from katydids without leaf-like wings?). Students received two items before they read (pygmy seahorse & seal) and two different items after they read (katydid & cheetah); none of which were animals described in the texts.

Texts. There were four texts written at an introductory level (Flesch- Kincaid grade level of 8.6). The principle text (168 words), which was adapted from Anderson et al. (2002), described five main principles of natural selection (e.g., differential survival). The three animal texts were adapted from the materials used in Shtulman et al. (2016), one each for the Guinea turaco (121 words), Arctic hare (120 words), and zebra (135 words). The animal texts used the five principles of natural selection from the principles text to describe how each of the three different animals had changed over time but did not explicitly mention the principles. Each animal text had four images (adapted from Shtulman et al., 2016) that illustrated the five principles of natural selection from the principles text. For instance, the image for differential

reproduction for the Arctic hare showed a brown hare with three offspring and a white hare with five offspring.

Questionnaires. The *personal interest* questionnaire (adapted from Rotgans, 2015) consisted of six items (e.g., Outside of school I read a lot about biology; α = .92) that asked participants to rate their enduring and context-general interest in biology. The *situational interest* questionnaire (adapted from Schraw, 1997) consisted of 10 items (e.g., I thought the texts were very interesting; α = .94) that asked participants to rate their spontaneous and context-specific interest in the texts. The *ease of comprehension questionnaire* (adapted from Lehman & Schraw, 2002) consisted of 10 items (e.g., The information in the texts was well-organized; α = .87) that asked participants to judge the coherence and ease of understanding of the texts. All three questionnaires used a 5-point Likert-type scale (1 = *strongly disagree* to 5 = *strongly agree*). We summed each participants' total score for each questionnaire separately and computed an average score for each participant for each questionnaire. Higher scores equated to greater interest or ease of comprehension for the respective questionnaire.

Data collection

The study was conducted on Qualtrics. Participants were given an overview of the study and provided informed consent. The data collection procedure consisted of five main parts. First, participants completed the two pre-reading knowledge items (pygmy seahorse & seal). Second, they received the think-aloud instructions and were asked to type their thoughts after reading each sentence from the texts. There was a text box below each sentence so that the readers could type thoughts that came to mind. They were also reminded that there were no right or wrong thoughts. They were asked to read the passage carefully and that they would be assessed on their understanding of the texts. We did not program the system to require participants to type their

thoughts after each sentence. Third, participants read the text using the think-aloud procedure. Fourth, participants completed the personal interest, the situational interest, and the ease of comprehension questionnaires. Lastly, participants completed the two post-reading knowledge items (katydid & cheetah), followed by the demographic survey. Students were thanked for their participation.

Data coding

Coding of knowledge item responses. We coded participants' explanations for the inclusion of five evolutionary principles described in the principles text. Participants received one point for the correct use of each principle. The scores for each item could range from zero to five (maximum of 10 points overall across two items). The following excerpt is an example that includes all five principles:

> Once, long ago, some ancestors of katydids were born with leaf-like wings due to random genetic events (*variation*). These ancestors were able to survive better (*differential survival*) than ancestors without leaf-like wings because they could avoid being eaten and camouflage in their environment. These leaf-like winged katydid ancestors reproduced (*differential reproduction*), passing down the genes for leaf-like wings to their offspring (*inheritance*). Over a long, long period of time, this led to all katydids having leaf-like wings (*population change*).

Two raters coded the four items independently, interrater agreement was 70.1% (Cohen's kappa = .70).

Coding of think-aloud data. Participants' think-aloud responses were parsed into idea units and coded by two raters. The coding scheme, which consisted of 11 categories. See Table 1 for definitions and examples of participant responses for each think-aloud category. Interrater agreement was 92.6% (Cohen's kappa = .93). Any disagreements between the raters were resolved via discussion. In our analysis, we specifically focused on bridges to the principle sentences, bridges to animal sentences, elaborations, paraphrases, and repetitions. We focused on

these processes because we were interested in comprehension strategies related to concept learning and they occurred frequently enough in the data to warrant analysis.

Results

Our research question examined the association between readers' cognitive processes during reading and their performance on the knowledge post-test. Correlations among key variables are provided in Table 2. We used multiple regression analysis to predict performance on the knowledge post-test based on readers' cognitive processes during reading, situational interest, and ease of comprehension. We controlled for prior knowledge (knowledge pretest) and personal interest in Step 1 and entered the cognitive processes, situational interest, and ease of comprehension in Step 2.

Table 2
Correlations Among Variables

	1	2	3	4	5	6	7	8	9	10
1. Knowledge pre-test	-									
2. Knowledge post-test	.479**	-								
3. Bridges to principles sentences	.318**	.494**	-							
4. Bridges to animal sentences	-.028	.247*	.127	-						
5. Elaborations	-.192	-.120	.060	.073	-					
6. Paraphrases	.038	.114	.232*	.066	-.137	-				
7. Repetitions	-.082	-.117	-.032	-.080	-.072	.142	-			
8. Personal interest	.119	.059	.136	.003	-.034	.133	-.156	-		
9. Situational interest	.071	.154	.176	.141	.036	-.022	-.222*	.297**	-	
10. Ease of comprehension	.096	.296**	.187	-.009	.179	-.037	-.140	-.007	.272**	-

* p<.05 (two-tailed), ** p<.01 (two-tailed)

The overall model was significant, $F(9, 85) = 8.28$, $p < .001$, $R^2_{adj} = .41$, reflecting a large effect size. Bridges to the principles texts ($b = .32$, $p < .001$), bridges to the animal texts ($b = .24$, $p < .01$), and ease of comprehension ($b = .22$, $p < .05$) were significant predictors in the model,

whereas paraphrases, repetitions, elaborations, and situational interest were not significant predictors (see Table 3 for a model summary).

