METAPHOR AND CREATIVITY IN LEARNING SCIENCE

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ABSTRACT

While much work has examined how students think and and learn *with* metaphors, relatively little research has focused on thinking *about* metaphors, that is, thinking critically about current metaphors and considering creative alternatives. This paper presents results from a classroom-based study that involves metaphor in science learning and incorporates a novel computational technique for analyzing metaphors in text. The results here show that students' ability to engage with a metaphor's deep, structural aspects significantly predicts ability to generate creative, novel metaphors. Not only do these results carry implications for how best to incorporate metaphor into instruction, but they also draw attention to the ability to reason critically about metaphors as an important area for future research.

PURPOSE

Metaphor plays a crucial role in human understanding of the world. A metaphor uses that which is familiar, a source concept, to understand that which is unfamiliar, a target concept (Gentner et al., 2001; Lakoff & Johnson 1980). Metaphors can be powerful aids in education because they can help learners begin to understand novel concepts. Although metaphors abound in human thinking, they can be surprisingly difficult to notice simply due to their ubiquity.

We describe a study using a novel computational technique: 1) to identify potential metaphors in students' classroom science writing and 2) to prompt students' metacognitive reflection upon the metaphors they use when learning science. We examined students' writing within a technology-delivered unit teaching cellular structure through a common instructional metaphor comparing a cell to a city. Analysis of student text identified novel metaphors that seemed to have been underlying student thinking about cellular organelles. The results of these analyses were provided back to some students. Interestingly, prompting students to reflect upon their metaphor use led to more creative, generative thinking about the science content. Thus, while most educational research on metaphor involves identifying metaphors that can enhance instruction, or that may invite misconceptions, this work reveals that making metaphors explicit can also be used to enhance students' thinking about the target concept.

THEORETICAL FRAMEWORK

Rather than being solely a literary device, metaphors permeate human thought and action (Lakoff & Johnson, 1980). For example, one might describe an argument: "I *attacked* the *weak point* in his statement," or, "you *defeated* the *opposition's* claims." The language used to describe an argument is similar to that used to describe combat, suggesting the metaphor ARGUMENT IS WAR. Some contend that most abstract concepts (Lakoff & Johnson, 1999), or virtually all concepts (Hofstadter, 2001), are understood in terms of metaphorical or analogical thinking. However, as Lakoff & Turner (1989) have noted, "because [metaphors] are used so automatically and effortlessly, we find it hard to question them, if we can even notice them."

Thus, it may be useful to have a technique for drawing attention to patterns of language potentially indicative of underlying conceptual metaphors. Most previous computational linguistic approaches have treated metaphors as relatively isolated anomalies that require exceptional processing (Fass, 1991; Lu & Feldman, 2007; Martin, 1990). Educational research has traditionally examined metaphors as being either instructionally helpful or, conversely, sources of misconceptions (Zook, 1991; Zook & DiVesta, 1991).

In contrast, the approach here is to focus on the ubiquity of metaphor in order to identify potential underlying conceptual metaphors, especially where exact expected metaphors are not known in advance. Identifying and making explicit metaphorical reasoning can perhaps foster critical and creative thinking not only about metaphors but also about the target concepts they represent.

Any given metaphor highlights certain aspects of a situation while simultaneously downplaying or hiding others (Lakoff & Johnson, 1980). Further, a metaphor will in some ways fit the situation it frames, and in other ways, not fit. For example, one common science education metaphor is ELECTRICITY IS WATER (Gentner & Gentner, 1983). In this metaphor, voltage is water pressure, current is the volume of water flow, etc. These are the ways in which the metaphor "fits." However, if one bends a pipe the flow of the water is impeded, whereas bending a wire has no impact on the flow of electricity. In this way, the metaphor does not fit. Understanding what a metaphor highlights and what it hides, how it fits and does not fit, are important aspects of understanding the implications of, and inferences sanctioned by, a given metaphor.

Drawing a learner's attention to his own potential metaphorical thought, and asking him to evaluate those metaphors may be one way to foster critical thinking. Furthermore, the patterns of thought exhibited by a student in evaluating metaphors may provide insight into whether he understands the deep, structural similarities and differences between the source metaphor and the target concept, or if he is simply relying on surface comparisons.

