Relational Categories: Why they're Important and How they are Learned

Dedre Gentner (gentner@northwestern.edu) & Nina Simms (ninasimms@gmail.com)
Department of Psychology, 2029 Sheridan Rd., Evanston, IL 60208
Kenneth J. Kurtz (kkurtz@binghamton.edu), Garrett Honke (garretthonke@gmail.com), & Sean Snoddy (ssnoddy@binghamton.edu)
Department of Psychology, Binghamton University, 4400 Vestal Parkway East, Binghamton, NY 13902
Kenneth D. Forbus (forbus@northwestern.edu)
Department of Electrical Engineering & Computer Science, 2029 Sheridan Rd., Evanston, IL 60208
Lindsey E. Richland[1] (lrichland@uchicago.edu), Bryan J. Matlen[2] (bmatlen@gmail.com), Emily M. Lyons[1] (elyons@uchicago.edu), & Ellen Klostermann[1] (eklostermann@uchicago.edu)
[1]Department of Comparative Human Development, University of Chicago, 1126 East 59th Street, Chicago, IL 60637
[2]WestEd, 400 Seaport Court, Redwood City, CA 94063-2767

Keywords: relational concepts; category learning and generalization; abstraction; analogical processing; comparison; computational modeling; cognitive development; education

Research on categories has historically focused on categories whose members share intrinsic properties, such as eagle and flute. But recent work has investigated a different kind of nominal category—relational categories (Gentner, 2005; Gentner & Kurtz, 2005; Goldwater & Markman, 2011; Markman & Stilwell, 2001). By relational category we mean a category whose membership is determined by common relational structure, rather than by common intrinsic properties. For instance, for X to be a bridge, X must connect two other entities or points; for X to be a carnivore, X must eat animals. Relational categories contrast with entity categories like eagle, whose members share many intrinsic properties. Relational categories (or concepts, if we want to think about their intension) are important in cognitive life, especially in higher-order cognition. They vastly increase our capacity to communicate and reason about complex ideas and are critical to acquiring expertise in mathematical and scientific domains (Goldwater & Schalk, 2016; Richland & Simms, 2015). Thus, an understanding of how such categories are learned and used is imperative.

The symposium presents talks integrating methodologies and perspectives from psychology, education, human development, and artificial intelligence. They explore how relational categories are learned, what we can do with them, and how they integrate with other cognitive factors (e.g., language). Together, these talks reveal both the challenge and the utility of acquiring relational categories, and highlight the need for continued examination of their role in cognition and education.

Promoting Knowledge Transfer via Relational Categories

Kurtz, Honke, & Snoddy

Accessing prior knowledge is critical to successful learning and thinking. The problem of inert knowledge is that people frequently fail to spontaneously retrieve highly relevant analogous content from memory even under optimal conditions for transfer. Such access failure is usually attributed to a retrieval bias favoring superficially similar matches even when structural (relational) similarity determines the utility of the knowledge. The *category status hypothesis* is that encoding examples that have common relational content in the form of a psychological category protects against inert knowledge. This hypothesis motivates new instructional techniques. Evidence from both laboratory and naturalistic (7th grade science) investigations of a category construction sorting task have produced impressive rates of spontaneous transfer within and across domains. Category building (using supports such as category labels, category summarization, and explicit framing of study materials as categories) has been found to increase access to analogous content. Our studies utilize approaches such as comparison, labeling, and use of multiple examples along with direct category-building techniques as potential paths to promoting category status. We present evidence on how established and emerging approaches serve to improve knowledge access under the conditions of high-relational, low-superficial match.

Labeled Relational Categories Combat Children's Object Bias in Relational Reasoning

Gentner & Simms

Higher-order reasoning relies on relational structure; yet early in learning, children are often distracted from relations by irrelevant or conflicting objects. In ongoing studies, we are testing (1) whether learning relational categories can help children overcome this object bias and (2) whether labeling these category matters (Simms & Gentner, 2013). 5- and 6-year-olds played a computerized pattern-matching game, in which they saw groups of three shapes in a particular pattern (e.g., ABA), and had to select the alternative with the same pattern (XYX) over one with a different pattern (WWZ). On Neutral trials, the correct relational match was pitted against a non-match, as in the above example. On Conflict trials, the correct match was pitted against an incorrect object match (e.g., XYX vs.

