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# Structure Mapping and Vocabularies for Thinking

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## Abstract

While extremes tend to capture attention, the ordinary is often most of the story. So it may be with the structure-mapping process. The structure-mapping process can account for such pinnacles of thinking as analogy and metaphor, which can lead to overlooking the mundane, incremental use of structure mapping. Consequently, the current discussion shifts focus to the value of close comparisons between literally similar items for the development of knowledge. The intent is to foster greater integration between process and content as well as between individuals and collectives. The payoff is identifying some undue simplifications and some promising new directions.

*Keywords:* Structure mapping; Encoding vocabularies; Vocabularies of practice

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## 1. Introduction

Every interpretation of every experience we have is both informed by our existing knowledge and has the potential to change that knowledge. The same is true of our communications and our collective knowledge. Yet how any particular interpretation or communication links with a larger body of knowledge is an often overlooked concern.

For example, we might consider this very article. In aiming to help understand our thinking, this article is like other articles. This article’s particular similarities and differences might matter, but to a much greater extent what matters is the accumulated contribution of many articles. That term “accumulated” is common but perhaps misleading if it

implies that piling another article on top of all the others will somehow amount to something, like snowflakes amassing to blanket the ground. But one article only contributes to the extent that we can understand how it relates to prior articles and beliefs. Detailed comparisons to closely related papers are needed to map an article and its contribution onto prior literature and put it into position in some larger structure of knowledge. Otherwise we just have a stack of papers with listings of claims, like having a brick pile rather than a brick house. It is easy to take close comparisons and the detailed mappings across items for granted and so fail to appreciate the contribution they make to developing knowledge. It is easy to emphasize *that* things are related and take for granted the crucial role of the process of understanding *how* things are related.

Understanding how things are related is useful for examining individual comparisons and individual concepts, but it is even more important to formulating larger structures of knowledge. For example, olives and olive oil are related, soybeans and soybean oil are related, and babies and baby oil are related. If you do not understand how the first two pairs are related and how the last pair is related, and how the relations used in the last pair contrast with the relations used in the first two pairs, then you are missing not just the joke but also the point of understanding how things are related.

That relations matter was a key starting point for structure-mapping theory. Structure mapping indicates that it is not useful to think about the comparison process as operating on lists of independent features. Instead, comparisons operate on systems of interrelated features and other concerns—the relations are crucial. Structure mapping also indicates, albeit less directly and so the topic of this article, that it is not useful to think about our knowledge base as consisting of lists of independent concepts. Systems of concepts, with an understanding of how concepts are related to one another, are crucial.

This article will err in the direction of magnifying the centrality of how items are related rather than that items are related, the centrality of close comparisons rather than analogies, and the centrality of developing systems of knowledge rather than individual concepts or schemas. To do so, it takes as a starting point that the comparison process is a structure-mapping process (Gentner, 1983) that relies on knowledge and can also change knowledge. A close comparison is a comparison between literally similar items (Gentner, 1983, 1989), or items that have many corresponding predicates, including both surface features and structural relations. A close comparison might be a comparison between a desk chair and a dining chair, or a comparison between giving a neighbor a ride and giving a friend a ride. In what follows, the terms “close comparison” and “literal similarity comparison” will be used interchangeably. There are simpler models than structure mapping that can account for aspects of how we compare two obviously related items (e.g., Tversky, 1977). Yet given the considerable evidence for the structure-mapping process (e.g., Gentner, 2010; Gentner & Boroditsky, 2001) that the process is a particularly apt account of analogy should not restrict us from applying it to close comparisons between literally similar items as well. Doing so is particularly helpful for addressing the question of how we amass not just individual concepts or schemas, but interconnected systems of such knowledge.

Developing systems of knowledge is both an individual and a collective activity. Individuals use a structure-mapping process to understand close comparisons and to develop their own systems of knowledge. That knowledge is in the form of systems of concepts with which to encode situations and events, or *encoding vocabularies*. Groups and communities of people also engage in what we might call social close comparisons as they coordinate their activities, and in the process develop systems of collective categories, or *vocabularies of practice*. Coming full circle, individuals learn from communities, turning their experiences with vocabularies of practice into personal encoding vocabularies, using, once more, close comparisons. Thus, close comparisons advance the development of individual knowledge and are also crucial to the development of collective knowledge.

