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Analogy Lays the Foundation for Two Crucial Aspects of Symbolic Development: Intention and Correspondence

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Abstract

We argue that analogical reasoning, particularly Gentner's (1983, 2010) structure-mapping theory, provides an integrative theoretical framework through which we can better understand the development of symbol use. Analogical reasoning can contribute both to the understanding of others' intentions and the establishment of correspondences between symbols and their referents, two crucial components of symbolic understanding. We review relevant research on the development of symbolic representations, intentionality, comparison, and similarity, and demonstrate how structure-mapping theory can shed light on several ostensibly disparate findings in the literature. Focusing on visual symbols (e.g., scale models, photographs, and maps), we argue that analogy underlies and supports the understanding of both intention and correspondence, which may enter into a reciprocal bootstrapping process that leads children to gain the prodigious human capacity of symbol use.

Keywords: Structure-mapping theory; Analogy; Symbol; Intention; Representation; Theory of mind; Development

1. Introduction

Two fundamentally important aspects of human cognition are analogy and symbol use. Gentner (2010) provides an elegant demonstration of how analogical reasoning and the

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acquisition of a symbol system, namely language, can bootstrap the development of cognition. She argues that the reciprocal relation between analogy and symbol use is responsible for the development of human prodigious cognitive capacity. Here, we extend and expand this important theoretical perspective to demonstrate how analogical reasoning supports the development of external symbol systems (e.g., scale models, maps, drawings, photographs, written text). Specifically, we argue that Gentner's (1983, 1989) structure-mapping theory provides a unifying framework that lays the foundation for two crucial aspects of symbolic development: the understanding of others' intentions and the establishment of correspondences between symbols and their referents. This framework can shed light on several ostensibly disparate previous findings and provide an integrative framework for understanding symbolic development.

We first review research on the definition and components of symbolic acquisition, emphasizing the two crucial aspects of understanding both the human intentions underlying symbol use and the correspondences between a symbol system and its referent. We then argue that analogy underlies and supports the development of both of these crucial aspects of symbol use. We demonstrate the value of our theoretical perspective by applying it to an extensive analysis on the development of children's understanding of scale models. We also briefly apply this perspective to the development of maps, photographs, drawings, and written and spoken language, emphasizing the important role that analogical reasoning plays in elucidating findings from different lines of research.

2. What are symbols and how do children come to understand them?

The acquisition of symbolic representations is a hallmark of cognitive development (DeLoache, 2004; Landsmann & Karmiloff-Smith, 1992; Vygotsky & Luria, 1994; Werner & Kaplan, 1963). Indeed, much of early development and education could be defined at least in part as the acquisition of a variety of symbol systems, starting with spoken language but then including written text, numbers and numerals, maps and scale models, and often music notation, computer icons, and many more. Delays in acquiring these symbol systems have been associated with poor academic achievement and attainment (Duncan et al., 2007; Stevenson & Newman, 1986).

Before beginning, we need to define what we mean by the term "symbol," which is a notoriously difficult task (De Saussure, Baskin, & Meisel, 2011; Goodman, 1976; Langer, 2009; Peirce, 1974). We adopt DeLoache's definition: A symbol is an "entity that someone intends to stand for something other than itself" (DeLoache, 2004; see also Perner, 1991). We have chosen this definition because it is inherently psychological; whether something is a symbol is defined by the presence or absence of human intention and action. Any object can be a symbol as long as someone intends it to be. For example, at the dinner table, you may want to show another person how to get to your office. In doing so, you might construct a makeshift map using forks and knives. The forks and knives were not symbols before this act occurred; they became symbols when you intended for them to serve a representational role and another person perceived this intention. Inversely, by our definition, conventionalized symbols, such as letters and numbers, are *not* symbols for young children because initially they do not understand the intention that motivated the creation of these symbols.

We (Uttal & Yuan, 2014) have extended DeLoache's definition and suggested that two (sets of) psychological processes are involved in defining symbolness: (a) *Understanding that* something is intended to be a symbol and (b) *understanding how* the symbol is related to its referent. To *understand that* something is a symbol means gaining insight into the intention of another person to create a representation to stand for another thing. For example, when we say, "Let X = 1," or construct a map to communicate to another person how to get to our office, we mean for one thing (X, or icons on the map) to stand for something else (1, or landmarks in a town). We state or imply *that* the writing or the map represents something other than itself. Thus, *understanding that* entails comprehending that something is intended (by another person) to be a representation.