Metaphors are not simply a conduit for critical thought, they are also linked to creative thinking processes (Dunbar, 1995; Gentner, 2002; Gordon, 1974). Metaphor has been found throughout all creative aspects of professional science (Dunbar, 1995, 1999; Dunbar & Blanchette, 2001). Facility with noticing, recognizing, and making use of metaphorical thought is thus a crucial part of developing academic creativity. A creative metaphor is both novel, drawing on a relatively uncommon source concept, and useful, with the framing and inferences it entails providing an effective understanding of the target concept. The ability to think critically about metaphorical relationships may in fact be one predictor of the ability to generate novel, creative, metaphors.

METHODS

Data Sources

Participants. The study included 353[1] seventh grade science students from 2 middle schools in a relatively high-SES school district. Seventh grade students in this district are generally aged 12-13 and primarily Caucasian and Asian American, with a smaller population of Hispanic students. Teachers identified 13 English language learners and 18 special education students.

Design and Procedures. Students were taught science lessons about animal cells and their organelles via a computer-based learning module in the Web-Based Inquiry Science Environment (see Slotta & Linn, 2009, for more information on the WISE project). The lessons began introducing the metaphor A CELL IS A CITY. This metaphor was selected for a number of reasons. First, it is a complex structural metaphor (cf. Lakoff & Johnson, 1980) with many component mappings and potential inferences about which students might reason. Second, many of the teacher consultants suggested this was a metaphor they had used in the past. Third, the metaphor is invoked in the textbook used in the participating school district (Coolidge-Stolz, 2008). Finally, not only does the A CELL IS A CITY metaphor draws on a domain with which most 7th

1 This paper presents results from data from the 146 participants in the group who received direct feedback on metaphors identified in student writing; see Results for details.

grade students have experience yet also provides conceptual room to generate different metaphors drawing on other source domains.

The study took place over four separate days. On day 1, students learned about a cell, along with the metaphor A CELL IS A CITY and the mappings for six major organelles (e.g., THE NUCLEUS IS CITY HALL, RIBOSOMES ARE FACTORIES). Following instruction, students were asked to write about their understanding of each organelle's function. This writing was analyzed using a computational technique (described below) to identify potential metaphors.

On day 2, students were first asked to simply match the organelles to the parts of the city they represented in the metaphor they had been provided on day 1. Next, students received specific explanation of how metaphors can be helpful in understanding unfamiliar concepts, but can also lead to misconceptions (cf. Gentner & Gentner, 1983; Smith, diSessa & Roschelle, 1993).

Students were then given examples of computationally-identified metaphors from their own writing. They were told*: "A computer program was used to analyze your answers and the answers of your classmates, to look for different patterns of words, and to see what metaphors you might be using."*

One at a time, three different metaphors that had been computationally identified in student writing were presented to the participants. The three metaphors identified were: A GOLGI BODY IS A PORT, AN ORGANELLE IS A BUILDING, and, ENERGY IS FOOD. Students were shown how their words mirrored the way people use words to describe the metaphorical comparative. An example from the first metaphor follows:

A GOLGI BODY IS LIKE A PORT

*Based on a computer program's analysis of your and other students' writing, one metaphor people seem to use is that the Golgi body is like a port or a harbor. A port is where boats come into and out of a city, often bringing or taking cargo with them. Many people used words like "transport," "send," "carry," and "move" with the Golgi body, which are words that are often used with ports or harbors. For example, "**transporting** protein **to** the **Golgi body**" might be like "**transporting** goods and products **to** a **port**."*

After introducing each metaphor, students were asked to respond to questions about the metaphor. They were asked whether the metaphor made sense, whether it was similar to their own thinking, and to describe why they agreed or disagreed with the metaphor. Then, they were asked to identify at least two ways the metaphor was not like the target concept.

Following the instruction utilizing the computational analysis, students were asked to generate a brand new metaphor for a cell. They were specifically instructed to avoid using the city metaphor. Students were also asked to map what each organelle would be like in their new metaphor and why.

Days 3 and 4 included additional tasks not reported in this paper.

Computational Metaphor Identification

This study employed *computational metaphor identification* (CMI), a novel computational technique for identifying potential conceptual metaphors in written text (Baumer, Hubin & Tomlinson, 2010). The crux of CMI is selectional preference learning (Resnik, 1993), which quantifies the degree to which certain classes of nouns tend to be associated with specific verbs. For example, words for the concept of *food* are often the direct object of the verb "eat." To identify metaphors, CMI looks for correspondences in selectional preferences between a source corpus and a target corpus. For example, in a corpus about architecture, terms for the concept *building* would select to be the direct object of "create," "build," "make," and so on. In science students' writing, words for *cell* select for those same verbs in the same grammatical relationships, indicating that they may be thinking of cells in architectural terms, i.e. CELLS ARE BUILDING BLOCKS. Based on the similarity of selectional preferences, each mapping is given a confidence score to indicate how likely the linguistic patterns are to evidence a conceptual metaphor. One of CMI's strengths is that it works in the aggregate. While individual instances of phrases such as "building a cell" or "created a new daughter cell" may not at first glance appear metaphorical, it is the systematic appearance of these patterns that becomes compelling evidence for the existence of a metaphor.