For example (borrowing from Kotovsky & Gentner, 1996, as well as from Hofstadter, 2008), we might compare oOo and cCc and consider their evident similarities. This literal similarity comparison might lead us to notice that there are three items, that there are bigger and smaller items, and that the big item is in the middle. We might next compare .oOo. with ,cCc, and realize that we could extend the sizes evenly on both sides. And perhaps oCo is also like cQc so the key issue may be the pattern not the items comprising the pattern. We might have a conversation with another person who suggests comparing oOo with OoO and also comparing Oo.oO with Cc,cC to see how these could be alike. We might together decide that oOo seems different than .oO and different than ,cC too. We might see that .oO seems like ,cC in an interesting way. We might decide to call these examples of symmetries, except the last two, which we decide to call asymmetries. In building up the relations among the components, we might then see oOo as being very similar to pPp, as the growing number of relational predicate correspondences allows us to rely a little less on surface feature correspondences. Then, perhaps .oOo. might strike us as matching ,xXx, and what now strikes us as a literal similarity broadens a little more. This progressive alignment (Kotovsky & Gentner, 1996) of multiple examples of several relational structures provides a springboard to noting that oOo is like  $\square \blacksquare \square$  and that .oOo is like  $\prec \langle l$ , if not other more distant comparisons of symmetry and asymmetry.

The usual emphasis is on how we can become able to appreciate the last comparisons, the analogies. But we should not neglect all the initial comparisons that enabled the last two. We should not neglect the gradual shifting of what strikes as literally similar as we develop greater knowledge of relations. We should not neglect the value of noticing distinct and contrasting relational structures (e.g., symmetry and asymmetry) as we build larger encoding vocabularies comprised of systems of interrelated concepts. We should not neglect the role of talking with others and leading each other to notice, share, and coordinate with one another on similarities and contrasts as we form collective vocabularies of practice. The structure-mapping process applied to close comparisons, repeatedly and collectively, does a vast amount of critical work to develop our knowledge.

This article will not present a complete discussion of close comparisons and developing knowledge, let alone the full particulars of structure mapping and vocabularies. Instead, it will suggest the outlines and value of having such a discussion and provide pointers to where to go to get more details. Discussions of process too often take content for granted and vice versa. Discussions of individual understandings too often take

collective knowledge for granted and vice versa. Thus, despite the existence of important complexities and additional concerns, outlining some basic aspects of close comparisons and knowledge while incorporating both process and content and both individuals and collectives provides an opportunity to paint the big picture that we do not always stop to appreciate, and so highlight some underdeveloped aspects of thinking.

## **2. Close comparisons**

In the 1880s, Claude Monet painted the same scenes repeatedly as he sought to convey the atmospheric sense of a scene. About 40 years earlier, Charles Darwin gathered with the ornithologist John Gould to engage in a close study of finches collected in and around the Galapagos Islands, finding that they were distinct species. Around the same time, Jacob and Wilhelm Grimm, Hans Christian Andersen, and Asbjørnsen and Moe published their influential collections of folktales, such as the Three Billy Goats Gruff, the folktale about one goat crossing a bridge past a troll, a second goat crossing the bridge past a troll, and a third goat knocking the troll off the bridge. Whether for children or adults, art or science, all of these classic examples illustrate the power of close comparisons for producing knowledge.

Comparing seemingly different, rather than similar, examples is the more common focus of research on learning, creativity, and scientific discovery (Hofstadter & Sander, 2013). Surely we do sometimes connect seemingly unrelated instances such as solar systems and atoms and so use analogies to make breakthroughs (Gentner, 1983; Holyoak & Thagard, 1995). In addition though, and far more frequently, we have the opportunity to pursue mundane likenesses—this cat is much like that one, this gift of wine is much like that gift of wine. Then, slightly less mundane—this bacterium is like that bacterium (Dunbar, 1995), this medical plastics device is like that medical plastics device (Christensen & Schunn, 2007). Close comparisons need not be dead ends, merely serving to lump items together into simple groups of interchangeable entities. If we consider the correspondences, then close comparisons can instead be springboards (Gamow, 1947): one, two, three, . . . infinity.

