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Structure-mapping: Directions from simulation to theory

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The theory of mind debate has reached a "hybrid consensus" concerning the status of theory theory and simulation theory. Extant hybrid models either specify co-dependency and implementation relations, or distribute mentalizing tasks according to folk-psychological categories. By relying on a nondevelopmental framework these models fail to capture the central connection between simulation and theory. I propose a "dynamic" hybrid that is informed by recent work on the nature of similarity cognition. I claim that Gentner's model of structure-mapping allows us to understand simulation as a process in which psychological representations are aligned, causing the spontaneous abstraction of theoretical generalizations about the psychological domain.

Keywords: Analogy; Cognitive Development; Folk Psychology; Gentner; Simulation; Structure-Mapping; Theory of Mind

A basic assumption in the early debate over what mechanisms and processes subserve the practice of folk psychology was that "theory theory" and "simulation theory" were engaged in a zero-sum game: the empirical data was forthcoming, and only one of the theoretical alternatives could successfully predict and explain it. That assumption, while seldom made explicit (but see Stich & Nichols, 1993), has now been rejected. In fact, it has become fairly common for authors interested in folk psychology to describe these original battle lines as overly strict and then state that the proper understanding of folk mentalizing lies in some sort of "simulation–theory hybrid."[1] However, it is less common for these authors to provide positive accounts for how these hybrids should be conceptualized. It is still less common for said authors to develop empirical models that support the conceptual constraints and combinatorial principles that are used towards the construction of hybrid theories.

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In sections 1 and 2 of this essay I discuss the motivation for a simulation–theory hybrid and examine some current attempts to unite these theories within a more general model of folk psychology. I will show that these approaches either catalogue straightforward dependency relations between simulation and theory or divide general mindreading tasks across simulation and theory. I argue that these approaches are uninteresting or unsuccessful, and that the source of the problem is a commitment to a nondevelopmental cognitive framework. In section 3 I offer a positive account of a simulation–theory hybrid in the form of what I term a "dynamic" or developmental hybrid. To support this account I draw on recent work in the cognition of analogical encoding and similarity comparison. I claim that Gentner's theory of *structure-mapping* provides an empirically established cognitive process that, when transferred to models of mental simulation, predicts a developmental relationship between simulation and theory. More specific, Gentner's model of structure-mapping allows us to understand simulation as a process where two psychological representations are aligned, causing the spontaneous abstraction of theoretical generalizations about the psychological domain. These abstracted schemas contribute to the body of metarepresentational information referred to by the theory-theorist as a "folk psychology."

1. Theory Theory, Simulation Theory, and Hybrid Theories

1.1. Information-Inclusive Knowledge Structures

The theory-theory approach (TT) to folk psychology is an application of the cognitive psychology paradigm in which impressive, often domain-specific, cognitive capacities are explained by positing internally represented knowledge structures. These knowledge structures consist of concepts and rules (perhaps laws) that are tacitly or subdoxastically represented. According to TT, the success of this strategy in the explanation of our competence with natural language and folk-physics provides inductive support for its application to the domain of folk psychology.

The version of TT I adopt in this essay is Stich and Nichols's (1995) *information-inclusive* model.[2] This model identifies a cognitive theory about a psychological domain with any "internally represented body of information (or perhaps mis-information) about psychological processes and the ways in which they give rise to behavior" (p. 88). Internally represented knowledge structures that satisfy the information-inclusive constraint may include nomological generalizations, but are not limited to such generalizations. Though Stich and Nichols are not explicit on this point, an information-inclusive "theory" could be an inductive script, the encoding of prototypical cases, an empirical generalization, a schema, or a narrative.[3] The law-like generalizations of folk psychology, which are supposed to be platitudinous, are notoriously difficult to articulate: a review of the literature reveals the "belief–desire law" as a rare example.[4] Thus an important advantage of the information-inclusive approach to theoretical knowledge is that it does not require mentalizers to represent such law-like generalizations.

1.2. The Simulation Heuristic

Simulation theory (ST) maintains that mentalizing does not require the deployment of theoretical knowledge about the target domain in its central function. Because the target domain under consideration consists primarily of representations (i.e., beliefs and desires), ST claims that mentalizing is not a metarepresentational activity. Or, as Davies and Stone (1996, p. 133) put it, ST denies that there is one level of ordinary thinking and then a further, metalevel of thoughts that constitute a theory about the lower level. Rather, people use their own mind to model or simulate the mind of a target individual, much like an engineer might use a model aircraft to simulate the behavior of an actual aircraft.[5] A successful aircraft simulation requires that the model is a (rough) causal analogue of the actual aircraft. Similarly, ST claims that accurate psychological interpretation requires the simulator's practical reasoning mechanism to function analogously to the target's. Success does *not* require the simulator to possess theoretical knowledge about the causal processes and mental categories that constitute their own (and others) practical reasoning mechanism.

The version of ST I adopt in this essay is most directly informed by Goldman's process-driven, ''off-line'' account of mental simulation. While several accounts of ST are on offer—most notably Heal's replication theory and Gordon's so-called ''radical'' approach to ST—Goldman's (2006) version is worked out in detail and most informed by empirical research. I analyze the off-line simulation heuristic in section 3.3, but a brief description can be given here. The heuristic begins with feeding ''pretend inputs'' into one's practical reasoning system in order to engage the situation from the target's perspective. The reasoning system then processes these inputs according to whatever principles and laws govern the functioning of the system, e.g., the belief–desire law. The process is off-line in the sense that the interpreter will ascertain the output of the reasoning process but stop short of converting this output into overt action. Rather, the interpreter projects the outcome onto the target in order to predict or explain the target's intentional behavior.

1.3. The Hybrid Requirement

In this section I motivate the recent consensus that both processes of simulation and theory contribute to an individual's mentalizing ability. My intent is only to make plausible the claim that simulation and theory are jointly required for mentalizing.[6] The best argument for this requirement is an empirically testable model that predicts a simulation–theory integration. Such a model is offered in section 3.

The most common concession made by simulation theorists to their TT rivals derives from the testimony of our everyday mindreading activities. Advocates of simulation such as Goldman assume that it is just *obvious* that we use some nonsimulative processes in our interpretation of other people:

> I have no hesitation in agreeing that inductively based attributions sometimes occur, with no simulative ingredient at all. Here is an example. Suppose that Maria is a frequent luncheon companion of mine. Expecting to be late today, she asks me to order drinks before she arrives. I easily predict her beverage preference because I

> know Maria always wanted iced tea as her luncheon beverage in the past. I don't perform a simulation to predict her beverage preference on this occasion. I simply extrapolate from the past pattern . . . the example illustrates the obvious need to refrain from claiming that simulation is involved in *all* cases of third-person attribution. (Goldman, 2006, p. 89)

While Goldman does not say what, exactly, makes this case an obvious example of the use of theory, the reason seems clear. It is surely obvious that we deploy scripts and schemas throughout our daily lives in nonpsychological domains, such as gauging the likelihood that one's car will stall in cold weather or knowing that the butter will turn brown if cooked too long. It would be utterly mysterious, the argument continues, if we could not bring this ability to bear on the project of interpreting intentional agents.[7]

Several things have happened to make simulation more attractive to even the most hard-line defenders of TT. Early on in the simulation–theory debate, TT was regarded as continuous with the "dominant explanatory strategy" of cognitive psychology, and ST represented "a bold challenge to the received view" (Stich & Nichols, 1993, p. 226). Theory-theorists claimed that *if* ST turned out to be correct, then cognitive scientists would have to make considerable adjustments to well-accepted background theories (Stich & Nichols, 1993, p. 227). For TT, there was no such price for success. At present, this asymmetry between ST and TT is no longer applicable. A wealth of empirical evidence has generated "explanatory strategies" within cognitive psychology that are continuous with simulation theory. For example, behavioral and neurological evidence pertaining to mirror neurons (Gallese, Keysers, & Rizzolatti, 2004), visual imagery (Spivey, Tyler, Richardson, & Young, 2000), motor mimicry (Decety & Ingvar, 1990), and facial mimicry (Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001) appeal to neural substrates and/or cognitive processes in parallel fashion to simulation theory.[8] While these studies might not *demonstrate* the use of simulation over theory, they at least show that the ST is continuous with, rather than a corrective to, popular explanatory strategies in cognitive psychology.

A second reason to think that simulation is necessary to folk-mentalizing derives from the simplicity of simulation. The following example from Harris (1992) has been illustrative on this point.[9] Imagine that you are given a list of grammatical and ungrammatical sentences and then asked to predict how members of your language community will judge the grammaticality of each sentence. TT predicts that you would perform this task by deploying a tacit theory about people and their grammaticality judgments—a metarepresentational theory that specifies causal connections among first-order mental states and behavior. But this seems wildly implausible. Instead, we would go about this task by asking *ourselves* whether the sentences are grammatical and then project our answers onto the target. To do so, we exploit a theory, but this theory is a body of knowledge about syntax, not about people's beliefs about syntax. That is, the theory is a tacit (or implicit-procedural) grammar theory that simulates the target's grammar theory, which is causally analogous.

2. Varieties of Simulation–Theory Hybrids

2.1. The Co-Dependency Thesis

As the above example indicates, it is not always possible to apply the simulation account of mindreading without appealing to some form of theory (especially if theory is understood in the information-inclusive sense). It is precisely these sorts of *co-dependencies* that have dominated discussion about ST–TT hybrids. In the grammar-prediction example, simulation requires at least a tacit theory of grammar. Whether simulation requires implementation of a tacit theory for routine psychological interpretation is less clear. If we think that our practical reasoning mechanism *represents* a theory about psychology and action, then simulation must implement this theory. If, on the other hand, we agree with Goldman (2006, p. 44) that our practical reasoning mechanism *obeys* but does not describe psychological "laws," then routine simulation is "process-driven" rather than "theory-driven."