Understanding how something is a symbol means figuring out the correspondences between the symbol and the intended referent. For example, most people have no trouble recognizing that assembly diagrams for furniture, toys, bicycles, etc., are intended to help them assemble the object, but figuring out *how* the diagram corresponds to the objects is often a struggle. This process of establishing correspondences between symbols and referents can be understood as a *mapping* problem (Fauconnier & Turner, 1998; Gentner, 1983): The symbol user must map out the specific relations between items in the symbol and those in their particular referents.

The distinction between understanding that and understanding how is well illustrated in Bloom and Markson's (1998) study of young children's understanding of drawings. Three- and 4-year-olds were asked to draw two objects that had similar shapes (e.g., a balloon and a lollipop). Although adults who were naive to the experiment could not distinguish the drawings of the two objects, the children nevertheless insisted on naming the drawings based on their own intentions. In this case, children relied on the intention (or understanding *that*) to define symbolness. In a second experiment, Bloom and Markson (1998) told children that a child of the same gender and age had broken his or her arm and made some drawings that did not come out as good as the child wanted. The participants were then presented with pictures of abstract shapes and asked to interpret the drawings. Four-year-olds correctly interpreted the drawings based on relational similarities, such as two big and one small oval depicting two elephants and a mouse. This finding suggests that young children can also rely on perceptual correspondence to understand the meaning of symbolic representation. Thus, young children can use both intention and correspondence as cues to interpret the meaning of symbolic representations.

The central claim of this paper is that both understanding intention and seeing correspondences can be understood and promoted by analogical reasoning. In particular, Gentner's (1983, 1989) structure-mapping theory can shed substantial light on both the development of intention and the establishment of correspondence between symbols and referents. Most previous research has considered these two elements as separate and perhaps unrelated, but we argue in the following sections that Gentner's theoretical perspective provides a framework to integrate them.

3. Analogy and understanding the intentions of others

Humans understand and explain human behavior on the basis of others' beliefs and mental representations of the world (Tomasello & Carpenter, 2007). The understanding of others' intentions guides young children's (even babies) interpretation of both what people do and what they create (Baldwin & Baird, 2001; Gergely & Csibra, 2003; Woodward, 2005); it is especially important for learning symbol systems, because symbols are intended by others to "stand for" their referents (Perner, 1991; Tomasello, Striano, & Rochat, 1999). One apt example is the demonstration that even 3-year-olds refused to name drawings that were created accidentally (without clear human intention), even when the drawings highly resembled the physical attributes of familiar objects (Gelman & Ebeling, 1998). The ability to correctly infer others' mental states is closely related to the understanding of the representational nature of symbolic representations (e.g., Leekam, Perner, Healey, & Sewell, 2008). For example, severe language delays in some autistic children may be attributed to an impaired capacity to reason about others' behaviors in terms of mental representations and intentions (Baron-Cohen, Leslie, & Frith, 1985). From our theoretical perspective, to acquire a symbol system, children need to grasp the "stand for" *relation* between a symbol and its referent, a relation that is deeply rooted in the appreciation of the intentions of others (Barresi & Moore, 1996).

How do children come to appreciate the "intentional relation" between human-created representations and their meanings? Although some studies have reported rudimentary understanding of others' intentions in infancy (Baillargeon, Scott, & He, 2010; Gergely, Nádasdy, Csibra, & Bíró, 1995), most researchers agree that a mature understanding of mental representation is not fully acquired until the end of the preschool period (Wellman, Cross, & Watson, 2001; Wellman & Liu, 2004). An increasing amount of research has suggested that analogical comparison contributes greatly to the understanding of others' intentions both early in life and later in development (Gerson & Woodward, 2012; Hoyos, Horton, & Gentner, 2015; Meltzoff, 2007). For example, Gerson and Woodward (2012) showed 7-month-olds a tool-use action—using a claw to fetch a toy. Infants in the *comparison condition* were allowed to reach for the object while observing the experimenter using the claw to reach for the same object. The control group simply observed the functional properties of tools without the opportunity to compare their own action with the action of the experimenter. Only infants in the comparison condition imitated the experimenter's tool-use action later. Gerson and Woodward (2012) argued that comparison and alignment, as a form of analogy, can promote the understanding of others' intentions, which in turn helps infants to understand goal direction actions, such as tool use.