Close comparisons are powerful because noticing obvious similarities can foster noticing less obvious similarities. We can notice this dollhouse like that dollhouse, and then leverage that starting point to identify that the chair in this dollhouse is in the same place as the chair in that dollhouse (Loewenstein & Gentner, 2001). We will probably be focused at first on corresponding surface features, but then we can follow the surface feature correspondences to additional commonalities. This can make corresponding relations apparent that might not have been evident initially (Loewenstein & Gentner, 2005). Close comparisons can enable us to leverage simple feature correspondences to identify patterns of relations.

Close comparisons can be springboards, but need not be. The general need to get on with our day, to take our initial interpretations for granted so that we can take our next action, can of course keep us from thinking much about a particular literal similarity

comparison. One item is like another, and so what? It is just another cat, bottle of wine, or article. We do not bother to think through the comparison and attend to the less obvious similarities. In contrast, our fascinations and curiosities, getting guidance from others to pay attention, getting stuck so we are unable to take the next action, or our dissatisfaction with the errors we are making can all nudge us to attend to close comparisons. The willingness to think through close comparisons provides an opportunity to connect the dots and identify relations that we need have been aware of initially.

Close comparisons are opportunities to appreciate, a little better than we previously did, new and larger patterns. Comparing literally similar items, because it engages the same structure-mapping process in analogy (Gentner, 1983; Gentner & Markman, 1997), fosters noticing similarities and contrasting differences. This allows us to form new knowledge (Gentner, 1989; Gentner & Wolff, 2000). For example, we can shift from thinking about full, detailed examples to thinking about just the core similarities, and so derive schemas, abstractions, or rules (Gentner & Medina, 1998; Gick & Holyoak, 1983; Loewenstein, Thompson, & Gentner, 1999). We can also generalize over contrasting elements to identify new roles, dimensions, or parts (Kotovsky & Gentner, 1996; Gentner, Loewenstein, & Hung, 2007; Goldwater, Bainbridge, & Murphy, 2016; Goldwater, Markman, & Stilwell, 2011). Close comparisons can lead us to identify subordinate categories (armless dining chair), superordinate categories (from chairs, couches, and stools to seating), and categories that do not fit our current classification taxonomies (from sharks and killer whales and tigers to predators). It depends on the particular commonalities we identify in the comparisons we make.

What is distinctive about all of this new knowledge generated through literal similarity comparisons is that, perhaps surprisingly, it is likely to be less concerned with the intrinsic surface features of the original examples that led us to draw the comparisons in the first place. The relations are more likely to capture our interest. As close comparisons become progressively less close (Fyfe, McNeil, Son, & Goldstone, 2014; Kotovsky & Gentner, 1996; Kuehne, Gentner, & Forbus, 2000), we are able to develop the relational knowledge that is the typical fodder of adult thinking. An apple and an orange become fruit. A wall and a fence and a moat and ignorance and poverty become barriers. Relational knowledge (Gentner, 1978, 2010) is crucial for thought and behavior (Goldwater & Schalk, 2016). Analogies are the culmination of close comparisons, as close comparisons appear to be the primary origins of relational knowledge.

### **3. Encoding vocabularies**

It is useful at this point to shift perspectives away from the comparison process and the kinds of comparisons, analogy and literal similarity, that we make to the knowledge that the comparison process takes as input and gives as output. We arrive at a moment of thought with vocabularies with which to encode items in the situation. Those encoding vocabularies are, in part, the product of a ratcheting effect. We use our knowledge to engage in a structure-mapping process for one comparison, which can result in forming

new knowledge that then is our starting point for our next comparison. Consequently, our encoding vocabularies are continuously evolving. Structure-mapping processes are a key mechanism contributing to their development, and so to the development of expertise. Our encoding vocabularies are a key product of that expertise.

Encoding vocabularies are systems of interrelated concepts. Emphasizing encoding vocabularies is useful because it places attention on the concepts we have available and accessible (Higgins, 1996) to interpret information in situations. The way in which we encode information influences what we think and do next. For example, memory retrieval relies on a match between the probe to memory and what is stored in memory (Tulving & Thompson, 1973). Thus, the encoding vocabulary used for the probe and stored items indicates the kinds of matches we are likely to recall. Even more simply, as riddles and insight problems illustrate, our initial encodings shape what we believe we are thinking about.