Still, there are additional reasons to think that simulation is dependent on theory. The projection step of the simulation heuristic might require the bit of theory that states "others are like me" (Jackson, 1998). Simulation's dependence on theory is even clearer when we consider mindreading cases that require the generation of pretend-inputs that are fed into the off-line practical reasoning mechanism. Surely, the types of theoretical knowledge structures discussed in section 1.1 often guide selection of these inputs. For example, in order to simulate the situation of a returning civil war veteran, I need to access a theory, script, or schema that describes the socio-historical context of the post-Civil War era.[10]

While it is important to be clear on the various dependency relations that obtain between simulation and theory, I think the real work for those pursuing a hybrid theory lies elsewhere. Call these dependency relations "trivial ST–TT interactions." Now, even assuming that every mindreading task requires a trivial ST–TT interaction, it is still the case that some tasks centrally exploit metarepresentational theories about the target domain while others do not (e.g., the grammar case). Importantly, the above dependency and implementation relations, or trivial ST–TT interactions, do not impact this bifurcation.[11]

The primary goals, then, for a hybrid theory of folk psychology should be to answer the following questions: (1) What are some general principles that can predict when these different styles of mindreading obtain and explain why it is that one type of mindreading is preferred over the other in the indicated context? (2) What are some general principles that predict when and how the different mindreading processes interact developmentally? An answer to the second question will take the form of a developmental model that articulates what can be termed "dynamic ST–TT interactions." One of the claims of this essay is that an answer to question (2) will inform an answer to question (1) and vice-versa. Thus the two questions cannot be considered in isolation. However, recent discussion of simulation–theory hybrids has shown a bias towards the first question.

2.2. Divided-Hybrid Models

The strategy of current researchers in folk psychology is to isolate question (1) and then proceed by dividing and conquering. This strategy distinguishes among the different types of mindreading tasks and then allocates some to theory and some to simulation. If the majority of tasks are given to simulation, then simulation is termed the "default" process (Goldman), and if the majority is given to theory, then theory is the default process (Nichols & Stich). Tasks that are commonly assigned to simulation are inference prediction (Heal, 1996b, 2003; Nichols & Stich, 2003), attribution of propositional content (Heal, 1996b), prediction of brief-term mental states (Perner & Kühberger, 2005), and mastery of the mental concepts, e.g., BELIEF and DESIRE (Gordon, 1996). Popular mindreading tasks to give to theory are desire attribution (Nichols & Stich, 2003), belief attribution (Nichols & Stich, 2003), and mastery of the mental concepts (Fodor, 1987; Gopnik & Wellman, 1992). I will use the expression "divided hybrid" for any model that achieves hybridization through this piece-meal distribution of types of mindreading task across simulation and theory.

I argue that the divided-hybrid approach fails to capture the theoretically important respect in which TT and ST are related because it misconstrues the nature of folk-psychological development. Implicitly or explicitly, divided-hybrid theorists agree that theoretical questions about the hybridization of simulation and theory are best answered while holding developmental factors *constant*. That is, they assume a nondevelopmental understanding of social cognition *in order to* hybridize simulation and theory. This theoretical assumption is most transparent when, in order to make plausible the compartmentalization of simulation and theory, researchers appeal to the "default habits" of the "normal adult." Jane Heal (1996b) is representative here: "The topic throughout is the nature of the fully developed adult competence with psychological notions . . . " (p. 75). Another example is Davies and Stone's (1996) list of nine questions intended to parse out the theory–simulation debate in which questions about development are distinct from "the explanatory question about normal adult folk-psychological practice" (pp. 119–120). Or see Harris's (1992) article that specifically focuses on the relationship between folk psychology and development but which explores development after the fourth year with only a parenthetical comment: "(No one, of course, thinks that the developmental story stops at [the acquisition of a representational theory of mind] but the evidence gets a lot more piece-meal)" (p. 127).[12]

These examples help reveal the tendency for participants in the simulation–theory debate to confine the theoretical importance of folk-psychological development to some early *phase*, for example when young children learn the concept of a (false) belief or when they learn folk-psychological platitudes "at mother's knee" (Churchland, 1988, p. 59). Authors might not deny post-childhood development (such as Harris), but nor do they explore any implication it has for the relationship between simulation and theory. At best, authors describe adults who have the capacity to occasionally deviate from default (simulative or theoretical) strategies.[13]

For instance, Goldman's example about predicting his companion's beverage choice demonstrates how the use of theory might override the simulation-default for the category of choice prediction. But after the deviation, defaults remain in place. What is missing here—what makes the example nondevelopmental—is a *dynamic* interaction between simulation and theory.

A dynamic-hybrid model, on the other hand, construes the relationship between simulation and theory not as intrusions on defaults but as a dialectical interaction in which two forms of mentalizing promote one another and create adaptive changes to mindreading skill. If this is correct, then assuming a nontransitional (i.e., normal, default) framework *in order to see how simulation and theory can be combined* is to have it backwards.

2.3. Dynamic-Hybrid Models

It is a mistake to restrict flexible cognitive development to children, as though adults were generally locked into default cognitive habits. While a bias towards child development has pervaded traditional approaches to cognitive development, contemporary research indicates that the cognitive life of adults is dynamic and adaptive.[14] Research on folk psychology has been slow to recognize the importance of adult cognitive development, and it is reasonable to attribute this lag to the emphasis that has been given to the false-belief task and the acquisition of a representational theory of mind. As I discuss below, there are now several empirical investigations of folk-psychological development in both younger and older adults (e.g., Blakemore, den Ouden, Choudhury, & Frith, 2007; Happé, Winner, & Brownell, 1998; Hess, Osowski, & Leclerc, 2005). However, the notion of adult folk-psychological development continues to be parenthetical with respect to the hybridization of ST and TT. This is, I submit, a critical error. The current proposal aims to correct this error by (1) accepting the information-inclusive account of theoretical competence—an account that requires a developmental explanation for the fine-grained and often novel knowledge structures that are employed in daily mindreading activities; and (2) directly examining adaptive changes in adult mindreading skill with respect to the uses of simulation and theory. Below I focus on this second point and provide reasons in support of a dynamic-hybrid model.

It is far from obvious why it would not be the case that adults learn to adapt their preference of simulation over theory (and vice versa) rather than rely on default settings, as assumed on the divided-hybrid model. For an analogous case, consider the use of memory in the performance of everyday tasks. It is widely accepted by most researchers that the memory system is not unitary but rather fractionates across at least six different mechanisms, each of which can be selectively impaired and has a distinct neural substrate. This confederacy of systems includes explicit memory, working memory, priming, motor skill learning, classic conditioning, and emotional conditioning (Willingham, 1997, p. 3). The implication for development is that honing the use of one's memory system will largely consist in being able to effect adequate interactions across the different systems (Ashby & O'Brien, 2005;

Hartley & Burgess, 2005). Developing this proficiency through adult life will often require increasingly elaborate interactive structures rather than default settings that delegate tasks to individual subsystems.

This point is not restricted to exotic tasks, but generalizes to the mundane skills of daily living. For example, how do people go about driving their cars? Learning to drive a car requires a rather complicated interaction of memory systems. Category learning (e.g., stop sign, right-of-way), episodic memory (e.g., past driving experiences), and motor programs (e.g., down-shift, brake) each causally and developmentally interact so as to promote driving ability. But adult driving does not signal the end of these developmental interactions. Novel stimuli, which are ubiquitous given the quantity of variables involved in any driving experience, require the development of novel interactions among the memory systems in order to promote changes, however transient, to one's driving competence. Thus, to be competent in the use of one's episodic memory, say, is to be able to implement its function developmentally with other memory subsystems for the purpose of achieving some goal. In order to understand episodic memory's contribution to task performance, we require an understanding of how episodic memory is developmentally structured with other memory systems (e.g., semantic memory) that are also required for task performance. A corollary is that a wide array of disorders can be explained by positing *interactive* deficits between memory subsystems (McDonald, Devan, & Hong, 2004).

People are, at least to some degree, engaged in a constant process of developing their driving competence, their cooking skill, their parenting style, etc. In no area is the case for ongoing development more clear than in folk psychology, where the complexities of social life introduce the need for a matching complexity of theoretical representation. In a recent review, Hess (2006) points to a pattern of data indicating that adults develop new and superior mindreading strategies as a result of increased social experience. Emerging neurological evidence is consistent with this claim.[15] These findings support the folk intuition that (social) wisdom improves with age, and may even be superior in elderly individuals (Happé et al., 1998). If, as argued in section 2.1, both theory and simulation have obvious roles in mindreading activity (where these processes are understood as conceptually distinct despite trivial ST–TT interactions), it would be surprising if the ongoing development of mindreading skill were not driven by an interaction between the two processes. According to the dynamic hybrid I offer in the next section, one of the *mechanisms* for such adaptive change is the interplay between simulation and theory.