Analogical reasoning can also contribute to a more complete understanding of theory of mind (ToM)—the ability to reason about one's own and others' actions and thoughts in terms of mental states, such as desires, beliefs, intentions, emotions, and knowledge (Gopnik & Wellman, 1994; Wellman et al., 2001). For example, analogical training can help children to solve a commonly used test of ToM—the false-belief task (Hoyos et al., 2015). This task requires children to know that people may hold beliefs that are incongruent with reality. For instance, consider a cereal box that contains pencils rather than cereal. A person who has never looked inside the box may falsely believe that it contains cereal. Before about age 4, when asked about "What person A thinks is in the cereal box," children often fail this task, reasoning on the basis of their knowledge of the reality, rather than on the basis of others' mental representations. Hoyos et al. (2015) showed that training based on analogical comparison improved preschoolers' false-belief understanding. One group of children first saw training materials that helped them to compare the mental states of two characters (e.g., what character A thinks is in the cereal box and what character B thinks is in the cereal box), as well as to compare the characters' mental states to the realities (e.g., what really is in the cereal box). Receiving analogical training significantly improved children's performance on this task.

What is the mechanism through which analogical reasoning promotes the development of a mature understanding of theory of mind? To understand a false belief is to have a general notion or folk theory that a person can hold a belief that is *different* from the reality, which in essence is a relational proposition. A critical way through which children can extract such relational patterns is by relying on comparison and alignment, as many studies have demonstrated in the development of various conceptual domains (Christie & Gentner, 2014; Gentner et al., 2016; Loewenstein & Gentner, 2001; Namy & Gentner, 2002; Thompson & Opfer, 2010). For example, comparing a person's belief about what is in the cereal box (cereal) to reality (pencils) may lead children to notice the relation: *Different* (person A's belief about object C, the real status of object C). This process can import a more general psychological principle that a person can hold a belief that is different from the reality—a false belief. Likewise, Bach (2011) suggested that analogical reasoning can support the simulation of aligning one's own mental state with that of other people, which in turn promotes the extraction of a general theory of folk psychology (see also Hoyos et al., 2015; Meltzoff, 2007). Thus, by drawing analogies between mental states and reality, and between self and others, children can acquire insight into others' beliefs and intentions that underlie human actions, tool use, and symbol use.

4. Analogy and establishing correspondences

The problem of understanding *how* a symbol relates to its referent involves establishing correspondences between elements in the symbol to the elements in the referent. For example, figuring out how an assembly diagram uses lines or boxes to represent different parts of a piece of furniture requires drawing correspondences between the diagram and the objects. Solving this "mapping problem" (Gentner, 1988; Markman & Gentner, 2000) relies heavily on the perception of similarities between two representations, a general capacity that underlies the development of a host of cognitive abilities, such as categorization (Kotovsky & Gentner, 1996; Medin, Goldstone, & Gentner, 1993), word learning (Imai & Gentner, 1997; Namy & Gentner, 2002), relational thinking (Christie & Gentner, 2010; Gentner & Medina, 1998; Loewenstein & Gentner, 2005), and problem solving

(Gentner & Colhoun, 2010; Gentner & Markman, 1997). Thus, research on similarity and comparison, particularly Gentner's (1983, 1989) structure-mapping theory, can shed substantial light on when and how children develop the ability to establish correspondences between symbols and their referents.

Gentner (1983, 1989) suggested that the mapping between two representations is established on the basis of two kinds of similarities—*object similarity* and *relational similarity*. Two representations have high object similarity when they share a high degree of physical resemblance. For example, if the furniture in a scale model and the room it represents are covered with the same fabric, we can say that the scale model and the room share a high degree of object similarity. In contrast, relational similarity focuses on common relational structures such as shared causal structures. For instance, to understand the metaphor "A tape recorder is like a camera [for sound]," we rely on their common relations—"both can record something and view (or hear) them far later" (Gentner, 1988; Gentner & Rattermann, 1991). In the context of visual symbols, relational similarity generally refers to the common spatial relations between icons and referents. For example, two icons on a map of the United States may share little physical resemblance to the cities of Chicago and New York; they nevertheless preserve the spatial relationship between the two cities (Liben, 2009; Loewenstein & Gentner, 2001, 2005; Uttal, 2000; Yuan, Uttal, & Gentner, in press).

Gentner (1988) explained development in terms of a shift from focusing primarily on object matches to a focus on common relations. According to this *relational shift hypothesis*, children initially are more likely to establish correspondences between two representations on the basis of object or physical similarity, showing an object bias (Rattermann & Gentner, 1998). Eventually, children can establish analogies on the basis of relational correspondences, due to both increased knowledge of relational concepts (Gentner, Anggoro, & Klibanoff, 2011; Rattermann & Gentner, 1998) and increased ability to resist the temptation of drawing analogies based solely on object similarity (Richland & Burchinal, 2013; Thibaut, French, & Vezneva, 2010). For example, Gentner and Toupin (1986) told children stories about toy animals and asked them to recreate the stories using different animals. Younger children (4- and 6-year-olds) performed better when the new animals shared high levels of object similarity with the old animals (e.g., old character: horse; new character: zebra) than when the animals shared low levels of object similarity (e.g., old character: horse; new character: cricket). In contrast, 8- and 10-year-olds successfully retold the stories even when the old and new toy animals were perceptually very different.

