DEVELOPMENT OF GENERALIZATION: WHAT CHANGES?

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

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The Ohio State University
2008

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ABSTRACT

Development of reasoning is often depicted as involving increasing use of relational similarities and decreasing use of perceptual similarities (“the perceptual-to-relational shift”). I argue that this shift is a special case of a broader developmental trend: increasing sensitivity to the predictive accuracy of different similarity types. To test this hypothesis, young children were asked to label, to infer novel properties, and to project future appearances of a novel animal that varied in two opposite respects: (1) how much it looked like another animal whose name and properties were known, and (2) how much its parents looked like parents of another animal whose name and properties were known. When exemplar origins were known, children generalized to exemplars with similar origins rather than with similar appearances; when origins were unknown, children generalized to exemplars with similar appearances. Results support claims that young children can ignore salient perceptual information to generalize on the basis of non-obvious causal relations. In a further study, I asked participants (3-, 4-, 5-year-olds and adults) to generalize novel information on two types of problems—offspring problems, where, again, relational matches yield accurate generalizations, and prey problems, where perceptual matches yield accurate generalizations. On offspring problems, I replicated the previous findings of increasing relational matches with age. However, I observed decreasing
relational matches on prey problems. Provided feedback on their responses, three-year-olds showed the same trend. In a final study, I looked at costs of task switching between the offspring and prey problems in young children and adults. Contrary to findings supporting the perceptual-to-relational shift, adults failed to inhibit incorrect perceptual matches but were well able to inhibit incorrect relational matches. Young children had difficulties inhibiting both incorrect perceptual matches and incorrect relational matches. It appears then that adults, and not children, are perceptually bound. Findings suggest that the relational shift commonly observed in categorization and analogical reasoning may reflect a general increase in children’s sensitivity to cue validity rather than an overall preference to generalize over perceptual similarity.
To Ithaka, with gratitude for getting me out the door.

As you set out for Ithaka
hope your road is a long one,
full of adventure, full of discovery.
Laistrygonians, Cyclops,
angry Poseidon—don't be afraid of them:
you'll never find things like that on your way
as long as you keep your thoughts raised high,
as long as a rare excitement
stirs your spirit and your body.
Laistrygonians, Cyclops,
wild Poseidon—you won't encounter them
unless you bring them along inside your soul,
unless your soul sets them up in front of you.

Hope your road is a long one.
May there be many summer mornings when,
with what pleasure, what joy,
you enter harbors you're seeing for the first time;
may you stop at Phoenician trading stations
to buy fine things,
mother of pearl and coral, amber and ebony,
sensual perfume of every kind—
as many sensual perfumes as you can;
and may you visit many Egyptian cities
to learn and go on learning from their scholars.

Keep Ithaka always in your mind.
Arriving there is what you're destined for.
But don't hurry the journey at all.
Better if it lasts for years,
so you're old by the time you reach the island,
wealthy with all you've gained on the way,
not expecting Ithaka to make you rich.
Ithaka gave you the marvelous journey.
Without her you wouldn't have set out.  
She has nothing left to give you now.

And if you find her poor, Ithaca won't have fooled you.  
Wise as you will have become, so full of experience,  
you'll have understood by then what these Ithakas mean.

--C.P Cavafy
Many thank yous are in order. My committee has provided much advice and intellectual stimulation these years. To Vladimir, for sharing his Kurt Lewin connection with me, reminding me of the history all psychologists share. To Laura, for her practical advice and for providing living proof of what girls can do. To my advisor, John, *inter silvas mortuus Academi quærere verum* (Horace). Thanks for taking me on, arguing with me about Rome and Greece, worrying about me and somehow along the way turning me into a developmental psychologist. You *really* are my favourite advisor. I also thank my dear colleagues and friends, Ellen Furlong and Clarissa Thompson, without whom, this wouldn’t have been as fun as it was. And to Darrell, Sarah, Sheba, Kermit, Keeli, Harper, Ivy and Emma for getting me here: May you find peace.

I thank whatever forces led me to Gary Berntson’s neuropsychology seminar where I found my heart friend and business partner, Chris Gibbons. My two closest friends, Rachel Hurst and Tracy Roberts, have provided a network of elegance, honesty, support and a history that I cannot now live without.