Our initial encodings when we are novices differ from those when we are experts. The encoding vocabularies of learners are likely to be dominated by simple, local concepts. This result has been found repeatedly in work both with young children (e.g., Gentner & Rattermann, 1991) and with adult learners (e.g., Gentner, Rattermann, & Forbus, 1993) showing a reliance on surface characteristics. Greater levels of expertise mean greater proportions of relational knowledge in our encoding vocabularies (e.g., Chi, Feltovitch, & Glaser, 1981). The overall developmental progression then is from surface characteristics dominating encoding vocabularies to relational knowledge playing a large role (Gentner, 1988).

The progression from encoding vocabularies dominated by surface characteristics to also using relational knowledge is not rapid, consistent with observations about conservative learning (Medin & Ross, 1989). We only move away from object concepts and contextualized understandings with support, whether that support comes from our own accumulated experiences or the influence of others. The conservatism implies a transition through partial abstraction as surface consistencies persist. For example, the category “leader” is a relational category, but if certain kinds of people are usually leaders (e.g., in the United States and Western Europe, there is a history of leaders being tall, middle-aged, white males), then the characteristics of these people are not abstracted away but become part of the understanding of the category. The structure-mapping process incorporates commonalities, not just relational commonalities, across examples. Accordingly, encoding vocabularies are likely to change only gradually away from the concrete, and do so only provided sufficient variety of examples. Critically though, those comparisons can be close comparisons. As long as the concrete aspects are not fully shared across examples, the repeated application of the structure-mapping process to an array of similar examples yields increasingly sophisticated concepts, schemas, and rules.

The notion of progressively abstracting away the core relational structure from a series of concrete comparisons is well established, even if not always a focus (e.g., Braithwaite & Goldstone, 2015; Kotovsky & Gentner, 1996). Yet this work tends to emphasize the progressive abstraction of some core relational category or schema. It is worth turning our attention to another outcome of repeatedly making close comparisons, which is that

we are learning how different concepts relate to one another. We need not be forming isolated bits of knowledge, but instead repeated close comparisons can foster the learning of systems of knowledge.

Concepts are often interrelated rather than isolated (Goldstone, 1996). Role categories, for example, such as *driver* or *seller*, derive their meaning from the larger event in which they occur and so are understood only with respect to that larger event (Goldwater et al., 2011; Markman & Stilwell, 2001). Because the structure-mapping process fosters the identification of systems of relations, it can yield not only individual relational categories (e.g., symmetry) but also links between categories (symmetry and asymmetry). In the aggregate, repeated comparisons can yield broader encoding vocabularies capturing systems of knowledge.

Not just commonalities but also differences are important for developing useful encoding vocabularies. Alignable differences (Markman & Gentner, 1993) that indicate contrasting possibilities are particularly important here. Darwin's finches provide a ready example. While in most ways alike, the specific configurations of contrasting physiological features—such as thinner, longer beaks versus shorter, stouter beaks—indicated relevant distinctions as to the birds' likely ecological niches. More generally, the structure-mapping process fosters developing links among concepts within individual comparisons and also fosters developing links among concepts across multiple comparisons.

The result of engaging in the structure mapping process repeatedly across collections of examples is a tendency toward systems of relational concepts. Whether it is collections of causal structures (Goldwater & Gentner, 2015) or some other kind of information, our encoding vocabularies are not lists of terms, but systems of knowledge. The systems of knowledge might vary in the completeness and coherence of their structures. Our encoding vocabularies are continual works in progress, as we are continually engaged in new structure mappings that bring possibilities for additional learning and adjustments of our knowledge. Yet we are developing not only progressively refined individual relational categories but also progressively interrelated networks of concepts to use to encode situations.

The progression in the make-up of encoding vocabularies allows for a progression in the character of our thinking. Initial encoding vocabularies encourage forming representations of situations that emphasize concrete characteristics. For example, young children more readily notice similarities based on an object's shape than its function or relative position (Gentner, 1978; Loewenstein & Gentner, 2001). Adult learners link proverbs or stories with similar objects or settings more readily than similar morals or underlying principles (Gentner, Loewenstein, & Thompson, 2003; Markman, Taylor, & Gentner, 2007). Yet expertise changes these patterns. One example of resolving conflicting demands by distributing value according to future performance can lead to another, even if one example is about farmers arguing over future crop prices and the other is about a buyer and a supplier shipping merchandise internationally. The learner's encoding vocabulary for such examples would, in emphasizing the concrete specifics, lead to construing the examples in ways that differ dramatically. The expert's encoding vocabulary for such examples would, in emphasizing their underlying relational structures using a consistent

collection of relational terms (e.g., “contingent contracts”), lead to construing the examples in similar ways. Such encoding consistencies matter for memory retrieval (Clement, Mawby, & Giles, 1994). Thus, the encoding vocabularies developed in the course of attaining expertise are likely to lead to using a consistent system of relational terms (Forbus, Gentner, & Law, 1995). What for a learner is a nearly unreachable analogy becomes, for an expert, a reachable analogy or just a close comparison drawn from the same relational category because the features they attend to are so different than those of novices.