In the present study, student responses to prompts within the computer learning module were aggregated for computational identification of the most commonly used metaphors. Because the metaphors students were invoking to understand a cell and its organelles was not known in advance, a comparative body of writing that included both scientific knowledge and a layman's writing style was an appropriate source of comparison. The comparative body of writing was taken from the Internet site Wikipedia.

Data Coding

Student responses were coded by at least two independent coders, with a minimum reliability of Cohen's κ=.80. Responses evaluating the suitability of computationally-identified metaphors were analyzed to determine whether critical reasoning was based on functional dis/similarities between metaphor and target, featural dis/similarities, or some other type of dis/similarities (see Gentner, 1983 for discussion of functional/featural metaphor mapping).

To assess creativity, student-generated metaphors were coded for *uniqueness* of the overall metaphor (as defined as different from peers' metaphors), and for *aptness* of the mappings for each organelles. A mapping was coded as apt if it both fit with the overall novel metaphor and was justified using functional reasoning. An example of one student's unique metaphor compared a cell to a pizza. The mappings for the organelles in this metaphor, however, relied on featural reasoning: "You can relate the different parts of a cell to the different topping of a pizza. You could relate based on: shape, color, texture, appearance." Clearly, the reliance is on the featural aspects of a cell rather than the functions of the organelles themselves. An example of a metaphor that was both novel and apt compared a cell to Disneyland: *"the nucleus is the owner, the workers are the mitochondria giving the rides energy…"* This student focused on the functions of each organelle rather than nonessential features in describing the reasoning for the given metaphor.

RESULTS

The results presented in this section are a part of a larger study, one goal of which was to assess the impact of CMI on learning. Therefore, students were divided into different conditions. The analyses presented here are based on data from 146 students who saw and responded to the computationally-identified metaphors.

To understand the relationship between critical thinking about metaphors and metaphorical creativity, regression analyses were used to determine what aspects of critical thinking predicted which facets of creativity. The maximal model, including pairwise interactions, was specified, and stepwise modeling selection (Venables & Ripley 2002) with Akaike's information criterion (Akaike, 1974) was used to find the final model.

Table 1 describes the resultant regression model, which was highly significant, along with the coefficients and significance values for each predictor. Decreased use of featural reasoning about how well a metaphor fit significantly predicted increased creativity, as did a combined decrease in featural reasoning and increase in functional reasoning. Functional reasoning alone was not a significant predictor. The interaction between use of functional and featural reasoning when giving reasons that a metaphor did not fit was also statistically significant, but the coefficient is much lower, indicating it as less of an important predictor on overall creativity.

[INSERT TABLE 1 ABOUT HERE]

DISCUSSION & SIGNIFICANCE

These results demonstrate that the ability to think critically about metaphors is related to the ability to generate creative novel metaphors. Specifically, decreased reliance on featural reasoning seems to predict improved ability to generate novel metaphors that are novel and apt. Therefore, this work indicates that engaging students in thinking critically about one's metaphors may be a pathway to enhancing learners' creativity and conceptual understanding of science content. These data also indicate that instruction involving metaphors might benefit from not only emphasizing the structural relations in a metaphor that map from source to target, but also noting the irrelevant featural, or appearance-based similarities. Overall, this work suggests that thinking critically about science metaphors can lead to the generation of creative metaphors, which in turn encourages an increased depth of thought about the conceptual target; a primary goal of high-quality science instruction.

REFERENCES

Akaike, H. (1974). A new look at the statistical model identification. *Automatic Control, IEEE Transactions on*, *19*(6), 716-723.

Baumer, E. P. S., Hubin, D., & Tomlinson, B. (2010). Computational Metaphor Identification (No. LUCI-2010-002). Laboratory for Ubiquitous Computing and Interaction (LUCI) Technical Reports. Irvine, CA: Department of Information, University of California, Irvine. Retrieved from http://luci.ics.uci.edu/websiteContent/repository/techreports/2010/LUCI-2010-002.pdf

Coolidge-Stolz, E. (2008). *California Life Science (Focus On)*. Prentice Hall.

Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories. In *Mechanisms of insight* (pp. 365-395). Cambridge, MA: MIT Press.

Dunbar, K. (1999). The Scientist InVivo: How scientists think and reason in the laboratory. In *Model-based reasoning in scientific discovery*. New York: Plenum Press.

Dunbar, K., & Blanchette, I. (2001). The Invivo/Invitro Approach to Cognition: The Case of Analogy. *Trends in Cognitive Sciences*, *5*, 334-339.

Fass, D. (1991). Met*: A method for discriminating metonymy and metaphor by computer. *Comp Ling*, *17*(1), 49-90.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science*, *7*, 155-170.

Gentner, D. (2002). Analogy in scientific discovery: The case of Johannes Kepler. In *Modelbased reasoning: Science, techonlogy, values* (pp. 21-39). New York: Kluwer Academic /Plenum.

Gentner, D., & Gentner, D. (1983). Flowing waters or teeming crowds: Mental models of electricity. In D. Gentner & A. Stevens (Eds.), *Mental Models* (pp. 99-129). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gentner, D., Bowdle, B., Wolff, P., & Boronat, C. (2001). Metaphor Is Like Analogy. In D. Gentner, K. J. Holyoak, & B. Kokinov (Eds.), *The Analogical Mind: Perspectives from Cognitive Science* (pp. 199-253). Cambridge, MA: MIT Press.

Gordon, W. (1974). Some source material in discovery-by-analogy. *Journal of Creative Behavior*, *8*, 239-257.

Hofstadter, D. (2001). Epilogue: Analogy as the Core of Cognition. In D. Gentner, K. J. Holyoak, & B. K. Kokinov (Eds.), *The Analogical Mind: Perspectives from Cognitive Science* (pp. 499-539). Cambridge, MA: MIT Press.

Lakoff, G., & Johnson, M. (1980). *Metaphors We Live By* (2003rd ed.). Chicago, IL: University of Chicago Press.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the Flesh*. New York: Basic Books.

Lakoff, G., & Turner, M. (1989). *More Than Cool Reason: A Field Guide to Poetic Metaphor*. Chicago and London: University of Chicago Press.

Lu, X., & Feldman, A. (2007). Workshop on Computational Approaches to Figurative Language. In *Human Lang Tech / Conf of the North Amer Chapt of the Assoc for Comp Ling (HLT/NAACL 2007)*. Rochester, NY. Retrieved from http://chss.montclair.edu/~feldmana/FigLang2007/.

Martin, J. (1990). *A Computational Model of Metaphor Interpretation*. San Diego, CA: Academic Press.

Resnik, P. (1993). *Selection and Information: A Class-Based Approach to Lexical Relationships*. University of Pennsylvania, Department of Computer and Information Science.

Smith, J. P., diSessa, A. A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. Journal of the Learning Sciences, 3(2).

Venables, W., & Ripley, B. (2002). *Modern Applied Statistics with S*. New York: Springer.Zook & DiVesta, 1991

Zook, K. B. (1991). Effects of analogical processes on learning and misrepresentation.

Educational Psychology Review, *3*(1), 41-72. doi: 10.1007/BF01323662

Table 1. Regression Model indicating how various aspects of critical thinking about metaphors predict metaphorical creativity.

Predictor	Description	Coeff	p-value
AgrDis	mixed agreement and disagreement with a computationally identified metaphor	0.060	0.190
Disagree	disagreement with a computationally identified metaphor	0.014	0.638
AgrDis : Disagree	interaction between disagreement and mixed agreement and disagreement	0.128	0.142
FuncAgr	functional reasoning used to justify dis/agreement	-0.040	0.175
FeatAgr	featural reasoning used to justify dis/agreement	-0.250	0.00420 **
FuncAgr : FeatAgr	interaction between functional and featural reasoning when justifying dis/agreement with a metaphor	0.194	0.000945 ***
FuncNotFit	functional reasoning used to describe how a computationally identified metaphor does not fit	0.047	0.202
FeatNotFit	featural reasoning used to describe how a computationally identified metaphor does not fit	0.023	0.560
FuncNotFit : FeatNotFit	interaction between functional and featural reasoning when describing how a metaphor might not fit	0.065	0.00396 **
intercept		0.491	< 0.0001 ***
model		n/a	0.000612 ***

Increased creativity most significantly associated with decreased use of featural reasoning when justifying dis/agreement with a metaphor, even more so when combined with an increase in functional reasoning.