Finally, I thank my incredible family. Dad: for a place to escape, infusions of cash and a fabulous analogy—The Stanley Cup and Candidacy Exams. Mom: for a shoulder, a stern talking to, and depthless pools of pride and confidence. And, in order of appearance, Stinky GFN, Ms. Hissy Pants, Random (Aktiv’s
Nordic Guardian Spirit), Cornelius, (Prince) Rupert and Valentino – your unwavering companionship, kitty craziness and puppy love kept me sane. And finally, I thank Pete, who came willingly across the country in a tiny car with a puppy, two cats and three ferrets, and has never again asked, “What’s next?” without a wry grin.
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viii
PUBLICATIONS


FIELDS OF STUDY

Major Field: Psychology

Concentrations: Comparative Cognition, Cognitive Development
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CHAPTER 1

INTRODUCTION

A hallmark of human intelligence is the ability to generalize flexibly over different types of similarity (Gentner, 2003). Two types of similarity are clearly important: perceptual similarity, degree of overlap in perceptual features, and relational similarity, degree of overlap in common roles (Medin, Goldstone & Gentner, 1993). In some situations, generalizing over features of individual entities is important. For example, given the relation between fins and ocean living, the fact that dolphins and swordfish both have fins suggests that they, unlike bears, live in the ocean. Sometimes different patterns of generalization are warranted, based on relations among different entities. For example, given the relation between mammals and nursing, the fact that both dolphins and bears are mammals suggests that they, unlike swordfish, nurse their young. Although generalization by either type of similarity alone has been found in both animals and human infants (Marcus et al., 1999; Hauser, Weiss & Marcus, 2002; Shepard, 1987), whether children can ignore perceptual similarities and generalize over opposing relational similarities is at the heart of a lively debate in cognitive development (Gentner, 1988; Gentner & Toupin, 1986; Goswami, 1992, 1995; Halford, 1992, 1995).

Evidence of such cognitive flexibility is found in adults’ generalizations from familiar to novel exemplars. This flexibility is typically influenced by those
same two types of similarities – relational similarity, the degree of overlap in common roles (e.g., a mosquito and a leech each playing a parastical role with respect to people) (Medin, Goldstone, & Gentner, 1993) and perceptual similarity, the degree of overlap in perceptual attributes (e.g., two mosquitoes each possessing six legs) (Shepard, 1987; Tversky, 1977). To address some terminology, a relation takes more than one argument, commonly occurring between objects (i.e., the chair is under the table); a feature is an attribute of an object (i.e., the chair is red). At issue here is whether the flexibility to switch between matching based on relational or features is also evident in children’s generalization. This issue is important because the idea that children’s generalization undergoes a perceptual-to-relational shift has had a long tradition in developmental psychology (e.g., Keil & Batterman, 1984; Keil, 1989; Gentner, 1988; Ratterman & Gentner, 1989; Gentner, 2003), and although accounts differ in claims about domain-specificity, the notion that perceptual matching is the initial default in children’s reasoning (Keil’s “Original Sim”) is widely shared.

One reason to doubt the perceptual-to-relational shift hypothesis is that young children’s categories often map onto shared taxonomic, functional, and social relations more closely than onto holistic perceptual similarity (Brown & Kane, 1988; Goswami, 1995; Opfer & Siegler, 2004; Springer, 1992). In a seminal study demonstrating this principle, Gelman and Markman (1986) found that 5-year-olds could generalize properties to a bat-like bird from a flamingo (same taxonomic relation, dissimilar appearances) rather than from a bat (different taxonomic relation, similar appearance). On the other hand, these reports of children ignoring perceptual similarities have also been challenged. Findings in
which preschoolers generalize using taxonomic relations can be explained using a model of perceptual similarity that is relative rather than absolute (Medin et al., 1993), or that has a differential weighting of exemplar features driven by attentional biases (Jones & Smith, 1993; Rakison, 2000), or by feature–feature correlations (McClelland & Rogers, 2003; Rakison & Hahn, 2004), or that treats labels as perceptual features of exemplars rather than category markers (Sloutsky & Fisher, 2004). For example, when young children generalize from a flamingo to a blackbird, common labels (like ‘bird’) and even non-linguistic sounds (e.g., a beep) may simply increase the two birds’ perceptual similarity (Sloutsky & Fisher, 2004; Sloutsky & Lo, 1999; Sloutsky & Napolitano, 2003).

In this chapter, I discuss two distinct conceptualizations of the perceptual-to-relational shift. Namely, first, that the shift is a maturational process that occurs across domains, and second, that the perceptual-to-relational shift is an epistemologically driven change based on comparison. Following my discussion of conceptualizations of the perceptual-to-relational shift, I reinterpret evidence supporting these conceptualizations in light of my cue validity hypothesis, suggesting instead that children are learning to track cues that maximize accurate generalizations over both perceptual and relational similarities. I conclude by describing tests of my alternative explanation.