The relational shift hypothesis also sheds light on children's understanding of spatial representations, such as photographs and maps (Uttal, Gentner, Liu, & Lewis, 2008; Uttal, Gregg, Tan, Chamberlin, & Sines, 2001; Yuan et al., in press). Nine-month-olds seem to perceive the similarity between a photograph and the object it depicts, even attempting to pick up the depicted object off the page (DeLoache, Pierroutsakos, Uttal, Rosengren, & Gottlieb, 1998). However, the understanding of the similarities between photographs and their depicted scenes also undergoes substantial developmental change. Uttal et al. (2008) examined children and adults' understanding of the similarities between photographs and their referents. Children and adults were told that a toy bear (with a miniature camera) liked to take pictures, but his camera was broken and thus did not make accurate photographs. For example, some photographs showed objects that differed from those in the photographed scene, and others showed the correct objects but in the wrong spatial positions. The children then were asked to pick the “best” photograph of a given scene among several alternatives. Consistent with the relational shift hypothesis, 3- and 4-year-olds distinguished the photographs only on the basis of what objects they depicted; in contrast, 5- to 7-year-olds and adults considered whether a photograph correctly depicted the spatial relation among depicted objects.

Through development, not only do children start to appreciate the relational similarity between spatial representations and their corresponding spaces, they also start to notice and take advantage of hierarchical relational structures. For example, Uttal et al. (2001) demonstrated that showing children a map with lines connecting hiding locations to form a systematic structure (a dog) enhanced their performance at searching for hidden objects, compared to showing the same map without lines highlighting the structure. This result is consistent with the principle of *systematicity*—higher order relational structures help to unite isolated individual relations (Gentner & Toupin, 1986), allowing for a better representation of the correspondences between spatial symbols and spaces.

5. How understanding intentions and drawing correspondences work together to promote symbol learning

We argue that understanding others’ intentions and drawing correspondences between symbols and referents can jointly promote cognitive development (Barresi & Moore, 1996; Chen, 1999; Gerson & Woodward, 2012; Hoyos et al., 2015; Meltzoff, 2007; Moll & Tomasello, 2007): The process of understanding a given symbol involves a reciprocal interaction between *understanding that* (intention) and *understanding how* (correspondence); either component could provide the initial foothold into the learning process. For instance, the perception of correspondences could be the engine that begins the process of gaining insight into a symbolic relation. A young child may perceive that a blue area on a map looks like water, even though he or she may not fully grasp the cartographer’s intention to use the map to convey spatial information. These correspondences are established mostly (or even solely) on the basis of perceptual similarity, but they nevertheless may play a critically important role in giving the child an initial foothold into thinking about the intention-based representational relation between the symbol and its referent—that the map is intended to represent the layout of the space. Thus, establishing correspondences can beget the search for *why* the correspondences exist, and this promotes insight into the intention that motivated the creation of the symbol. In this sense, perception of correspondence (*understanding how*) can precede and support *understanding that* symbols represent their referents.

People can also gain an initial foothold into symbolic representation through understanding others’ intentions, which may in turn prompt them to look for ways of how symbols relate to their referents. For example, when an adult views an electronic wiring diagram for the first time, he or she might not know either that or how the diagram is a symbol. However, simply telling the person *that* the diagram is designed to help electricians figure out how to wire components into a working circuit could prompt a search for *how* the elements in the diagram correspond to specific electrical hardware (e.g., a tilted line represents a switch). The person would bring to bear whatever knowledge of electrical circuits he or she may have, even if this knowledge is far from complete. In this case, understanding *that* the diagram is a symbol begets a search for understanding *how* it corresponds to its referent.

In summary, *understanding that* and *understanding how* reinforce and support each other in the sense that gaining a foothold into one component of a given symbol may facilitate or bootstrap (Carey, 2004; Gentner, 2010) some insight into the other component. Neither has priority in our developmental analysis. Even at a young age, children sometimes can use either or both to understand a symbolic representation. Whether the child is able to do so depends critically on particular aspects of each task, a fundamental part of the following analysis. We next illustrate the dynamic interaction between *understanding that* and *understanding how* through a review of research on the development of children's understanding of scale models.