3. Structure-Mapping and the Development of Folk Psychology

> But the real question for developmental cognitive science is not so much what children know and when they know it, but how children's theories develop and change and why children's theories converge towards accurate descriptions of the world. It is all very well to suggest that children's learning mechanisms are analogous to scientific theory-formation. However, what we would really like is a

> more precise specification of the mechanisms that underlie learning in both scientists and children. (Gopnik & Schulz, 2004, p. 371)

Gopnik and Schulz answer their own question by appealing to the causal Bayes net account of causal knowledge and learning (see Gopnik et al., 2004). However, this model of causal learning remains speculative, and it has not yet been tested in the domain of mentalizing.[16] My goal here is to make the case for an additional method of theory-formation that has yet to receive attention in the literature on folk psychology. The method of theory-formation I propose draws from an empirically established process in the theory of *structure-mapping* and, more important for our purposes, predicts a developmental collaboration between simulation and theory throughout both child and adult cognitive development. I begin by presenting the theory of structure-mapping. In section 3.3, I apply this theory to the abstraction of folk-psychological schema. In section 3.5, I suggest that the theory of structure mapping helps explain how children acquire folk-psychological concepts such as BELIEF.

3.1. Structure-Mapping Theory

Work in the area of analogical and similarity cognition is widely considered one of the "success stories" of cognitive science (Forbus, Gentner, Markman, & Ferguson, 1998) and boasts a substantial convergence on foundational questions (Gentner & Kurtz, 2006, p. 609). While there are several models of analogical cognition, Gentner's theory of structure-mapping has received the widest acceptance and has been applied fruitfully to several areas of research (e.g., mathematical problem solving, Dixon & Bangert, 2004; spatial reasoning, Gattis, 2002). The theory is complex, so the following exposition is a simplification.

Structure-mapping theory (SMT) investigates forms of cognition that are based on similarity. Prior approaches to similarity comparison (see Tversky, 1977) focused on the degree of feature overlap between two objects or events, such as the salient perceptual matches "*red* apple" and "*red* fire-engine." SMT departs from this tradition by claiming that further axes of similarity—specifically deep relational commonalities—are necessary to the process of similarity cognition, and in particular analogical comparison. For example, understanding that "2:4::9:18" or that "a battery is like a reservoir" requires picking out the relational similarities "twice as great as" and "stores potential energy" respectively. SMT provides a cognitive model for how these comparisons are performed and how they impact learning.

According to SMT, comparison involves the juxtaposition of two structured representations, such as the representation of a battery and the representation of a reservoir. The juxtaposed representations are aligned, and knowledge is either directionally mapped from one representation to the other, or the representations are mutually aligned and abstracting commonalities generates knowledge. A central thesis of SMT is that relational commonalities are *privileged* in the comparison and mapping process. Aligning representations is a cognitive process that induces focus on common relational structure, and a variety of empirical studies have shown that people in fact prefer "deep" relational commonalities over superficial matches (Gentner, 1983; Gentner & Kurtz, 2006; Kotovsky & Gentner, 1996). Metaphorically, when we align two representations a common relational structure will "pop-out." Gentner et al. (1997) call this "the comparison as X-ray phenomena." But which relations are highlighted? As Goodman pointed out, there are an indefinite number of common relations that any two events or any two representations might share. For instance, it is true of almost any object pair (e.g., a battery and a reservoir) that they share the relation "larger than a grain of sand." If comparison creates a focus on relational structure, there must be a constraint that guides the mind towards one or several of the potentially infinite number of relational commonalities.

To solve this problem, SMT puts forth its central claim in *the systematicity principle*. This principle asserts that when aligning two representations, people prefer "a predicate that belongs to a mappable system of mutually interconnecting relationships" (Gentner, 1983, p. 163). Thus the representational alignments that drive similarity cognition create a focus only on those relational commonalities that are similarly embedded in interconnected systems of relations. In other words, the mind will seek out a relation if it is a component of some larger *system* of relations. Consider the Rutherford analogy, "the atom is like our solar system." The systematicity principle predicts that alignment of the atom representation and solar-system representation will highlight the common relation: *The planets/electrons REVOLVE AROUND the sun/nucleus*. This relation is preserved because it is constrained by the higher order relation: *The fact that the X attracts Y CAUSES Y to revolve around X*. This deep relational system can also be extended to include the mass of the sun/nucleus and its causal connection to the above higher-order relation. Because *hotter than* does not participate in an interconnected system of relations, it is (fortuitously) an ignored relation in the mapping process. The predictions made by the systematicity principle have been replicated in dozens of empirical studies, one of which is discussed below. The principle has also been computationally simulated with considerable success (see Falkenhainer, Forbus, & Gentner, 1989).

3.2. Progressive Alignment and Re-Representation

It is important to note the implications of the systematicity principle for the general problem of schema abstraction and the learning of rules and theories. Here, I think, is where SMT makes its most important contribution to cognitive psychology and is most relevant to a hybrid model of folk psychology. Aligning representations will induce a focus on, and lead to the disembedding of, valuable higher-order relations that are central to the formation of theoretical knowledge. The claim is not just that alignment can draw attention to tacitly known rules and schemas, but that alignment actually imports new relational knowledge, causing the spontaneous abstraction of a schema that was not previously known—explicitly or tacitly—by the subject.

But on the surface this hypothesis might seem implausible. How, after all, can the mind extract information that is not somehow already encoded in the aligned representations? The answer is: through a process of *progressive alignment* that leads to a *re-representation* of knowledge. Progressive alignment and subsequent re-representation occur when individuals have repeated experience aligning and mapping structured representations. Figure 1 (from Gentner & Medina, 1998) demonstrates how in perceptual patterns higher-order relations (in this case symmetry) are separable from both first-order relations (e.g., polarity) and object-level attributes.

For this experiment, children were presented with a standard that exemplified the higher-order symmetry relation. Given two choice alternatives, they were asked which ''goes best'' with the standard. In the relational choice the higher-order relation was preserved. The other choice, the *foil*, presented the same objects but arranged so as to remove the higher-order pattern. Thus the experiment was ''a pure test of children's appreciation of relational similarity'' (p. 272). The results of the experiment indicate that learners first grasp object-level commonalities, then first-order relations, and finally higher-order relational similarities: 6- and 8-year-olds were able to detect higher-order relations in the absence of object-level commonalities and first-order relational commonalities, while 4-year-olds were unable to perceive cross-dimensional relational matches.

The most important experimental finding, however, was the following. Four-year-olds who were *first* given *blocked* within-dimension matching trials (e.g., little–big–little,

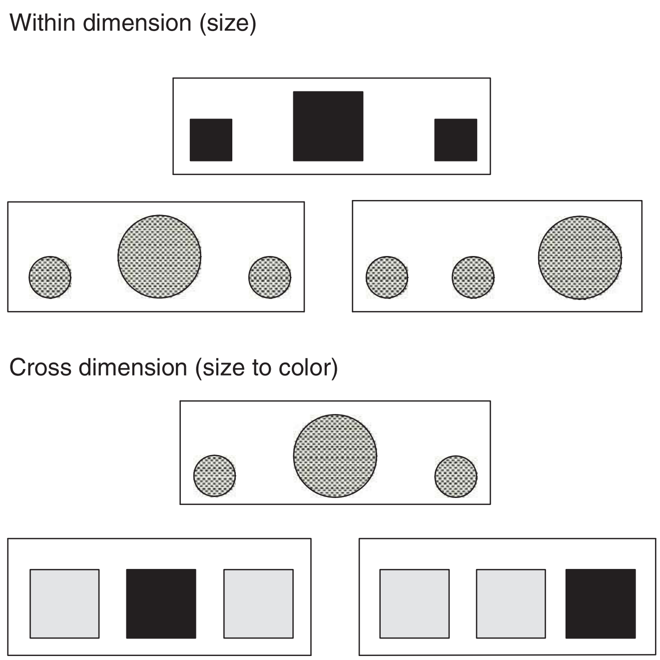

Figure 1 Sample within-dimension and cross-dimension triads from Kotovsky and Gentner's (1996) progressive alignment study. Children who were given a mixed trial of both within-dimension and cross-dimension triads chose 47% relationally on the cross-dimension triads. Children who were first given a blocked trial of within-dimension triads chose 80% relationally on a subsequent blocked trial of cross-dimension triads (recreated from Gentner & Medina, 1998, p. 272).

little–big–little), in which alignment was fairly easy and supported by object-level similarities, scored significantly higher (80%) in subsequent trials that tested cross-dimensional relational matches (e.g., little–big–little, light–dark–light).[17] In contrast, 4-year-olds who were first given a *mixed* trial of within- and cross-dimensional matching tasks remained at chance (47%) in subsequent trials that tested cross-dimensional relational matching.

SMT offers an explanation for this surprising result. Repeated experience in concrete representational alignment bootstraps the ability to perform the more challenging cross-dimensional alignments. By performing the fairly straightforward concrete similarity alignments, the systematicity constraint literally invites the mind to search for and locate deeper and more interconnected relational commonalities. In terms of the above experiment, each time a child aligns the within-dimension pattern, the deeper relational pattern of symmetry is promoted or caused to "pop-out." This then is the first part of the answer: aligning representations highlights interconnected systems of knowledge.[18]

The second part of the answer refers to a shift in representational coding that reflects the knowledge-change that occurs as a result of progressive alignment. Consider a child who has learned to map a relation of monotonic increase across the dimensions of saturation and size:

> . . . [children's] representation of a difference in magnitude is typically conflated with the dimension of difference: for example *darker* (a, b). Later, they re-represent these differences in a manner that separates the comparison and the dimension: for example *greater* [*darkness* (a), *darkness* (b)]. Such a re-representation would make it possible to notice that there is some commonality between change in size and change in darkness. The idea is that extracting the specific dimensions from the relation of change along a dimension permits flexible cross-dimensional alignment. (Gentner, Rattermann, Markman, & Kotovsky, 1995, p. 289)

In the newly represented codes, relational schemas are put in the conceptual foreground. This is a necessary step in the epistemology of relational categories and relational schema. For instance, to understand that the lamp is a "gift" the child must predicate the lamp with the {giver–gift-recipient} relation. This, of course, presupposes the prior capacity to *represent* the {giver–gift-recipient} relation.