AAB). Prior to this task, children were divided into 3 groups. One group was taught to sort items by color (red, green or blue). The other 2 groups were taught to sort by spatial relational categories (AAB, ABA, or BAA); these two differed in that for one group, the relational categories were labeled (e.g., "*Lefties* go in this box"), while for the other, they were not ("This kind goes in this box"). As expected, in the matching task, among children who had learned color categories, performance was disrupted by conflicting object matches. However, children who had learned spatial relational categories showed no object bias—they were equally accurate with or without conflicting object matches. Further, children who had learned labels were significantly better than those who had not. These findings suggest that learning relational categories supports children's relational reasoning, especially if those categories are labeled. More broadly, these results suggest that the shift from object focus to relational focus is driven by learning, not simply by maturation.

Simulating relational category learning via analogical generalization

Forbus

How might relational categories be learned? People do not need millions or even hundreds of examples to begin appreciating relational categories. The Sequential Analogical Generalization Engine (SAGE) is a structure-mapping model for learning relational categories. Given a stream of examples, SAGE incrementally builds up a set of generalizations and outliers that reflects the common structure of what it has seen. Generalizations capture important common relational structure. Furthermore, each fact in a generalization has a probability based on frequency of occurrence for aligned statements, thereby providing a basis for probabilistic reasoning, including Bayesian reasoning. This talk will describe some experiments using SAGE to learn relational categories, showing that it is data-efficient in doing so.

Prior Knowledge and Worked Examples in Learning the Concept of Proportionality

Richland, Matlen, Lyons & Klostermann

The concept of proportionality is critical to logical and mathematical reasoning. Proportionality is a higher-order relational concept, in that to recognize that two proportions are equal requires perceiving a relation between relations (e.g., perceiving that the relation between 1 and 2 is the same as the relation between 3 and 6). Not surprisingly, reasoning about proportionality is highly difficult for middle school learners (Fuson & Abrahamson, 2005). Our goal in this research was to is improve children's ability to categorize proportional word problems as having higher order relational structure—thus requiring solutions that take this structure into account—rather than categorizing them as simple ratio problems that require a lower order solution. We tested two strategies drawn from research on analogical development: 1) increasing/ activating prior knowledge representations, and 2) reducing EF load. Worked examples of division on non-ratio problems were used to activate prior knowledge, and visible visual representations and gesture were used to reduce EF load. Results with 218 5th grade students (58% Females, 87% Underrepresented Minority), reveal that (a) integrating these approaches was the most effective at both increasing higher order strategies and reducing lower order strategies, and (b) reducing EF had a main effect on performance, though increasing/ reminding of prior knowledge did not.

References

Fuson, K.C., & Abrahamson, D. (2005), Understanding ratio and proportion as an example of the apprehending zone and conceptual-phase problem-solving models, IN J. Campbell (Ed.), *Handbook of mathematical cognition,* Psychology Press, New York, 213–234.

Gentner, D. (2005). The development of relational category knowledge. In L. Gershkoff-Stowe & D. H. Rakison, (Eds.), *Building object categories in developmental time.* (pp. 245-275). Hillsdale, NJ: Erlbaum.

Gentner, D., & Kurtz, K. (2005). Relational categories. In W. K. Ahn, R. L. Goldstone, B. C. Love, A. B. Markman & P. W. Wolff (Eds.), *Categorization inside and outside the lab*. (pp. 151-175). Washington, DC: APA.

Goldwater, M.B. & Markman, A.B. (2011). Categorizing entities by common role. *Psychonomic Bulletin and Review*, 18(2), 406-413.

Goldwater, M. B., & Schalk, L. (2016). Relational categories as a bridge between cognitive and educational research. *Psychological Bulletin*, *142*(7), 729.

Markman, A. B., & Stilwell, C. H. (2001). Role-governed categories. *Journal of Experimental & Theoretical Artificial Intelligence*, *13*(4), 329-358.Richland, L. E., & Simms, N. (2015). Analogy, higher order thinking, and education. *Wiley Interdisciplinary Reviews: Cognitive Science*, *6*(2), 177-192.

Richland, L. E., & Simms, N. (2015). Analogy, higher order thinking, and education. *Wiley Interdisciplinary Reviews: Cognitive Science*, 6(2), 177-192.

Simms, N., & Gentner, D. (2013) Encoding time and allocation of attention in analogical development. In M. Knauff, M. Pauen, N. Sebanz, & I. Wachsmuth (Eds.). *Proceedings of the Thirty-fifth Annual Meeting of the Cognitive Science Society*. (pp.1318-1323) Austin, TX: Cognitive Science Society.