6. Children's understanding of scale models

Research on children's understanding of scale models (DeLoache, 1987, 1995) has delineated several foundational concepts important to our understanding of many other visual symbols (e.g., photographs and maps). We begin by discussing classic findings and subsequent follow-up research highlighting different influences on children's success or failure in search tasks. Then, we apply our theoretical perspective to an analysis of children's performance in these tasks. We argue that when considered together, the pattern of findings can be best explained from a perspective that emphasizes the interaction between children's nascent *understanding that* the model is a symbol and *understanding how* it relates to the room. In particular, we argue that the comparison and alignment process plays a crucial role that sets the stage for gaining insight into the representational nature of symbols.

6.1. The standard model search task

Research on the development of children's understanding of scale models burgeoned after DeLoache's (1987) demonstration of a rapid developmental change in young children's use of a scale model to find hidden toys in a room. In the study, children were told, "Big Snoopy's room is just like Small Snoopy's room." They were also shown one-to-one correspondence between furniture in the model and those in the room. Children then watched as an experimenter hid a toy in the model. They were then asked to use the scale model to find the toy that was hidden at the corresponding place in room. Children who were 2.5 years old performed at the chance level; they did not use what they saw in the model to guide or constrain their search in the room. Children only 6 months older (3-year-olds) performed very well. The younger children's difficulty was not due to forgetting where the toy had been hidden in the model, as even the youngest children were able to point out the hiding location in the model regardless of where they searched in the room.

DeLoache (1995, 2000) proposed *dual representation theory* to explain these results. This theory suggests that children have to appreciate that a symbol is an object on its own, but at the same time, it also represents something other than itself—its referent. Children less than 3 years of age failed the model search task because they did not understand the dual nature of symbols. Dual representation theory is a useful way to think about what mental representations are required to understand a symbol from the perspective of a child. Our goal here is to be more specific about when, how, and why children do (or do not) acquire dual representation. We emphasize that both the understanding of others' intentions and the establishment of correspondences between symbols and referents are important sources of information that young children can rely on to *understand that* and *how* scale models relate to the corresponding rooms. Importantly, analogical comparison supports the development of both components; whether children are able to obtain dual representation may depend greatly on the interaction between them.

6.2. Understanding that

We first considered the role of children's understanding of the experimenter or the model creator's intentions. Young children's success in the model search task often depends critically on whether they understand that models are intended to represent rooms. Sharon (2005) tested whether directly communicating to children the intention of the person who created the model affected their performance in the model search task. After the standard introduction, children in the *intention group* heard the experimenter said, "I made something [the scale model] to help you find Big Bear"; the *control* group did not hear this instruction. Children in the intention group performed significantly better than the control group at the search task. This advantage still held even when the intention group was asked to use a low-similarity (and hence more challenging) model, in which the elements in the model did not closely resemble the corresponding elements in the room. This result suggests that direct communication of symbol creators' intention helps children acquire *understanding that* the model is intended to be a symbol. Conversely, removing the need to understand that the model is a symbol led to dramatic increases in performance. DeLoache, Miller, and Rosengren (1997) removed the need to think of the model as a representation by convincing 2.5-year-olds that a shrinking machine has shrunk the room into the scale model. Now, there is no need to understand that the model is a symbol; in the children's minds, the model is the same as the room (only shrunken). The excellent performance of 2.5 year olds indicates that they can perceive the similarity between the model and room, but cannot mentally represent the intended "stand for" relation between them.

In contrast, removing or interfering with children's understanding of the social context or communicational intention underlying symbol use can have a detrimental effect on their understanding. Using the standard model search paradigm, Uttal, Schreiber, and DeLoache (1995) introduced a delay period between the experimenter's instructions and the search task to test this possibility. After the standard introduction, 3-year-olds were made to wait for 20 s, 2 min, or 5 min before searching for the toy in the room. Children performed relatively well after shorter delays (20 s), but their performance suffered greatly after longer delays (5 min). The negative effect of delay on search performance cannot be attributed to memory decay, as children from all conditions successfully retrieved the hidden toys in the scale model beyond chance level. Inserting a delay period possibly detached children from the social setting that supports them to understand the experimenter's intention underlying the creation of scale models. Without the *understanding that* scale models are intended to represent rooms, children failed to use symbols to guide their search.