Table 3
Model Predicting Knowledge Post-test

	B	**SE**	***b***	***t***	**Sig.**	**Correlations**		
						Zero-order	**Partial**	**Part**
Step 1: Control Variables								
Pretest knowledge	.72	.72	.48	5.19	.00	.48	.48	.48
Personal interest	.01	.33	.01	0.03	.98	.06	.00	.00
Step 2: Processes, SI, & EOC								
Bridges to principles sentences	.20	.05	.32	3.73	.00	.49	.38	.30
Bridges to animal sentences	.39	.13	.24	2.95	.00	.25	.30	.23
Paraphrases	.03	.04	.07	0.84	.40	.11	.09	.07
Repetitions	-.05	.15	-.03	-0.35	.73	-.12	-.04	-.03
Elaborations	-.09	.08	-.09	-1.09	.28	-.12	-.12	-.09
Situational interest	-.04	.32	-.01	-0.13	.89	.15	-.02	-.01
Ease of comprehension	1.19	.46	.22	2.60	.01	.30	.27	.21
Overall: $F(9, 85) = 8.28$, $p < .001$, $R^2_{adj} = .41$								

Note. Effect size for zero-order correlation: ±.10, small effect size, ±.30, moderate effect size, ±.50, large effect size.

Discussion

There were three main findings. First, bridging inferences from the examples to the principles predicted near transfer. Second, bridging inferences between examples predicted near transfer. Third, none of the other cognitive processes predicted near transfer. Reader attempts to build connections between examples and principles, and their attempts to build connections between examples, supported their ability to apply those principles to novel contexts, whereas other types of cognitive processes, such as elaborations and paraphrases did not. Thus, text-based inferences can be used to support near transfer when learners have low prior knowledge. Importantly, these findings suggest that both deductive and inductive reasoning contribute to principle-based knowledge construction.

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Table 1
Definitions and Examples of Each Think-Aloud Category

Category	Definition	Text Excerpt	Sample Participant Response
Bridge to principles text	Backward inference to a sentence in the principles text to explain the current sentence	*Principle text sentence*: The offspring who are best suited to the environment tend to have better rates of survival than the offspring who are less well-suited to the environment. This is known as differential survival. *Current sentence*: The green-feathered turacos lived longer than the grey-feathered turacos because they were better able to hide from hawks and snakes.	This is differential survival.
Bridge to animal texts	Backward inference to a sentence in an animal text to explain the current sentence	This is an Artic hare. Artic hares have white fur so they can blend into the snow and avoid being eaten by wolves and foxes.	Also avoiding a predator, like the previous bird,
Paraphrase	Restatement of the current sentence in different words that captured gist meaning	After many, many years, all the black zebras were replaced by striped ones.	Black zebras went extinct.
Repetition	Verbatim restatement of the current sentence	These principles include variation, differential survival, differential reproduction, inheritance, and population change.	Principles: variation, differential survival, differential reproduction, inheritance, population change.
Elaboration	Retrieving relevant background knowledge to help explain the current sentence	The offspring who are best suited to the environment tend to have better rates of survival than the offspring who are less well-suited to the environment. This is known as differential survival.	This sounds a lot like natural selection. Offspring who have the better genes and traits are more likely to survive and pass those traits on through differential survival.
Predictive inference	Anticipation about what will come after the current sentence	Once, by chance, some turacos were born with green feathers.	They will better survive in green areas than grey ones.
Association	Retrieving background knowledge that is not relevant to the topic	This is an Artic hare. Artic hares have white fur so they can blend into the snow and avoid being eaten by wolves and foxes.	Rabbits, a white rabbit and they are eaten reminds me of home.
Comprehension monitoring	Statements reflecting on one's own understanding	Through differential reproductive success, the frequency of different genetic types in the population can change with each succeeding generation. This is population change.	These principles make sense in the way that a species can rapidly drop. Adjusts must be made in order to prevent extinction.
Question-asking	Asking a question about the text	These variations arise through mutation and genetic recombination, which are random events that occasionally produce beneficial traits.	But why do the "random events" occur?
Affective response	Making a comment about one's own emotions, or having an emotional reaction	The offspring who are best suited to the environment tend to have better rates of survival than the offspring who are less well-suited to the environment. This is known as differential survival.	Interesting, depending on where they live depends on if they survive -other factors must play into this as well.
Other	Any response that did not fit into any of the other categories	Through differential reproductive success, the frequency of different genetic types in the population can change with each succeeding generation. This is population change.	There are a lot of vocab words.