3.3. Structure-Mapping and the Abstraction of Folk-Psychological Schema

I now argue that the learning principles of structure-mapping anchor a developmental collaboration between simulation and theory. I will claim that the off-line simulation heuristic involves the juxtaposition, alignment, and mapping of two structured representations. This means that mental simulation deploys the cognitive process of structure mapping and, consistent with the developmental tenets of SMT, generates causal and theoretical knowledge of the psychological domain. In order to demonstrate this I will analyze a stock example of simulation from the folk-psychological literature (originally from Kahneman & Tversky, 1982). This example will focus on the folk-psychological categories of inference and choice and will assume the prior acquisition of basic mental concepts such as BELIEF and DESIRE. In section 3.5, I describe how SMT helps explain the acquisition of mental concepts.

> CrT. Mr. Crane and Mr. Tees were scheduled to leave the airport on different flights, at the same time. They traveled from town in the same limousine, were caught in a traffic jam, and arrived at the airport thirty minutes after the scheduled departure time of their flights. Mr. Crane is told that his flight left on time. Mr. Tees is told that his flight was delayed, and just left five minutes ago. Who is more upset?

According to the current hybrid consensus, (CrT) is indicative of mindreading contexts in which the simulation heuristic is preferred: most people agree that they would answer this question by ''putting themselves in the shoes'' of Mr. Crane and Mr. Tees. The alternative TT approach would require the deployment of a folk-psychological generalization such as the following:

> *G**. ''other things being equal, persons who believe that they have come close to attaining a desired goal will, upon failing to meet that goal, be more upset than persons who have also failed but who believe that they have not come close.'' (Fuller, 1995, p. 20)

Now, if one were loyal to the divided-hybrid strategy they might generalize this intuitive plausibility of simulation throughout the folk-psychological category of inference prediction and then conclude that simulation is the default procedure for this category.

The dynamic-hybrid approach offers a different strategy. Rather than focusing on which mentalizing tactic fits a general category, the strategy focuses on which tactic fits the demands of a particular task relative to considerations about the individual's folk-psychological development. A central component of the model I advance is that simulation is used when the mentalizer has not yet developed a metarepresentational knowledge structure that is adequate for the mindreading task, and also that this use of simulation will cause the development of a metarepresentational knowledge structure that *is* adequate for the mindreading task.

Consider the simulation of Mr. Tees. According to a widely accepted functional description of the off-line simulation process (see Goldman, 2006; Stich & Nichols, 1993), the mindreading task will require the input of various (pretend) propositional attitudes. For reasons that are made clear below, these propositions must cohere in a structured initial representation of the target, Mr. Tees. This representation, which we can call the *initial target representation*, includes the following facts:[19]

(1) Mr. Tees desires to make his flight on time.
(2) Mr. Tees drove to the airport in a limousine.
(3) Mr. Tees was caught in traffic.
(4) Mr. Tees arrived 30 minutes late to the airport.
(5) Mr. Tees' flight was delayed by 25 minutes.
(6) Mr. Tees was accompanied by Mr. Crane, who was also 30 minutes late but whose flight was not delayed.

Running the reasoning mechanism off-line on the basis of these inputs produces a *base representation*. The base representation will include first-person translations of facts (1)–(6), as well as, due to the ampliative power of simulation, the additional fact(s) "I am upset because I just missed the flight" and perhaps "I am more upset than Mr. Crane, who did not *just* miss his flight." Next, these additional facts are projected back onto the initial target representation, producing the *final target representation*. The final target representation will include facts (1)–(6) plus the third-person translation of those fact(s) carried over from the base representation. Lastly, it is likely that the simulator will analyze the fit of the projection.

Based on the above analysis of the simulation heuristic, there are several junctions at which the base and target psychological representations are juxtaposed, aligned, and mapped. I discuss three of these opportunities below and demonstrate their impact on the development of (information-inclusive) folk-psychological theory.

3.3.1. Generating the base representation from the initial target representation

The role of belief and desire inputs (often "pretend" inputs) and how they are "fed into" the practical reasoning mechanism has received limited attention in the literature on off-line simulation. The process is often assumed as automatic and unproblematic.[20] But a little reflection reveals that the inputs for simulation cannot be fed into the practical reasoning mechanism in just any sort of way. Specifically, the input process must preserve relationships that the inputs bear to one another. When I place myself in the shoes of Mr. Tees, I form a desire to make my flight, a belief that the flight was delayed, a belief that I was stuck in traffic, etc. But this list leaves out important relationships among the inputs that I must also replicate. I must replicate: the late airport arrival as occurring *after* the period of traffic; the late arrival as *caused* by the traffic delay (and not, say, the company of Mr. Crane); the desire to make the flight on time as *persisting* through the traffic and airport arrival; and so on. A structured "initial target representation," coded with information about relations between propositions, is needed to guide the input process during simulation.

There are two basic ways that the input process can receive this guiding structure. First, the simulator can already possess various (information-inclusive) bodies of knowledge with built-in normative expectations for the ordering of inputs. For example, a person's traffic-script will likely encode a late arrival as occurring after a traffic delay. Another way inputs become ordered is when individuals are guided by an external script. People who read (CrT) are *given* a script that already encodes relations between the propositions of (CrT), and they generate relations between pretend inputs because they possess a general ability to process external scripts. That is, readers of (CrT) generate and feed pretend beliefs and desires into their practical reasoning system according to the order and logic that is presented in the (CrT) script. In either case, it is more accurate to say that simulators feed structured units—a "pretend schema," a "pretend script," or more generally "an initial target representation"—into their practical reasoning system. Cursory reference to "feeding pretend beliefs and desires" misses this important fact.

These considerations help provide an analysis of what it could mean to "step into the shoes" of another, or try to understand them "from the inside." In order to produce a base representation of what we would do in a certain situation, simulators must map an initial target representation (e.g., of Mr. Tees) onto a representation of their occurrent subjective reality, and this mapping process must be guided by either internally or externally stored relational information. What is important from a developmental perspective is that this process will invoke the learning principles of structure-mapping theory: aligning third-person and first-person representations will promote relational information that is important to the formation of theoretical generalizations. For example, the identity of oneself and a familiar airport (encoded at the object-level in the base representation) and the identity of Mr. Tees and his airport (encoded at the object-level in the target representation) are epistemically demoted, while the deeper relation that connects these items—the relation between people and goals—is epistemically promoted.

3.3.2. Projecting new predicates from the base representation onto the final target representation

Of course, the *point* of mapping an initial target schema onto one's representation of what is now happening to oneself is to allow one's practical reasoning system to operate on this information in order to produce further beliefs, desires, and intentions. This is the ampliative step of simulation in which one exploits one's own decision-making mechanism in order to produce an interpretation of the target. In the case of (CrT), the decision-making system might issue the further belief, "I am upset that I *just* missed my flight," and perhaps, "I am more upset than Mr. Crane, who did not *just* miss his flight." Propositional attitudes and intentions that are generated through simulation will complete the base representation.

The final phase of the off-line simulation heuristic involves projecting the results of simulation back onto the target. This step requires mapping the now complete base representation back onto the initial target representation, producing the final target representation. This process, much like that discussed above, reflects what Gentner terms "projective analogy," in which individuals carry over information from one representation to another. According to SMT, this step involves the same basic process of alignment and mapping—a process "which causes the matching aspects of the domains to become more salient" (Gentner, 2005, p. 255). Given our built-in preference for relational commonalities constrained by higher-order relations (e.g., causal relations), this projective step of the simulation process will further highlight the relational structures of folk-psychological theory.

Consider the folk generalization G^*, which contains the theoretical clause: "people who believe they came close to attaining their goal but fail to meet that goal become upset." The SMT construal of the simulation heuristic predicts that simulators who engage the mapping processes discussed above will develop this piece of theory. Note that the clause makes no reference to object-level predicates such as "flight," "traffic," or "Mr. Tees." Rather, it consists of relational categories that are multiply realized at the object level. For instance, just about anything could be a goal because goals are defined by their role in more general relational systems that consist of people and desires. Mapping representations that encode object-level instantiations of a relational schema will, as discussed in section 3.2, induce a focus on the underlying relations that compose that schema, and this is precisely what happens as simulators map an initial target representation onto a base representation, and then map a completed base representation back onto the target representation. By making the relatively easy self–other alignments required by the "pretend inputs run off-line" and "projection" stages of simulation, simulators are *progressively aligning* the underlying relational structure of these representations via the guidance of the systematicity constraint. This principle, recall, promotes relations that are components of a larger system of relations. This principle then predicts that through progressive alignment simulators will focus on the higher-order relation: CAUSE [coming close but failing (persons, goal), more upset than (person's current emotional state, person's prior emotional state)].