6.3. Understanding how

How do children solve the mapping problem—establishing *how* a model stands for a room? Several studies have shown that young children initially establish correspondences between a model and the room on the basis of physical similarity (DeLoache, de Mendoza, & Anderson, 1999; DeLoache, Kolstad, & Anderson, 1991). For example, 3-year-olds' ability to use a scale model as a representation of a room is moderated by the similarity between the model and the room; altering the degree of this perceptual similarity dramatically affects 3-year-olds' performance. Although most 3-year-olds succeed in the standard model search task, in which the furniture in the model and those in the room were covered with the same fabric, changing the fabric of either the model or the room caused children's performance to fall to the chance level (DeLoache et al., 1991). Thus, physical similarity is important for children to establish the mappings between elements in the model and those in the room.

Blades and Cooke (1994) suggested that children could pass the standard model search task simply by matching perceptually similar objects. They gave 3-year-olds a model search task similar to the one used in DeLoache's original study; however, the model and the room included both identical and unique items. When the hiding locations involved identical items (e.g., two identical chairs), children had to rely on relational information (e.g., the chair on the left) to locate the target. Thus, failure in this task indicates that children relied solely on object similarity to draw correspondences between the model and the room. Results confirmed this hypothesis: 3-year-olds failed when hidden locations involved identical items but succeeded when hidden locations involved unique items, indicating that they may have trouble understanding the relational correspondences between a scale model and a room.

In response, Marzolf, DeLoache, and Kolstad (1999) argued that young children could use relational correspondence in conditions where object correspondences were not explicitly pointed out by the experimenter. Three-year-olds were presented with a scale model and its corresponding room; the objects in the model and room were the same, but the spatial relations among the objects were different. For instance, in the scale model, a chair might be on the left side of a table, but in the room, the chair was on the right side of the table. When detailed instructions on the object correspondence between the model and the room were provided, 3-year-olds searched under the objects that shared physical similarity with those in the model. In contrast, when the experimenter did not explicitly point out the object correspondences, children took into consideration the spatial relations among the objects. This result suggests that children's sensitivity toward relational correspondence is affected by the presence and salience of object correspondence between the model and the room.

Structure-mapping theory can shed light on these disparate research findings. As stated earlier, analogy can be established based on two kinds of correspondences—object correspondence and relational correspondence (Gentner, 1983, 1989). Developmentally, there is a shift from focusing mainly on object similarity (matching similar objects) to an appreciation of common relational structures (Gentner & Toupin, 1986; Rattermann & Gentner, 1998). The instructions that promoted children's performance highlighted exactly the two kinds of correspondences that are critical for establishing analogies. In the standard model search task, the experimenter held up each piece of furniture in the model and pointed out the corresponding items in the room, emphasizing the object-level correspondences to children (DeLoache et al., 1999). Three-year-olds failed when the model and room were covered with different fabric, because this modification decreased the object similarity between the symbol and its referent (DeLoache et al., 1991). Besides object correspondence, instructions such as "Little Snoopy's room is just like big Snoopy's room" could encourage children to notice the overall relational similarity between the spatial layout of the model and that of the room. These two kinds of correspondences and their underlying developmental patterns can also help to clarify whether and when children can utilize relational information in scale models. In Blades and Cooke's (1994) experiment, young children (3-year-olds) failed when the hiding location involved identical items. Consistent with the relational shift hypothesis (Rattermann & Gentner, 1998), children at this age tend to focus on object correspondence while overlooking the relational similarities between models and rooms. In contrast, in Marzolf et al.'s (1999) study, object correspondence was downplayed by not explicitly pointing out object similarity in the verbal instructions, which allows children to resist the temptation to rely solely on object correspondence.

6.4. The interaction between understanding that and understanding how

In this section, we consider how children develop the ability to connect scale models and their corresponding rooms by analyzing the interaction between *understanding that* others intend to use symbols to represent referents and *understanding how* correspondences are established between them. Importantly, we outline a process through which comparison and alignment can promote insights into these two crucial components of symbol use.