A further change in our thinking that follows from repeated structure mappings changing our encoding vocabularies is that the nature of what we think we are thinking about is likely to shift. We might begin by thinking about particular situations and contexts, defined by the prominent entities present. As we develop expertise, we focus less on the surface characteristics of prominent entities and more on their functions, roles in events, and the underlying principles at play (Chi et al., 1981). There is a series of shifts that gradually releases our thinking from being closely linked to contexts to instead allowing our thinking to operate within domains. We shift from thinking dominated by immediate situations and local contexts to thinking more strongly guided by broader knowledge of the domain and deeper implicit theories.

This brief review of individual-level cognitive activity was intended to indicate the power of making countless mundane close comparisons on gradually changing the nature of our encoding vocabularies and so the character of our thinking. Rather than encoding vocabularies dominated by surface features, we develop encoding vocabularies incorporating relational knowledge. Rather than thinking about whatever clusters of concepts are thrown together in particular situations, we develop systems of concepts that we bring to bear and apply to make sense of situations. These changes allow us to transform what used to be distant analogies into close comparisons. Then, we can look for the next set of corresponding and contrasting relations to push our thinking still farther.

#### **4. Vocabularies of practice**

Individual learning through drawing many close comparisons is just a start. The larger effects of close comparisons are social and cultural. Given the infinite possible new interpretations that we might learn, which do we actually learn? The structure-mapping process itself can guide us toward particular interpretations (Medin, Goldstone, & Gentner, 1993), where better and worse are dictated by the system of correspondences we find when we compare (Falkenhainer, Forbus, & Gentner, 1989). The system of correspondences we find when engaging the structure-mapping process is governed by the particular knowledge representations we submit to the process (e.g., Loewenstein & Gentner, 2005). The structure-mapping process itself does not solely govern what to compare. Stepping back from an individual mind reflecting on an individual example to retrieve a matching one from memory (e.g., Gentner, Loewenstein, Thompson, & Forbus, 2009), the actual examples that individuals consider and the examples that are likely to come to

mind as similar are predictable. What we end up thinking about is strongly shaped by social and cultural influences.

Social and cultural influences on what we compare are primarily governed by language (Gentner, 2010). While independent experience interacting with the world might lead us to develop knowledge of concrete objects like cats or balls, absent engaging with others we are unlikely to arrive at the particular relational knowledge (Gentner, 1982; Gentner & Boroditsky, 2001) we use in the course of adult and professional action (Loewenstein, 2014), such as *negative feedback* (Goldwater & Gentner, 2015), *cooperation* (Keller & Loewenstein, 2011), or *creativity* (Loewenstein & Mueller, 2016). Most of our knowledge is learned from collectively established vocabularies of practice, or socially constructed systems of categories (Clark, 1998; Loewenstein, Ocasio, & Jones, 2012). Without denying the power of individual discovery that so impressed Piaget in his observations of young children and that feels so crucial to those of us living in individualistic cultures, this takes for granted what Vygotsky rightly emphasized, which is the pervasive influence of social interactions that channel individuals into adopting and using culturally developed understandings (Levinson, 2003; Ocasio, Loewenstein, & Nigam, 2015). Social interactions, such as conversations supporting group activity, rely upon and are opportunities for further developing vocabularies of practice. And this process of developing and using vocabularies of practice hinges on a particular kind of close comparison, what we might call a social close comparison.

For example, in a referential communication task with one person giving instructions to a second person assembling a model car out of little plastic bricks (Markman & Makin, 1998), pairs quickly develop vocabularies. The vocabularies typically consist of names for kinds of pieces, as well as related names picking out alignable differences across kinds of pieces:  $2 \times 2$  yellow,  $2 \times 6$  red, and so on. Part of the challenge of communication is establishing referential relations. We will agree to call this little piece a “ $2 \times 2$  yellow,” or these rooms “the lab,” and we will mutually acknowledge that common understanding (Clark, 1996). This is the mutual establishment of a symbolic relation: a given word or shape can stand for an item in the world (DeLoache, 2004; Yuan & Uttal, 2017). But the structure-mapping process makes it clear that the formation of individual correspondences is just a beginning.