3.3.3. Checking the fit between base and target analogues

Research has shown that individuals often analyze and/or tinker with the results of an analogical mapping, particularly when there is a need to improve the match (see Gentner et al., 1997, p. 9; Gick & Holyoak, 1983). This process can induce re-representation and lead to the abstraction of a common schema. After the projective step of simulation, individuals will often assess the fit of their projection. Simulators could ask, "Does the fact that Mr. Tees is upset comport with all available evidence?" If there is some mismatch between the simulator's state and Mr. Tee's apparent state (e.g., if one had never been to an airport, and instead used a schema about bus stations to run the simulation) then re-representation of the base and target analogues is likely. This would require comparing the base representation and the final target representation and focusing on some relational commonality (e.g., comparing the predicates "airport" and "bus station" and focusing on their status as goal destinations). This suggests a further opportunity for individuals to invite mutual alignment of psychological representations and abstract relational commonalities.

The above analysis demonstrates how simulators can align structured psychological representations during the prediction of inference and choice. While these alignments are relatively easy and supported by object-level matches, they enable the progressive alignment of relational structures that are more deeply explanatory of human psychology and behavior but were unnoticed prior to simulation. The account also predicts that similar structural alignments occur when simulation is used for other types of mindreading tasks. While it is outside the scope of this paper to examine further applications of structural alignment to simulation (but see the discussion of pretense in section 3.5.2), I hope that future research can explore this issue.

3.4. Development Reconsidered

The SMT dynamic hybrid does not presuppose that adult mentalizing consists in a set of default strategies. A guiding assumption here is that various forms of mentalizing—belief attribution, desire attribution, inference prediction, etc.—are "multiply realized" by both simulation and theory, and which heuristic is preferred is largely a function of the individual's developmental status. The case for this thesis is clearest when we consider the theoretical deployment of fine-grained schemas such as G^*. Returning to the (CrT) example, the *reason* that the simulation account seems more likely is that most people do not adequately possess the theoretical schema G^*. However, it is clearly possible to learn the schema. In fact, it would not be surprising if certain airport employees tacitly possessed something like G^* on the basis of their past experience.

So far we have focused on the simulation-to-theory direction of folk-psychological development. However, the structure-mapping framework has important implications for the theory-to-simulation direction as well. Several leading simulation theorists emphasize that simulation is particularly well suited for situations in which one already knows some psychological facts about a target and then wants to find out what further psychological facts follow on their basis.[21] Identifying these initial psychological facts is an important aspect of constructing initial target representations. While this task was relatively easy for the simulation of Mr. Tees (because we were given a script, and because the simulator has a default desire to make flights on time) it is clear that other cases—especially those for which our desires/beliefs do not naturally align with those of the target—require additional mentalizing effort and skill. According to the co-dependency thesis (section 2.1), folk-psychological theory will often facilitate the identification of initial propositional attitudes. I propose a dynamic modification of the co-dependency thesis: the psychological theories used to identify these initial propositional attitudes are often theories, or knowledge structures, that were abstracted from previous simulations. For example, there is no *prima facie* reason for why airport employees who have abstracted G^* on the basis of prior simulations could not use this bit of folk theory when constructing initial target representations for future simulations.[22] Assuming that these simulations also involve structural alignments, we can predict that simulators will abstract a *further* bit of theory—call it G^{**}—that has distinct structural features as a result of the structurally distinct initial target representation from which it was progressively aligned. Now, G^{**} can be used towards the construction of future initial target representations . . . and so on.

The claim that folk-psychological development is driven by a dialectical interplay between simulation and theory helps unify two areas of empirical research. As reviewed in section 2.4, there is evidence that adult folk-psychological skill improves as a result of social experience. The considerations advanced here indicate a mechanism—the dynamic between simulation and theory—which explains the relationship between social experience and improved mindreading skill. Of course, other candidate mechanisms may be available for this explanatory purpose. Gopnik and Schulz would likely argue that adults construct increasingly accurate causal Bayes maps as a result of social experience. But the dynamic explanation on offer is particularly compelling because it receives independent support from a second area of research, namely SMT's account of the development of domain-specific knowledge.

In several studies (Forbus et al., 1998; Gentner et al., 1995, 1997), Gentner and colleagues cogently argue that theoretical knowledge is a result of domain experience rather than a global change (e.g., increased processing speed), and also that the *way* in which experience develops domain knowledge is by prompting structural comparisons (see section 3.2). But where, within social-cognitive experience, do individuals encounter comparison opportunities? The proposed dynamic model answers this question by construing simulation itself as a naturally occurring comparison opportunity for which representational resources are continually updated as a result of prior simulations.

These claims have testable implications. Gick and Holyoak (1983) demonstrated that subjects were more likely to learn a general problem-solving schema when they compared two domain-specific instantiations of the schema than when they were directly told the schema and given only one instantiation. This paradigm suggests a possible test for the simulation-to-theory direction of development and the abstraction of the G^* schema. The SMT dynamic hybrid predicts that subjects who are directly told G^* and given one instantiation of G^* will be less successful at transferring G^* than subjects who are induced to simulate Mr. Tees.[23] The proposed hybrid also suggests some novel parameters to investigate in connection with the developmental dynamic between simulation and theory. Divided-hybrid models determine mindreading habits for general folk-psychological categories such as inference prediction, or generic domains such as the valuing/buying/selling of items. In contrast, the SMT dynamic hybrid abstracts away from folk-psychological categories/domains and instead seeks an understanding of what developmental factors influence the selection of stored folk-psychological schemas versus use of the simulation heuristic. One candidate hypothesis is that the use of folk-psychological schema will bear less cognitive load, or consume less working memory, than running a simulation. For instance, if you are asked a question that is analogous to the Mr. Tees and Mr. Crane example, and you have understood the G^* schema, it is unlikely that you will bear the cognitive load required to arrive at the answer through simulation. This and similar parameters might be considered in balance with pragmatic considerations such as the *force* versus *scope* of the sought after generalization (see Griffiths, 1999). If one's mentalizing goals require an explanation or prediction with high precision but little generality, it is less likely they will already possess the corresponding fine-grained schema.[24]

3.5. Structure-Mapping and the Development of Folk-Psychological Concepts

In this section I extend the application of structure-mapping in order to sketch an explanation for the mastery of mental concepts such as BELIEF and DESIRE.

Accounts of learning are seriously challenged by children's acquisition of relational categories. Research shows that object categories are understood earlier than relational categories, and first-order relations prior to higher-order relations. A relational category is one whose members are united on the basis of relational properties rather than intrinsic properties.[25] Relational categories are further subdivided between "relational role categories" and "relational schema categories" (Gentner, 2005, p. 246). The former (*thief*, *predator*, *president*) consist of category members that play the same role in a relational schema. The latter (*robbery*, *ecosystem*, *democracy*) are relational systems defined by an internal relational structure. In order to negotiate the *relational shift* children must represent those relational structures that are definitive of relational categories. The object-category *apple*, for instance, is understood on the basis of salient, typically intrinsic, similarities (e.g., shape). In contrast, because members of the relational category *gift* can be realized by just about any object, identifying something as a gift requires grasp of the more conceptually complex relational schema of gift-giving.

The research of Gentner and colleagues shows how structure-mapping processes account for the relational shift. These learning processes (progressive alignment and re-representation) are prompted in two different contexts:

(1) *Symbolic juxtaposition*: during language learning, common labels serve to symbolically juxtapose objects and induce relational comparisons.
(2) *Spatio-temporal juxtaposition*: through domain experience, the spatio-temporal juxtaposition of objects/events causes "natural," relational comparisons.

While there is little consensus concerning the metaphysical properties of "beliefs" and "representations," most agree these terms designate relational categories *par excellence*. Not surprisingly, researchers have struggled to develop an account for how these concepts are understood and have instead focused on the timing of their development according to children's performance on false-belief tasks.[26] In the next two sections I explore how symbolic and natural comparison opportunities can promote children's grasp of relational, psychological categories.

3.5.1. Symbolic juxtaposition and the belief concept

A series of studies by de Villiers and colleagues shows that individuals with little access to embedded sentential complements (e.g., "Sally thinks that her room is messy") have considerable difficulty with false-belief tasks (de Villiers, 2000). Complement structures are syntactically unique because their embedded propositions can be false yet the sentence true. Because false-belief tasks contrive a similar disparity in truth-values, it is not surprising that exposure to sentential complementation might correlate with possession of the belief concept. In order to explain this correlation, de Villiers claims that children first learn from overt evidence that the embedded "says-that" complement can be false and then reason analogously to the (structurally equivalent) "think-that" complement form, which provides the conceptual resources needed to pass the false-belief task.

I think the theory of structure-mapping helps further explain the developmental relationship between syntactic form and folk-psychological skill. According to the thesis of symbolic juxtaposition, providing a common label for multiple items will induce comparisons that privilege relational content over perceptual content. For example, labeling various cutting devices a "blick" across different contexts invites children to perform structural comparisons that result in the abstraction of a relational category (see Gentner, 2005, p. 261, for a description of this experiment). However, symbolic juxtapositions are not limited to relational nouns. Comparing entire sentences can also highlight the relational structures of grammatical constructions (Fisher, 2000; Gentner & Namy, 2004, pp. 557–559). If certain grammatical constructions have an underlying structure that is similar to or equivalent to the structure of belief contexts, then comparing these sentence forms should result in the abstraction of relational content that is definitive of belief.