Viewed from the analogical mapping framework, the understanding and use of symbols involve a structure mapping between a symbol system and its referent system. In particular, we suggest that the comparison process promotes *understanding that* and *understanding how* through three levels of correspondences. At the lowest level are the local correspondences between elements in a scale model and those in the referent room, including both object-level mapping, for example, *correspond* (big chair, small chair), as well as relational-level mapping, for example, *left of* (big chair/big couch, small chair/small couch). The establishment of these correspondences promotes *understanding how* a symbol system is linked to its referent system. Establishing these local correspondences both promote and can be promoted by the next level, higher order global correspondence, or the "*stand for*" relation between the particular symbol system and its referent system —*stand for* (scale model, room). This global relational mapping between two systems supports *understanding that* a symbol system represents its referent system, which is at the heart of the understanding and use of symbolic representations (DeLoache, 1987). At a still higher level, the cognitive system can strip away specific details concerning the particular medium of symbolic representations—whether it is a scale model, a map, or a photograph—and abstract the principle that symbol systems in general represent their referent systems—*stand for* (symbol systems, referent systems). This meta-representational mapping can permit re-representation upon encountering novel symbolic systems, allowing for inter-representational flexibility and cross-domain transfer (Forbus, Gentner, & Law, 1995; Karmiloff-Smith, 1990; Son, Smith, & Goldstone, 2008).

Under this framework, we suggest that the best account of children's thinking in the standard model room task is as follows. We assume that when a child first comes to the task, he or she has not been asked before to use a model as a symbol. Thus, the child does not know either that or how the model stands for the room. However, in optimal conditions (e.g., high perceptual similarity, smaller scaling disparity between the model and the room, or specific instructions regarding the local correspondences), 3-year-olds (and even 2.5-year-olds; see Marzolf & DeLoache, 1994) can *discover* the "stand for" relation in real time (DeLoache et al., 1999). The child does *not* need to understand, initially, that the model is intended to be a symbol; rather, the child can start with noticing the perceptual similarities between the model and the room through a process of comparison (e.g., the sofa in the model looks like the sofa in the room). Establishing these local correspondences can support (or bootstrap) the insight of the symbolic nature of scale models—they are representations of their referent space. "Little Snoopy's room is just like Big Snoopy's room" now starts to makes sense, in part, because the child has begun some initial object-based mapping between individual objects in the model and those in the room. In this sense, establishing local correspondences promotes *understanding how* models correspond to rooms, leading to *understanding that* models are intended to "stand for" their referents.

Understanding that can also lead to *understanding how*. For example, direct instructions concerning the intention behind the creation of scale models can help children to establish local correspondences and figure out how this representation is physically realized. As mentioned earlier, explicitly pointing out the experimenter's intention, such as "I made this [scale model] to help you to find X," leads to increased search performance (Sharon, 2005). Such instructions about the experimenter's intention can provide necessary scaffolding for the discovery of the "stand for" relation between symbols and referents; in other words, it helps children to *understand that* symbols are representations of their referents. Importantly, conveying intentions leads to better search performance even for models that share a low degree of similarity with the room (Sharon, 2005). That is, understanding that the model is intended to represent the room prompted a search for the local correspondences, even when these correspondences are perceptually harder for the same developmental age group. Thus, *understanding that* symbols "stand for" their referents can lead to the search of *how* correspondences are established.

Although the interaction between understanding others' intentions and establishing correspondences has generated increasing interest (Bach, 2011; Gerson & Woodward, 2012; Hoyos et al., 2015), very few studies have directly tested this mechanism and its implications for symbol learning. There are, however, at least two examples. Marzolf and DeLoache (1994) examined whether 2.5-year-olds can learn about the "stand for" symbolic relation from an easy task of using 3D scale models to locate hidden objects and transfer this understanding to a more difficult task with 2D maps (Bluestein & Acredolo, 1979). Two-and-a-half-year-olds were first given a scale model task with a model room that was similar in scale (1:2) to the real room and they succeeded at the search task (DeLoache et al., 1991). They were then asked to search for hidden objects in a different room based on information provided on a map. Although 2.5-year-olds normally fail the map search task (Bluestein & Acredolo, 1979), children in this experiment who were first given the model search task performed well. This improvement was not due simply to practice or familiarity, as children who performed the map search task twice did not improve over time. Marzolf and DeLoache (1994) suggested that children had transferred their understanding of the "stand for" symbolic relation between a model and a room to that between a map and a room. They also carefully pointed out that it is also possible that children might have learned about how to better establish local correspondences from the scale model task, although the perceptual differences between a model and a map might require certain degrees of abstraction and transfer. From our perspective, these two hypotheses are not mutually exclusive; instead they may be exactly the dynamic process through which seeing correspondences and understanding intentions mutually promote each other to propel symbolic understanding: Aligning a model and a room causes children to abstract their higher order relation—*stand for* (symbols, referents), leading to the transfer of the "*stand for*" relation to a map and a room, which in turn motivates the search for more correspondences.