The theory is called “structure mapping” rather than “correspondence making” for good reasons. Finding individual correspondences is just the start of the structure-mapping process (Falkenhainer, Forbus, & Gentner, 1989). Then, individual correspondences are gathered into consistent systems of correspondences. At that point, if there are common systems of relations, items that do not appear to correspond individually can be placed into correspondence because they play the same role in the relational structure. And correspondences between items that are individually similar may be overridden because they are inconsistent with the larger system of relations. For instance, if we have an example of a woman hiding a briefcase under a bed and another example of a man putting down a briefcase to hide a shovel behind a barn, the relational commonalities can make it apparent that the woman’s briefcase should not be placed into correspondence with the man’s briefcase, but rather with the man’s shovel, as they are both hidden items.

Structure mapping is not just about identifying that something matches something, but specifically how. And as we figure out how, we may override some of the initial correspondences to fit the overarching understanding.

Bringing this discussion of correspondences and structure mapping back to the social context of coordinating our behavior with another person to complete a task, we can think again about the process of labeling some little piece a “ $2 \times 2$  yellow” or a “ $2 \times 6$  red.” In this case, hearing our counterparts say something and indicate something in our task environment sets up a correspondence. The individual process of appreciating systems of correspondences between two examples can also be applied to the social process of finding correspondences between our understandings and another communicator’s statements. Communication is not only about establishing particular names for particular items as common ground, it is also about establishing connected systems of names and items, so that we can form mutual understandings of entire events, places, histories, and more. We can agree not only that this item is the  $2 \times 2$  yellow piece but also that it holds two other pieces together, that it is part of a pattern of alternating colors, and so forth.

Finding consistent systems of correspondences between our own interpretations and what others seem to be saying and doing matters. Computational modeling efforts exploring the added value of connected systems of concepts over and above isolated lists of concepts found that identifying a correspondence between concepts across two individuals was easier and more powerful when each of those concepts was part of a system of concepts (Goldstone & Rogosky, 2002). The system aspect allowed for drawing inferences, greatly reducing the number of correspondences necessary for establishing detailed mutual understandings.

One way to think about communication then is that it is a means for generating structure mappings between our own conceptual systems and our impressions of others’ conceptual systems, based on perceptions of the situations and what they say and do (Raizada & Connolly, 2012; Stolk, Verhagen, & Toni, 2016; Zinszer, Anderson, Kang, Wheatley, & Raizada, 2016). These social close comparisons give us the ability to leverage the structure-mapping process to form inferences to guide our conversations.

The social close comparisons we form in conversations between our understandings and the information we see and hear communicated can enable us to arrive at deeper understandings, just like the close comparisons we make between a current and prior example. For example, conversations between two learners can result in both developing deeper and more comprehensive understandings than either learner would likely have formed alone (Schwartz, 1995), just as one person comparing two literally similar examples can foster the development of more complete understandings than is likely from studying one example alone (e.g., Loewenstein & Gentner, 2001). In enabling people to identify and then jointly flesh out a relational structure, conversations—because they are social close comparisons—can lead to better understandings.

The power of social close comparisons is magnified as one conversation between two people becomes many conversations. This is because we often talk about similar things in multiple conversations. For example, pairs of individuals engaging in the same activity might each develop their own unique mutual understandings. However, as pairs split and

reform to do the same activity with different partners, mutual understandings between pairs can become conventional across pairs (Garrod & Doherty, 1994). This is not just about agreeing upon correspondences, but also about agreeing upon systems of interrelated categories. The social close comparison process that fosters aligning pairs of people's understandings, replicated across many encounters and many people, provides a means for generating consistencies in understandings across large groups of people. This move from the immediate social encounter to collective conventions is a means for close comparisons to help enable extensive collective consistencies in knowledge (Goldstone, 2015). The eventual result (Clark, 1998; Ocasio et al., 2015) is collective knowledge in the form of vocabularies of practice that capture those consistencies (see also Glushko, Maglio, Matlock, & Barsalou, 2008). Close comparisons are not just important for the development of sophisticated systems of individual knowledge. Social close comparisons are also crucial to the development of sophisticated systems of collective knowledge.