My speculation is this: the sentential complement form serves as a label for the logical structure which underlies a ‘‘belief schema’’ or a ‘‘belief–desire schema’’:

> *CAUSE [Possession (person, desire and belief with content P), acting (person, P's referent)]*

This schema, which centralizes the causal relationship between mental representation and behavior, informs success on the false-belief task.[27] Its subcomponents (e.g., *belief*) are then defined by their relational roles within the schema (in the same way that *gift* is defined by its relational role in the *gift-giving* relational schema). If children are induced to compare syntactic structures that are structurally analogous to the belief schema, then the systematicity constraint will dictate a focus on, and progressively align, explanatorily important higher-order relations (relations that constrain other relations) of this logical form. Now, consider that the relationship between an agent and the belief *that P* is a component in a larger system of belief–desire–behavior relations. On the other hand, because agents act on the basis of their representations rather than the actual correspondence (or lack of correspondence) of those representations, the relationship between propositional content *P* and the world (e.g., corresponding vs. noncorresponding) is not part of this interconnected system. Put differently: the relationship between an agent and the belief *that P* constrains the relationship between agent and object-directed behavior (in the same way that the attraction relation constrains the revolving relation in the Rutherford analogy), but the relationship between propositional content *P* and the world does not constrain the relationship between agent and object-directed behavior (much like the relation *hotter than* that is neglected in the Rutherford analogy). Ability to favor the former (constraining) relation is precisely what is measured on false-belief tasks. The thesis of symbolic juxtaposition helps explain this learning achievement if children who are exposed to sentential complementation progressively align the higher-order relation that is essential to the belief–desire schema.

3.5.2. Spatio-temporal juxtaposition and the belief concept

Children's nonlinguistic environment provides opportunities for relational comparison when object or event pairs are either copresent or contiguous. For example, a child's repetitive act of knocking-over and reassembling a block tower (Gentner, 2005, p. 259) is a source of comparison-based learning. I propose that children's activity of pretense, and in particular pretend role-play, provides them an opportunity to naturally encounter and compare psychological representations.

Several leading researchers agree that pretend role-play is a form of mental simulation (Gordon, 1995; Harris, 2000; Lillard, 2001). On this view, when children pretend to be a pirate they ''put themselves in the shoes'' of the pirate and then behave accordingly. An important motivation for this account is its explanation of folk-psychological development. Numerous studies indicate that children's level of pretend role-play correlates with success on the false-belief task (Harris, 2000, pp. 42–45; Lillard, 2001, p. 521). Simulation theorists explain this developmental correlation by claiming that role-play is a type of practice in simulative flexibility (Harris, 2000). While young children are prone to ''total projection'' of their own perspective during simulation (Gordon, 1992), five-year-olds who are practiced in the art of simulation through role-play possess enough simulative flexibility to pass the false-belief task. Critics respond that imaginative flexibility, a type of know-how, is not the same as possession of a (belief) concept, which is a type of know-that (Leslie & German, 1995). Critics also point out that the projective step of simulation requires prior possession of a theoretical understanding of the ascribed mental state (Fuller, 1995).

The SMT framework offers a solution to this impasse and suggests how simulation and theory dynamically interact during role-play in order to develop the belief concept. According to the simulation model of role-play, when children pretend to be a pirate ''an initial step is to imagine the situation that the pirate is currently in and to adopt—in a pretend fashion—the attitude that someone might adopt toward that situation'' (Harris, 2000, p. 35). The attitudes of a pirate include wanting treasure, wanting to plunder, and so forth. These desires are not, I assume, the default or natural desires of a child. Nor are they prompted by the child's external environment. This is because there is no *actual* village, ship, or treasure at which the child can direct attention, and also because the imaginary identity of these objects typically follows from the prior stipulation that one is a ''pirate.'' This indicates that the child must generate pretend ''pirate-desires'' that will serve as inputs for the reasoning system. In order to do so, they must first identify these desires and then adopt them as their own in pretend fashion. This psychological process corresponds to the activity of constructing an initial target representation and then mapping this representation onto a subjective base-representation. The implications of this activity for the development of folk-psychological theory were described in section 3.3.1. However, the theory-to-simulation direction of folk-psychological development is particularly important in this context. As discussed in section 3.4, the developmental effect of structure mapping is constrained by the structure of the aligned representations. The structure of these representations, in turn, is constrained by the simulator's (role-player's) antecedent knowledge. It is essential to determine, then, the type of cognitive-behavioral theory that is available to children during role-play.

Children begin role-play at 2 years (Harris, 2000). Numerous studies indicate that children under the age of 4 possess the desire-schema, or some other less explanatory/predictive version of whatever schema is central to a mature folk psychology. This implies that a child's representation of a pirate's (or bus-driver's, or parent's) situation, which they will map onto themselves during pretense, is encoded by the desire schema (or the desire–belief schema). Given the ampliative principles of SMT, the implication is that repeated experience in the alignment of instantiations of these schemas during role-play will eventually highlight deeper and more explanatory cognitive-behavioral structures (e.g., the belief–desire schema). In addition, many instances of role-play include a prop that carries out a role. This form of role-play will involve the projective step of simulation (section 3.3.2). Consider a 3-year-old who pretends that a doll "wants her mommy" (Harris, 2000) and then brings the doll to the location of "mommy." Plausibly, such a child will project her own desire for mommy, and also the belief that mommy is in the yard, onto the doll. This suggests a further respect in which role-play can serve as a vehicle for the spatio-temporal juxtaposition, and thereby representational alignment, of folk-psychological structures.

These considerations help reconcile the ST intuition that simulation is central to the correlation between role-play and success on the false-belief task and also the TT objection that simulative know-how does not equate to a psychological concept. The reason that role-play *qua* simulation is a valuable form of mentalizing experience is because it provides opportunities for the comparison of cognitive-behavioral representations. The SMT theses of progressive alignment and re-representation predict that these comparisons will facilitate the theoretical transition from a desire-based folk-psychological schema to a representation-based folk-psychological schema.

4. Conclusion

Hybrid models of folk psychology are needed to understand the nonnegotiable contributions of both metarepresentational knowledge structures and the process of mental simulation. However, it is not enough to depict dependency relations, or to attribute default uses of simulation and theory across various folk-psychological categories. Such hybrids, while not unimportant, are best seen as the product of concessions made by two opposing sides of a formerly winner-takes-all debate. In contrast, a more natural hybrid is one in which the development and value of each capacity is promoted by the other, resulting in a type of dialectical interaction that drives the ongoing development of mentalizing skill. I argued that a dynamic hybrid of this sort follows from a proper understanding of the process of simulation. If simulation involves the juxtaposition and alignment of two psychological representations, then the theory of structure-mapping predicts that metarepresentational schema will be spontaneously abstracted. In addition to the development of folk-psychological schema, I suggested that structure-mapping could also promote the acquisition folk-psychological concepts. These claims have testable implications and point towards clearly defined areas of empirical research.

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Notes

[1] "The original controversy between the two camps, based on all or none positions, muscled empirical evidence from social and developmental psychology. These theoretical positions, however, turned out to be too flexible to be constrained by the available evidence" (Perner & Kühberger, 2005, p. 174); "Many writers, ourselves included, began to characterize debates over the plausibility of these new accounts as part of a two-sided battle in which either simulation theory or the 'theory theory' (a term used for all information-inclusive accounts) would "win". Though understandable enough in the context of those early debates, this proved to be a very unfortunate way of characterizing the theoretical landscape, since it ignored the theoretical possibility that the correct account of mindreading might be provided by a hybrid theory . . . " (Nichols & Stich, 2003, p. 132); "attempts by one perspective to best the other in a winner-takes all competition all but ignored the possibility that both strategies might be used or that other strategies might be in play" (Malle & Hodges, 2005, p. 2); "The study of mentalizing requires less debate about what may be a false dichotomy between simulation and theory theory and increased focus on the different circumstances in which observers flexibly deploy one or the other process to understand the minds of others" (Mitchell, 2005, p. 363); " . . . contrary to traditional wisdom, simulation and theory need not compete with one another" (Goldman, 2006, p. 43).

[2] More "monolithic" versions of TT include the child-scientist and modular views. Supporters of the child-scientist view claim that folk-mentalizing skill is the product of domain-general learning mechanisms. These mechanisms develop and deploy psychological theories that have the same structural and functional properties as theories in scientific discourse (e.g., appeal to unobservable entities, predictive and explanatory power, causal generalizations), and which undergo the same type of theoretical change as theories in scientific discourse (e.g., experimentation, defeasibility, adjustment to counterevidence). Supporters of the modular approach agree that folk mentalizing is a theoretical competence but, reacting to developmental evidence such as selective impairment of mentalizing skill in autistic individuals, argue that folk mentalizing is a domain-specific skill that results from the coming on-line of cognitive modules. Note that the information-inclusive model of TT is consistent with, and may subsume, certain claims made by both the child-scientist and modular views.

[3] See Gopnik and Meltzoff (1997, pp. 59–68) for a fuller discussion of the "nontheoretical" properties of these knowledge structures.

[4] The belief–desire law states that "people do what will satisfy their desires." Besides the difficulty with required ceteris paribus clauses, this rare example of a psychological law has also been challenged—see Gauker (2005).

[5] This is not to say that the use of a model aircraft to simulate an actual aircraft is completely devoid of theory. The important point is that key predictions of the actual aircraft follow from the simulation and are not deducible from the preexisting theory that informed the construction of the model and experimental setup. See Heal (1996a) for a fuller discussion of this example and its nonthreatening dependence on theory. In the next section I provide a more detailed analysis of these "trivial" ST–TT interactions, as I term them, and suggest that more interesting interactions lie elsewhere.

[6] Several motivations for a hybrid theory are not discussed here. In particular, one important factor that has encouraged a simulation–theory mix is the increasingly broader conception of what practices should be subsumed under the label "folk psychology." Many researchers now count gaze-following and emotional-state recognition as important mentalizing practices.