1.1 Development of Generalization: Early studies

Development of performance on Piaget’s class inclusion tasks stand as a classic example of cognitive changes in early categorization and reasoning. Initially, when young children are given a set of objects, say, roses and primroses, and asked to “put the things that are alike together,” children sort the
objects into subsets based on perceptual similarities and can accurately compare the numerical magnitude of the two subsets, such as by saying that there are more primroses than roses. However, when young children are asked if there are more primroses than flowers, most five-year-old children answer incorrectly, whereas most eight-year-old children answer correctly. Thus, although five-year-olds can accurately use perceptual information to categorize, the ability to use the class-inclusion relation to categorize seems to develop later, around eight- or nine-years-old, acting as the threshold to the concrete operational stage (Piaget & Inhelder, 1969; see also Deneault & Ricard, 2006; Goswami & Pauen, 2005; Halford & Andrews, 2004; Siegler & Svetina, 2006). Piagetian class-inclusion tasks provide an early example of the perceptual-to-relational shift. Children are unable to overcome their perceptual bias (i.e., paying attention to the primroses) and use the relation (i.e., more flowers than primroses) to solve this task.

The explanation that Piaget offered for the development of the ability to solve class-inclusion problems—namely, the ability to conserve the relation between primroses and flowers—generated a flurry of programmatic research on the development of children’s reasoning, including their ability to categorize using abstract information, to induce novel properties based on abstract similarities, and thus to generalize information beyond the perceptual features (Markman, 1989). Whereas Piaget viewed class-inclusion tasks as critical markers of development given that they rely heavily on logical reasoning and combine reasoning about class hierarchies and relations, other researchers have demonstrated that young children can solve the class-inclusion task using
relations. For instance, if given collection terms rather than class terms, five-year-olds are able to map collection terms, such as family or bunch, onto individuals within a subset and thus solve the class inclusion tasks successfully (Markman & Siebert, 1973). It appears then that there are reasons to doubt Piaget’s analysis of the class-inclusion tasks, as a strict perceptual-to-relational shift.

1.2 Development of Generalization: The Perceptual-to-Relational shift

In this section, I want to consider a set of related non-Piagetian proposals about what develops in these cognitive processes, specifically by taking a critical look at one of the most influential proposals—the perceptual-to-relational shift hypothesis. Although there are differences among specific proposals about how this developmental shift might take place, here I am questioning the entire theoretical stance underlying existence of the perceptual-to-relational shift. That is, I take issue with the assumption that generalizing over perceptual similarity necessarily precedes generalizing over relational similarity.

1.2.1. Maturational accounts of the Perceptual-to-Relational shift

One way to understand the development of generalization is in terms of a “perceptual-to-relational shift.” Namely, a change with development from an early reliance on generalizing over perceptual similarities to a later reliance on generalizing over relational similarities, finally culminating in the adult-like flexibility to generalize information about dolphins to swordfish or bears, depending on the purpose of generalization. One version of the perceptual-to-relational shift hypothesis posits that cognitive change takes place as a domain-general maturational shift (Halford, 1987; 1992; Halford, Wilson & Phillips, 1998).
In the example of Piaget’s class-inclusion task above, the maturation theory predicts that with an increase in working memory, a child will be able to correctly answer that there are more flowers than primroses because she is able to keep the subset (primroses) and set (flowers) in her working memory at one time. The brain’s processing capacity, particularly in working memory, serves as a limiting factor on children’s ability to use relational information and make more difficult comparisons (Andrews & Halford 2002; Andrews et al. 2003; Halford 1993; Halford et al. 1998; Halford et al., 2002). The ability to use relations is particularly important within this theory because logical reasoning rests on the individual making appropriate mappings from real world relational structures (Halford, 1993). For example, children can solve a transitive inference problem, such as “Tom is happier than Bill and Bill is happier than John; who is happiest?” by mapping this problem on to a more familiar analogy, such as “Daddy is bigger than Mummy and Mummy is bigger than Baby; who is biggest?”

Evidence of this maturational shift comes from Halford’s analysis of the balance-beam task. In the balance beam task, participants are asked which side will go down in response to different combinations of weights and distances from the fulcrum. Halford and colleagues (2002) analyzed performance of children on the balance-beam task in terms of binary and ternary relations and found that the complexity of relations accounted for almost all of the age-related variance. That is, the three- and four-year-olds could solve the balance beam problems that required they pay attention to only distance or only weight. This is a binary relation. Older children could attend to ternary relations. That is,
older children could solve balance-beam problems that involved weight and distance combined. This suggests that with maturation – rather than domain specific knowledge, for example – children are able to perform more complex cognitive operations.