Consistencies in knowledge and vocabularies of practice are collective and distributed, but this does not make them universal nor does it mean each person's contributions are equal (Loewenstein, 2014). We might know about baseball but not soccer, jazz but not ballet, accounting but not journalism. Our individual encoding vocabularies might only draw from some collective vocabularies of practice. Furthermore, some individuals and kinds of individuals have greater influence over vocabularies of practice. For example, children often attempt to map the beliefs of their parents, and students often attempt to map the beliefs of their teachers. That is, children and students make efforts to compare their encoding vocabularies—both individual concepts and relations among concepts—with the vocabularies of practice that parents and teachers use. Parents and teachers model the use of vocabularies of practice so that children and students can develop their encoding vocabularies. So too do professionals generate and model vocabularies of practice to shape the encoding vocabularies of laypeople, as do media for citizens, leaders for followers, old timers for newcomers, and so on. Individuals develop expertise in the form of encoding vocabularies emphasizing relational categories and information beyond surface features, and this effort is largely guided by learning the vocabularies of practice capturing extensive and sophisticated understandings that others have collectively developed. Thus, social close comparisons are part of the ongoing process of passing along knowledge from one generation to the next.

Social close comparisons are also part of developing and changing vocabularies of practice. Usually individuals are aligning with collective meanings. Key texts, such as speeches, books, definitions, contracts, and laws, can be influential as many people coordinate and align with them. Individuals might simply seek to understand them, but might also be subject to abiding by them, might learn and repeat them, might consider them central to their own thinking or superior to their own knowledge. The interaction between collective vocabularies of practice and individual encoding vocabularies is asymmetric, with individuals changing to fit collective understandings far more than the reverse. But sometimes, necessarily, individuals generate knowledge distinct from existing vocabularies of practice and through social interactions spread that knowledge to others and so change the vocabularies of practice. And sometimes groups of people collectively

negotiate changes. Historical events, changes in technology, and the interaction of different communities are just some of the triggers that can prompt changes to vocabularies of practice (Ocasio et al., 2015). There are considerable and fascinating aspects to the development and change in vocabularies of practice; for current purposes though the key point is that social close comparisons are fundamental to the collective establishment of vocabularies of practice and to individuals generating and changing their own encoding vocabularies through engagement with collective vocabularies of practice.

## **5. Implications**

The argument laid out in the preceding sections started from the observation that we often overlook the role that close comparisons play in cognition, taking for granted the value of noticing literal similarities both individually and collectively. We segment off the role of communicating as a separate concern, discussing mutual understanding without an appreciation of the complexity of aligning beliefs across people. We take collective knowledge as a given rather than a cultural product formed through cognitive and social processes, with all the messiness that this implies. The brief caricature sketched here is an attempt to emphasize the centrality of many people applying the structure-mapping process repeatedly across many close comparisons both individually and socially to the development of individual encoding vocabularies and collective vocabularies of practice.

The rough model sketched here indicates that there is a link between the different kinds of similarities that individuals note between items and collective knowledge. There is a tendency in some literatures on thinking, knowledge, and cognition to examine complexities in individual understandings but to treat collective knowledge as clear, fixed expert definitions. Yet if collective knowledge is generated through local coordination and the development and maintenance of conventions, then this is just a simplification.

We can reconsider this simplification using our discussion of the structure-mapping process. As noted earlier, the developmental and learning literatures note the progression from understandings driven by surface characteristics to understandings placing greater emphasis on relational knowledge. But this progression is treated as an individual concern. How far along are children and adult learners toward ideal expert knowledge? For much of what we think about, the question is not even particularly well formed; there is often no ideal expert knowledge. Even if there is ideal expert knowledge, there is no need for collective knowledge to be shaped primarily by experts. Nor is there any need for individuals to appreciate the similarities that experts do. Collective knowledge can be complex and messy because it is collectively generated and maintained, because it has to be applied in many specific contexts, and because it is used by us limited human beings.

Individuals in contemporary society can and very often are required to rely on their extraordinary interdependence with others (Loewenstein, 2014). We can get by with understandings driven by surface characteristics in many domains. We have divisions of cognitive labor (Kitcher, 1990) as well as divisions of linguistic labor (Putnam, 1973).