[7] Now, this does not demonstrate that it is also obvious that we wield nomological generalizations in psychological interpretation. However, given the developmental link between script, schema, and nomic theory, it shifts the burden of proof onto those who

assert that explanatorily robust theories have no role in folk psychology. It seems uncontroversial that psychiatrists make predictions and explanations on the basis of explanatorily robust theories. While this may not represent an instance of *folk* psychology, it at least demonstrates the use of nomological theory in the interpretation of intentional agents.

[8] Specifically, the evidence has led researchers to appeal to the following explanatory strategy: (1) identify a cognitive process *P* subserved by neural substrate *N* for veridical representation/activity *R* (e.g., visual perception); (2) based on neuroscientific data, argue that the mimicry or simulation of *R*, (*R**), also exploits process *P* and is subserved by and neural substrate *N*.

[9] This is not an obvious example of *off-line* simulation. Nonetheless, the example has been historically important in suggesting how simulation can be a more simple explanation than theory. I thank an anonymous referee for this point.

[10] Additional co-dependencies between simulation and theory might include exploiting a theory in order to select the correct psychological reasoning mechanism to be run off-line (if there are several), or exploiting a theory that determines how and when inputs should be fed into the selected system (Goldman, 2006, p. 44). The special case of retrodictive mindreading, where one infers mental causes on the basis of their observed behavioral effects, may also require theory in order to generate different hypotheses that are then tested through simulation (Goldman, 2006, p. 45).

[11] Several other commentators have also noted the persistence of the simulation–theory contrast even when various implementation and/or cooperative relations between ST and TT are regarded as uncontroversial. For discussion see Heal (1996a).

[12] The assumption of a nondevelopmental framework for adult folk-psychological cognition can manifest in more subtle forms. Common use of thought experiments are designed to induce an introspective focus on mindreading contexts during which developmental considerations are ignored. For example, Harris (1992) asks us to imagine confronting a shadowy figure in an alley. But, the reader implicitly understands that they are supposed to filter out any contextual or historical fact that could influence their developmental relation to this event (i.e., do they know the alley well? Have they been mugged before? Are they trained for this situation? And so on.).

[13] But see Mitchell, Currie, and Ziegler (2009) for a recent paper that grants an expanded role to development in the relationship between simulation and theory.

[14] Piaget's formal operations approach to cognitive development has played an important role in promoting this traditional bias. See Fischer, Yan, and Stewart (2003) for a critical comparison between Piagetian "ladder development" and the more recent "developmental web" approach.

[15] A recent fMRI study (Blakemore et al., 2007) indicates that adolescents (aged 12.1–18.1 years) use anterior regions to think about intentional causality (recruiting more of their medial prefrontal cortex) while adults (aged 22.4–37.8 years) rely on posterior regions (recruiting more of their superior temporal sulcus) when thinking about intentional causality.

[16] See Goldman (2006, pp. 83–87) for criticism of the application of the causal Bayes net account of learning to the domain of mentalizing.

[17] Importantly, children were not given feedback on their performances.

[18] Gentner and colleagues have operationalized relational comparison with the "Structure-Mapping Engine" (SME). SME is a real-time mechanism that simulates how the brain might start with isolated "kernels" of knowledge and, through a local to global mapping process, arrive at deeper relational structures. See Falkenhainer et al. (1989) for discussion.

[19] There are several different ways to construe the structure of the initial target representation. According to the co-dependency thesis, the use of theory will often determine the amount and content of structure. I further discuss this point in section 3.4.

[20] An important exception is the simulation theorist's explanation of egocentric bias, or the "curse of knowledge" (for discussion, see Birch & Bloom, 2004), during simulation. Goldman (2006) explains the bias in terms of "input inadequacy" and then explains input inadequacy in terms of either an "excess" or "deficiency" of inputs (p. 174). But as I argue in this section, it is essential to also consider the structural and theoretical relationships between the inputs. For example, it is possible to have the correct number of inputs (satisfying Goldman's constraint) but fail to represent accurate relationships between them.

[21] See especially Heal (2003) where she claims that simulation is "particularly at home, its strengths and plausibility particularly apparent" (p. 31) when mentalizers "come to some prediction or further belief about another's thoughts on the basis of knowledge of some subset of her thoughts" (p. 32).

[22] Here is an example. Suppose an airport employee has considerable experience dealing with customers who have just missed delayed flights. Through prior simulation of these customers she has abstracted G^* and is able to successfully transfer this schema to other domains. Now suppose the employee's daughter has applied to Prestigious University, which has a strict policy that all students must score at least 2100 on the SAT. Her daughter scores a 2090. When using simulation to predict her daughter's desires (will her daughter want to be alone? Or visit her favorite restaurant? Or immediately prepare for a re-take of the exam?), it would be mysterious, if not irrational, if she did not use G^* in order to characterize her daughter's initial situation—if she did not simulate her daughter on the basis of an initial target representation which encoded her as upset, and more upset than she would have been had she missed the 2100 cut-off by 360 points.

[23] In addition, it is plausible that the research paradigm used by Gentner and colleagues to test progressive alignment (see Figure 1, section 3.2) can be applied in this context. Specifically, it could be used to demonstrate how the theoretical structure of aligned representations with psychological content constrains the theoretical structure of abstracted representations. It is also possible to test these predictions with SME (see n. 18).

[24] The proposed dynamic-hybrid also comports with current evidence demonstrating a developmental symmetry between self-knowledge and third-person psychological knowledge (see Gopnik & Meltzoff, 1997; Nichols & Stich, 2003). The SMT dynamic hybrid does *not* require the simulator to first understand the principles that govern their practical reasoning system, and then project these principles onto the target. As such, it is consistent with the argument from parsimony that motivates ST. Knowledge of the principles that govern the practical reasoning system—for instance the "belief–desire law," or the G^* schema—emerge simultaneously in terms of their application to oneself and to others. This follows directly from the claim that the newly learned schemas are relational *abstractions* from a juxtaposed self-representation and other-representation.

[25] Relational categories and object categories are not mutually exclusive. Object categories defined on the basis of intrinsic similarities can also be represented as containing relational information.

[26] Several researchers (e.g., Keil, 1994) identify relational category knowledge with innately specified abilities, and the modularity variation of TT is an instance of this strategy. In contrast, TT researchers who privilege general learning mechanisms have recently argued that the relational categories of folk psychology are understood through the construction of causal Bayes maps. However, this hypothesis has yet to be tested for the domain of mentalizing and is still highly speculative in its application to causal relationships in general. The theory of structure-mapping, while also insisting on the importance of domain-general learning mechanisms, suggests an empirically supported alternative.

[27] See Bartsch and Wellman (1995). The belief–desire schema contrasts with the more primitive "desire-schema"—*CAUSE (internal drive, objected directed behavior)*—which does not encode a causal relationship between possession of false belief and behavior. Bartsch and Wellman also posit a "desire–belief psychology" as an intermediary theory. As was pointed

out by an anonymous referee from this journal, children's possession of the desire schema may not explain the results of certain experiments (e.g., the deceptive box test). While the dynamic hybrid on offer holds that simulation is a developmental complement to the "conceptual-change" approach to folk-psychological development (see Wellman, Cross, & Watson, 2001, pp. 677–678), it is not committed to any specific candidate model of conceptual-change. Rather, it is committed to there being one or several folk-psychological structures that are developmentally prior to the structures that inform success on the false-belief task, and that representational alignments of instantiations of the former will highlight the theoretical structure of the latter. The exact natures of these schemas are a matter of empirical discovery. It is also worthwhile to mention here the claim, typically advanced by modularists, that early failure on the false-belief task is caused by performance errors (e.g., inhibitory control, executive function) rather than conceptual errors. However, in their metaanalysis of false-belief task studies, Wellman et al. (2001) conclude that data on performance errors is consistent with the conceptual-change account. Scholl and Leslie (2001) agree that the meta-analytic data is compatible with the conceptual-change explanation but point out that it is also consistent with a performance-change explanation. Recent studies (e.g., Onishi & Baillargeon, 2005) which purport some form of false-belief reasoning in young infants further complicate this theoretical stand-off, with conceptual-change theorists such as Perner (e.g., Ruffman & Perner, 2005) arguing that the infants in these studies are not in fact responding to false beliefs. This remains an open debate.

References

Ashby, F. G., & O'Brien, J. B. (2005). Category learning and multiple memory systems. *Trends in Cognitive Sciences*, *9*(2), 83–89.

Bartsch, K., & Wellman, H. M. (1995). *Children talk about the mind*. New York: Oxford University Press.

Birch, S., & Bloom, P. (2004). Understanding children's and adult's limitations in mental state reasoning. *Trends in Cognitive Sciences*, *8*, 255–260.

Blakemore, S., den Ouden, H., Choudhury, S., & Frith, C. (2007). Adolescent development of the neural circuitry for thinking about intentions. *Social Cognitive and Affective Neuroscience*, *2*, 130–139.

Churchland, P. (1988). *Matter and consciousness*. Cambridge, MA: MIT Press.

Davies, M., & Stone, T. (1996). The mental simulation debate: A progress report. In P. Carruthers & K. Smith (Eds.), *Theories of theories of mind* (pp. 119–140). Cambridge: Cambridge University Press.

