The role of comparison in structure learning: Developmental, learning science, and computational perspectives

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The ability to perceive, comprehend and reason about relations (i.e., *relational thinking*) is central in human cognition. Relational thinking is powerful because it is structured. Specifically, relational thought allows inferences and generalizations that are constrained by the *roles* that elements play, rather than strictly the properties of the elements themselves.

The role of relational comparisons in learning is emerging as an important area of developmental and learning science research. Relational comparisons allow learners to derive symbolic, abstract, and conceptual knowledge representations that are generative, in that children and adults can then use them broadly in new contexts to reason about new elements. Indeed, comparison seems to underlie the very development of the structured relational representations that underlie relational cognition.

This symposium aims to bring to together research on the role of comparison in developmental and adult learning. Specifically, we present research on the role of comparison in the development of spatial reasoning, language learning, adult mathematics learning, and computational approaches to learning structured (i.e., symbolic) representations.

Christie & Gentner: Domain Specific vs Abstract Language in Spatial Learning

Many studies have suggested that language provides important tools for learning and thinking in cognitive development. In this work we test one specific claim concerning the cognitive effects of language learning: namely, that systematic semantic structure in language can invite correspondingly systematic conceptual structure (Gentner, 2010; Gentner & Christie, 2011). Evidence for this claim comes from prior studies by Loewenstein and Gentner (2005) in which children performed better on a difficult spatial mapping task involving three-tiered structures when they were given the monotonic set of spatial terms *top, middle, bottom* than when they were given the less systematic set of terms *on, in, under.* To discover the generality of these effects, in this series of studies we asked whether children given *nonspatial* (but systematic) language would still show an advantage in the spatial mapping task. We presented children with a spatial mapping task as in Loewenstein & Gentner (2005). There were three groups: one heard a systematic set of spatial terms (*top/middle/bottom*); one heard a systematic set of nonspatial terms (*one/two/three*); and a third heard a nonsystematic set of nonspatial terms (*dog/pig/cat*). In addition to the standard three-tiered mapping task, we also conducted a vertical-to-horizontal mapping task. The results suggest that (1) children benefit from systematic language; (2) domain-specificity benefits early learning; and (3) at older ages, abstract language can have a larger advantage in a difficult transfer task.

Imai, Haryu, & Okada: Progressive alignment in verb learning

Verbs should be extended by the sameness of action, whereas nouns should be extended attending to similarity of objects. Children under four years of age easily generalize a novel noun to other objects of like kinds, whereas even 4-year-olds tend to fail extending a novel verb to the same action performed by a different agent or with a different object (Imai et al., 2005, 2008). Children fail to segregate the action from the objects constituting it. In other words, children fail to structurally align action events. Previous research suggests that object similarity between objects in corresponding relational roles can promote structural alignment and help children notice higher-order relational similarity (e.g., Gentner & Toupin, 1986). Borrowing this idea, two experiments examined whether young children's verb generalization would be fostered by similarities between corresponding objects in the two events.

In the first experiment 4 year-old children were shown a video in which a woman was doing a novel action with a novel object, and heard a novel verb. Children were then asked to extend the verb to either a situation where the action from the video was performed on a novel object (AS), or a novel action was performed on the object from the video (OS). In the AS video, the object was either similar in shape to the object in the original action event (*same object condition*), or dissimilar to the original object (*dissimilar object condition*). Children performed better in the similar object condition, suggesting that object similarity enhanced overall similarity across events and helped children map a novel verb to the same action.

The second study tested whether verb generalization with the help of object similarity can bootstrap 4-year-olds into verb generalization even with perceptually dissimilar objects. Indeed, four-year-olds succeeded in verb generalization across dissimilar objects after having experienced a verb generalization task with similar objects; but they failed when they had experienced verb generalization with dissimilar objects from the beginning.

Son & Stigler: Fragmented analogies from procedural understanding of mathematics

Cross-national comparisons of math pedagogy (e.g., Stevenson & Stigler, 1994) indicate that US classrooms are highly focused on procedures without explanation of their conceptual foundations. The long-term consequences of such pedagogy are dire. Even though the domain of mathematics fundamentally requires an understanding of quantitative relations, students may merely amass a collection of seemingly arbitrary rules along with fragments of relational knowledge. Although analogical processes are typically powerful for reasoning across domains, when rules and procedures are not grounded in relational concepts, students may exhibit fragile or incorrect mappings across contexts thus resulting in inconsistent quantitative reasoning. We examined this hypothesis in a sample of college students (mostly Psychology majors) enrolled in a statistics course. In two studies, students were asked to reason about the results of dividing a positive value, a, with integers (e.g., a/5 vs. a/9), decimals (e.g., a/.1 vs. a/.05), and variables (e.g., a/n vs. a/(n-1), given that n>1). Students were asked to indicate which of two given values was larger and why. The integer problem was presented first because it could serve as a potential source for analogical transfer. The first study was conducted with individual interviews where students often chose not to use a pen and paper that was available to them. In study 2, students were asked to write down their choices and rationale. Judgments of quantity in the context of decimals and variables were reliably worse than with integers. Examinations of the rationale given for their choices showed that different numerical contexts yielded distinctly different reasoning strategies. Strategies used for reasoning about integers were either abandoned or misapplied when reasoning about decimals or variables. Research on analogical reasoning may help educators remedy such fragmented understanding.

Doumas: Developing structure

DORA (Discovery Of Relations by Analogy; Doumas, Hummel, & Sanhofer, 2008) is a symbolic connectionist network that uses time as a signal to dynamically bind distributed (i.e., connectionist) representations of relational roles and objects into explicitly relational (i.e., symbolic) structures. DORA relies on the processes of analogical mapping and intersection discovery to highlight shared abstract properties between separate systems and subsequently predicates these similarities as explicit (i.e., symbolic) representations that can be bound to arguments. Subsequently, DORA can exploit the pattern of activation that emerges between mapped role-filler pairs as a cue to combine these sets of role-filler pairs into a single multi-place relational structure. These processes permit the discovery and predication of shared properties and relations across otherwise different systems and thus allow DORA to learn structured representations from unstructured examples. The DORA model has been used to simulate more than 20 phenomena from child and adult relation learning (e.g., Doumas & Hummel, 2010; Doumas et al., 2008). We propose that DORA's learning mechanism provides an account of how humans learn relational representations and the development of analogical reasoning.

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