Only some of us need to understand the relational knowledge involved in a domain. The rest of us can just be users of that knowledge. Most of us just drive cars but do not know how they work. We can rely on surface characteristics, oblivious to the details. As a result, we are often mistaken about how much we understand (Kruger & Dunning, 1999; Rozenblit & Keil, 2002). It might be cute when a child mistakes a surface characteristic as defining a category (Keil & Batterman, 1984) or a similarity (Gentner, 1988). Yet we tend not to think about all the routine occurrences of adults relying on surface characteristics. The result is that collective knowledge is messier than the idealized expert knowledge routinely and often implicitly referenced in studies of cognition.

A further contributor to the complexity of collective knowledge comes from the complexity of the many social close comparisons involved in forming, distributing, and modifying it. Different communities engage in distinct acts of coordination and so align distinct interpretations. Different contexts and situations can call for distinct uses of terms within vocabularies of practice. The parsimony of leveraging related meanings, as opposed to inventing many narrow terms, yields multifaceted collective meanings shaped by overlapping communities and circumstances of use. For example, in contrast to the multiple narrow scholarly definitions of *cooperation*, collective knowledge about cooperation is wide ranging (Keller & Loewenstein, 2011). Some scholars define cooperation in terms of behaviors, others define it in terms of goal structures, and these are just the major theories. Collective knowledge about cooperation is more comprehensive, rendering it both more broadly useful and more complex. Likewise, in contrast to the consensus conceptual definition of creativity as novelty and usefulness, collective knowledge is wide ranging (Loewenstein & Mueller, 2016). In contrast to the richness of collective knowledge, then, our research tends to take much simpler views.

A simpler view of collective knowledge matters for its effects on other areas of research. For example, research on concepts builds and tests models to examine individuals' learning of categories governed by simple definitions. Yet people have to learn and use collective knowledge that is messy and complex. Research on concepts and schemas tends to focus on isolated bits of knowledge. Yet people learn and use systems of knowledge. Or, to take a different approach, most behavioral research presumes consistent understandings of collective knowledge. Yet subcommunities are free to generate distinct interpretations. Thus, if your views of collective knowledge differ from mine—the studies just noted found that one in four adults in the United States had distinct views of cooperation and of creativity from the majority—then that could be a reason for different behaviors. If vocabularies of practice are the result of complex learning and coordination processes, involving countless social close comparisons, then broad consistencies, even on surface characteristics, are an achievement rather than something to be presumed.

If we start from the presumption that consistencies in collective knowledge are an achievement, we can further appreciate the value of close comparisons. The complexity of collective knowledge and the divisions of cognitive and linguistic labor imply that individuals might form encoding vocabularies that are messy and often have only fairly shallow understandings. Consequently, communicating could be effective if individuals resist trying to achieve mutual understandings on anything terribly complex. Or

individuals could facilitate the establishment of correspondences and highlight key relationships. Relying on the kinds of close comparisons that ease individual learning can be the basis for effective communications (Loewenstein & Heath, 2009; Loewenstein, Raghunathan, & Heath, 2011). What makes the alignment of individuals' systems of concepts more difficult, like distinct examples, is likely to make drawing comparisons more challenging.

These are just a few, initial implications of considering the role of close comparisons in developing our vocabularies for thinking. Many more possibilities remain to be explored. Perhaps the role of goals in shaping individuals' thinking through a comparison will have similarities to the role of power in communication. Perhaps consistency in collective vocabularies of practice fosters gathering together surface dissimilar concerns, like consistent encoding vocabularies fosters forming consistent interpretations across surface dissimilar items for individuals. The larger point is that individual cognition is so strongly shaped by engagements with others and so often used in the course of engaging with others that bridging processes should draw attention. Processes that are fairly well understood and that are widespread, like the structure-mapping process, are a natural starting point.

## Conclusion

Systems of knowledge are achievements. Is it not just abstractions, which after all can be vague, but positive formalisms (Abbott, 1988) that enable us to imagine still larger frontiers and see still farther ahead. The structure-mapping process is one of the main mechanisms that enable us, individually and collectively, to generate systems of knowledge. But it is not just or even mainly because of its capacity for processing analogies. Mundane close comparisons, despite being easy to take for granted, are likely still more significant.

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