Decety, J., & Ingvar, D. H. (1990). Brain structures participating in mental simulation of motor behavior: A neuropsychological interpretation. *Acta psychologica*, *73*, 127–134.

de Villiers, J. (2000). Language and theory of mind: What are the developmental relationships? In S. Baron-Cohen, H. Tager-Flusberg, & D. Cohen (Eds.), *Understanding other minds: Perspectives from developmental cognitive neuroscience* (2nd ed., pp. 83–123). Oxford: Oxford University Press.

Dixon, J., & Bangert, A. (2004). On the spontaneous discovery of a mathematical relation during problem solving. *Cognitive Science*, *28*(3), 433–449.

Falkenhainer, B., Forbus, K. D., & Gentner, D. (1989). The structure-mapping engine: Algorithm and examples. *Artificial Intelligence*, *41*, 1–63.

Fischer, K., Yan, Z., & Stewart, J. (2003). Adult cognitive development: Dynamics in the developmental web. In J. Valsiner & K. Connolly (Eds.), *Handbook of developmental psychology* (pp. 491–516). Thousand Oaks, CA: Sage.

Fisher, C. (2000). From form to meaning: A role for structural analogy in the acquisition of language. In H. W. Reese (Ed.), *Advances in Child Development and Behavior* (Vol. 27, pp. 1–53). New York: Academic Press.

Fodor, J. (1987). *Psychosemantics: The problem of meaning in the philosophy of mind*. Cambridge, MA: MIT Press.

Forbus, K. D., Gentner, D., Markman, A. B., & Ferguson, R. W. (1998). Analogy just looks like high level perception: Why a domain general approach to analogical mapping is right. *Journal of Experimental and Theoretical Artificial Intelligence*, *10*, 231–257.

Fuller, G. (1995). Simulation and psychological concepts. In M. Davies & T. Stone (Eds.), *Mental simulation: Evaluations and applications* (pp. 19–32). Oxford: Blackwell.

Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences*, *2*, 493–501.

Gattis, M. (2002). Structure mapping in spatial reasoning. *Cognitive Development*, *17*, 1157–1183.

Gauker, C. (2005). The belief–desire law. *Facta Philosophica*, *7*, 121–144.

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

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

Gentner, D., Brem, S., Ferguson, R., Markman, A. B., Levidow, B., Wolff, P., & Forbes, K. D. (1997). Analogy and conceptual change: A case study of Johannes Kepler. *The Journal of the Learning Sciences*, *6*, 3–40.

Gentner, D., & Kurtz, K. (2006). Relations, objects, and the compositions of analogies. *Cognitive Science*, *30*, 609–642.

Gentner, D., & Medina, J. (1998). Similarity and the development of rules. *Cognition*, *65*, 263–297.

Gentner, D., & Namy, L. (2004). The role of comparison in children's early word learning. In D. G. Hall & S. R. Waxman (Eds.), *Weaving a lexicon* (pp. 533–568). Cambridge, MA: MIT Press.

Gentner, D., Rattermann, M., Markman, A., & Kotovsky, L. (1995). Two forces in the development of relational similarity. In T. J. Simon & G. S. Halford (Eds.), *Developing cognitive competence: New approaches to process modeling* (pp. 263–313). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology*, *15*, 1–38.

Goldman, A. (2006). *Simulating minds*. Oxford: Oxford University Press.

Gopnik, A., Glymour, C., Sobel, D., Schulz, L., Kushnir, T., & Danks, D. (2004). A theory of causal learning in children: Causal maps and Bayes nets. *Psychological Review*, *111*(1), 1–31.

Gopnik, A., & Meltzoff, A. (1997). *Words, thoughts, and theories*. Cambridge, MA: MIT Press.

Gopnik, A., & Schulz, L. E. (2004). Mechanisms of theory-formation in young children. *Trends in Cognitive Sciences*, *8*, 371–377.

Gopnik, A., & Wellman, H. (1992). Why the child's theory of mind really *is* a theory. *Mind & Language*, *7*, 145–171.

Gordon, R. (1992). The simulation theory: Objections and misconceptions. *Mind & Language*, *7*, 158–171.

Gordon, R. (1995). Folk psychology as simulation. In M. Davies & T. Stone (Eds.), *Folk psychology: The theory of mind debate* (pp. 60–73). Oxford: Blackwell.

Gordon, R. (1996). "Radical" simulationism. In P. Carruthers & K. Smith (Eds.), *Theories of theories of mind* (pp. 11–21). Cambridge: Cambridge University Press.

Griffiths, P. E. (1999). Squaring the circle: Natural kinds with historical essences. In R. A. Wilson (Ed.), *Species: New interdisciplinary essays* (pp. 209–228). Cambridge, MA: MIT Press.

Happé, F., Winner, E., & Brownell, H. (1998). The getting of wisdom: Theory of mind in old age. *Developmental Psychology*, *34*, 358–362.

Harris, P. (1992). From simulation to folk psychology: The case for development. *Mind & Language*, *7*, 120–144.

Harris, P. (2000). *The work of the imagination*. Oxford: Blackwell.

Hartley, T., & Burgess, N. (2005). Complementary memory systems: Cooperation, competition, and compensation. *Trends in Neurosciences*, *28*, 169–170.

Heal, J. (1996a). Simulation and cognitive penetrability. *Mind and Language*, *11*(1), 44–67.

Heal, J. (1996b). Simulation, theory, and content. In P. Carruthers & K. Smith (Eds.), *Theories of theories of mind* (pp. 75–89). Cambridge: Cambridge University Press.

Heal, J. (2003). Understanding other minds from the inside. In *Mind, reason, and imagination: Selected essays in philosophy of mind and language* (pp. 28–44). Cambridge: Cambridge University Press.

Hess, T. (2006). Adaptive aspects of social-cognitive functioning in adulthood: Age-related goal and knowledge influences. *Social Cognition*, *24*(3), 279–309.

Hess, T., Osowski, N. L., & Leclerc, C. M. (2005). Age and experience influences on the complexity of social inferences. *Psychology and Aging*, *20*(3), 447–459.

Jackson, F. (1998). All that can be at issue in the theory-theory simulation debate. *Philosophical Papers*, *28*, 77–96.

Kahneman, D., & Tversky, A. (1982). The simulation heuristic. In D. Kahneman, P. Slovic, & A. Tversky (Eds.), *Judgment under uncertainty: Heuristics and biases* (pp. 201–208). Cambridge: Cambridge University Press.

Keil, F. (1994). The birth and nurturance of concepts by domains: The origins of concepts of concepts of living things. In L. A. Hirschfield & S. A. Gelman (Eds.), *Mapping the mind* (pp. 234–254). New York: Cambridge University Press.

Kotovsky, L., & Gentner, D. (1996). Comparison and categorization in the development of relational similarity. *Child Development*, *67*, 2797–2822.

Leslie, A., & German, T. (1995). Knowledge and ability in ''theory of mind'': One-eyed overview of a debate. In M. Davies & T. Stone (Eds.), *Mental simulation: Evaluations and applications* (pp. 123–150). Oxford: Blackwell.

Lillard, A. (2001). Pretend play as Twin Earth: A social-cognitive analysis. *Developmental Review*, *21*, 495–531.

Malle, B., & Hodges, S. (Eds.) (2005). *Other minds*. New York: Guilford Press.

McDonald, R., Devan, B., & Hong, N. (2004). Multiple memory systems: The power of interactions. *Neurobiology of Learning and Memory*, *82*, 333–346.

Mitchell, J. (2005). The false dichotomy between simulation and theory-theory: The argument's error. *Trends in Cognitive Sciences*, *9*, 363–364.

Mitchell, P., Currie, G., & Ziegler, F. (2009). Two routes to perspective: Simulation and rule-use as approaches to mentalizing. *British Journal of Developmental Psychology*, *27*, 513–543.

Nichols, S., & Stich, S. (2003). *Mindreading: An integrated account of pretense, self-awareness, and understanding of other minds*. Oxford: Oxford University Press.

Niedenthal, P., Brauer, M., Halberstadt, J., & Innes-Ker, A. (2001). When did her smile drop? Facial mimicry and the influences of emotional state on the detection of change in emotional expression. *Cognition and Emotion*, *15*(6), 853–864.

Onishi, K., & Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science*, *308*, 255–258.

Perner, J., & Kühberger, A. (2005). Mental simulation: Royal roads to other minds? In B. Malle & S. Hodges (Eds.), *Other minds* (pp. 174–189). New York: Guilford Press.

Ruffman, T., & Perner, J. (2005). Do infants really understand false belief? *Trends in Cognitive Sciences*, *9*(10), 462–463.

Scholl, B. J., & Leslie, A. (2001). Minds, modules, and meta-analysis. *Child Development*, *72*, 696–701.

Spivey, M., Tyler, M., Richardson, D., & Young, E. (2000). Eye movements during comprehension of spoken scene descriptions. In L. R. Gleitman, A. K. Joshi, & L. R. Gleitman (Eds.), *Proceedings of the 22nd annual conference of the Cognitive Science Society* (pp. 487–492). Hillsdale, NJ: Lawrence Erlbaum.

Stich, S., & Nichols, S. (1993). Folk psychology: Simulation or tacit theory? *Philosophical Issues. Science and Knowledge*, *3*, 225–270.

Stich, S., & Nichols, S. (1995). Second thoughts on simulation. In M. Davies & T. Stone (Eds.), *Mental simulation: Evaluations and applications* (pp. 87–108). Oxford: Blackwell.

Tversky, A. (1977). Features of similarity. *Psychological Review*, *84*, 327–352.

Wellman, H., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development*, *7*(3), 655–684.

Willingham, D. (1997). Systems of memory in the human brain. *Neuron*, *18*, 5–8.