Another indication of a possible interaction between understanding that and how comes from Loewenstein and Gentner (2001). After seeing either one hiding room (control group) or two similar hiding rooms (comparison group), 3-year-olds were assessed on a transfer task involving a third room that they had never seen before. Children in the comparison group were much more successful in their search than their counterparts in the control group. Comparing two model rooms gave children the opportunity to see the object correspondence as well as the relational correspondence between them, hence promoting *understanding how* symbols represent spaces. Although this increased understanding of how models are related to rooms may be sufficient for children to perform well in the third novel room, this *understanding of how* may also help children to *understand that* the experimenter intended to use symbols to represent their referents. Children can then transfer this knowledge—models are intended to represent the layout of their referent space—to a new model that they had never seen before and figure out the specific correspondences. These interesting hypotheses merit future research with children of different ages and different types of symbolic medium (e.g., models vs. maps) to test potential transfer effects.

7. Implications for learning other symbol systems

In this section, we briefly extend our analysis to the learning of other symbol systems. Language is arguably one of the most important types of conventionalized symbol systems; delays in language acquisition often lead to many long-term challenges in schools and in daily communication with others. Because of their importance, spelling, reading, and writing have been the focus of much research and educational intervention efforts. There is evidence showing that even very young children understand the intention of using written marks on a piece of paper to represent words. For example, Tolchinsky (2003) noted that very young children's scribbles often follow a horizontal line, although lack of iconicity with any particular words, the scribbles reflect an understanding *that* people use written marks to represent words. Later, children start to establish correspondences between written marks and their meanings, making errors such as thinking longer words represent bigger objects (Bialystok, 1992). These errors may be wrongheaded, but are intelligent and reflect that children are actively trying to figure out *how* symbols represent their referents by comparing the properties of written symbols with the properties of their referents.

Understanding *how* conventionalized symbols represent their meanings can be quite challenging, as many conventionalized symbol systems have lost their physical resemblance with their referents over time. Consequently, the correspondences between symbols and referents are less transparent for modern conventionalized symbol systems, such as English, compared to pictographic languages, such as ancient Chinese pictograms. However, some remnants of language still preserve the close mapping of symbols to their meaning and, consistent with our theoretical framework, are therefore easy to be acquired by children. One such example is sound symbolism, which refers to words that share similarities between their phonological characteristics and their meanings (e.g., squeeze, bump) (Hinton, Nichols, & Ohala, 2006; Imai, Kita, Nagumo, & Okada, 2008). Not only do adults show sensitivity to foreign words that are based on sound symbolism (Iwasaki, Vinson, & Vigliocco, 2007), but sound symbolism also facilitates infants' learning of novel words, compared to non-sound symbolic words (Imai et al., 2008; Nygaard, Cook, & Namy, 2009). Thus, increasing the similarities between symbols and referents helps children to figure out how correspondences are established.

This analysis suggests that comparison and similarity play an important role in the learning of conventionalized symbol systems. For example, by comparing the phonological characteristics of sound symbolic words to their referents, children may notice the similarity between them, which helps them to establish correspondences, leading to the understanding that people use words to represent meanings and ultimately facilitating early vocabulary development. Not only has analogical comparison been applied to the learning of spoken (Gentner & Namy, 2006; Namy & Gentner, 2002) and written language (White, 2005), it has also been applied to the learning of many other conventionalized symbolic systems, such as mathematical notations (Landy, Brookes, & Smout, 2014), geosciences visualizations (Jee et al., 2010; Resnick, Shipley, Newcombe, Massey, & Wills, 2012), gestures (Cooperrider, Gentner, & Goldin-Meadow, 2016), and sketches and diagrams (Forbus, Usher, Lovett, Lockwood, & Wetzel, 2011). All of this evidence points to the important role that analogical comparison plays in facilitating the learning of symbol systems.

8. Conclusions

Human beings are a symbolic species. Much of our history and collective achievements rests on the creation and use of a variety of symbol systems. We have argued that the acquisition of these symbol systems can be accomplished through another arguably uniquely human cognitive capacity—analogical reasoning. In particular, we argued that the structure-mapping theory, proposed by Gentner (1983, 1989, 2010) and colleagues, provides an integrative theoretical framework through which we can better understand the developmental mechanisms of symbolic acquisition. Analogy underlies and promotes the understanding of others' intentions behind false-belief, tool use, and the comprehension of visual representations. Analogy also contributes to the establishment of object and relational correspondences between symbols and their referents. When considered together, the facilitative effect of analogical comparison on the establishment of correspondences and the understanding of symbol users' intentions can mutually reinforce each other in a bootstrapping process, leading children to acquire the prodigious human capacity of symbol use.

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