1.2.2 Epistemological account of the Perceptual-to-Relational shift.

If shifting from an easier perceptual matching system to a more difficult relational matching one were indeed due to maturational constraints on cognitive abilities, children would not be able to perform differently (better) when provided with feedback nor when given relational language to scaffold their comparisons. Several researchers have demonstrated that children can perform relational matches at varying ages and could perform correctly when provided with feedback and relational language to scaffold the relations (Rattermann & Gentner, 1998; Goswami & Pauen, 2006). Using different relations and different problems, researchers have found the perceptual-to-relational shift occurring as early as three-years-old and as late as 14-year-olds and undergraduates (Goswami, 1992; Rattermann & Gentner, 1998, Sternberg & Downing, 1982). This finding suggests that rather than a stage-like, maturational account, we should look to a learning account of the perceptual-to-relational shift. Further support for a learning explanation as opposed to a maturational explanation comes from studies using feedback or other scaffolding cues. A strict maturational account would not predict that children would succeed with feedback or relational language because the limiting factor on their ability to perform relational matches is their working memory and the relational complexity of the task.
Contrary to a maturational-driven shift, Gentner and colleagues’ relational shift focused on domain specific changes driven by systematic comparison within the system. That is, children’s knowledge in a specific area, about a specific relation, changes with development, which then generates a local relational shift. Conceptualizing the perceptual-to-relational shift in this way assumes the “career of similarity” is sequential: children first make object similarity matches, then, through comparison, learn relations between objects, and are finally able to make higher order relations among objects (Gentner & Rattermann, 1998). From such a sequence, the career of similarity predicts that children will rely on perceptual similarity of objects prior to relations. Thus, the perceptual-to-relational shift can be conceptualized as an epistemological relational shift, or “a shift from early attention to common object properties to later attention to common relational structure.” (Rattermann & Gentner, 1998, p. 453).

Returning again to Piaget’s class-inclusion task, the epistemological relational shift theory predicts that, following comparisons of various sets and subgroups of sets, the child will learn the relation between the subgroup and set and successfully solve the task. Thus, using a domain-general process – comparison – children, with the acquisition of specific knowledge about the relation, learn relations among objects or concepts they previously categorized using only perceptual similarity. In order to solve analogies, individuals map relational knowledge from one domain to another. The perceptual-to-relational shift occurs because younger children pay attention to feature similarities rather than structural or relational similarities.
To test this theory, preschool children watched an experimenter hide a sticker under one object within a triad of objects arranged in increasing size. When asked to “find the sticker in the same place” in their triad of objects, three-year-olds were successful when the objects were perceptually and relationally identical. However, they ignored the size relation (e.g., middle) and chose based on perceptual similarity when objects were cross-mapped (Gentner & Rattermann, 1991). That is, when the house was in the role “middle” in the experimenter’s triad, three-year-olds looked under the house in their triad (a perceptual match), although it was actually in the role of “largest” object (a relational mismatch). By five-years of age, children could select successfully based on the relational similarity. This is taken as evidence of the relational shift from perceptual to relational matching. In another example of this shift, five- to six-year-olds, 9-to-10-year-olds and undergraduates were tested on their ability to understand different kinds of metaphors (Gentner, 1988). Namely, relational metaphors, those that require relational reasoning to solve, attributive, those that require feature similarity to solve, and double metaphors that have both common attributes and common relations. Younger children interpreted the double metaphors in terms of common attributes, whereas older children used relations to interpret the double metaphors. Additionally, with age, individuals were able to make use of the relational structure of the metaphors rather than rely on surface similarities.

Although their mechanisms for the primacy of perceptual matching differ, Piaget, Halford and Gentner have suggested that young children first must generalize over perceptual similarities before acquiring the ability to generalize
over relational similarity. In contrast, evidence suggests that children are able to categorize using abstract information, to induce novel properties based on abstract similarities, and thus to generalize information beyond the perceptual information given. With these contradictory positions in mind, I turn to my alternative explanation for previous findings.

1.3 Questioning the perceptual-to-relational shift

The perceptual-to-relational shift is called into question due to the prevalence of results demonstrating that young infants and non-human primates are able to abstract relations from perceptual stimuli. Recall that Piaget believed that children were unable to use relations until they were at least eight- or nine-years-old. In contrast, Marcus and colleagues (Marcus et al., 1999; Hauser et al., 2002) demonstrated that seven-month-old infants were able to abstract relations, Y is the same as X, and to generalize these relations to novel instances. Infants were habituated to an ABA or ABB condition through a two-minute stream of speech either following an ABA grammar or an ABB grammar. At test, participants were presented with consistent (if ABA; then ABA) and inconsistent (If ABA; then ABB) sentences of novel “words”. Infants looked longer to the target when the inconsistent sentences were played. Similarly, cotton-top tamarins in the same experimental set up were able to discriminate novel strings of familiar and unfamiliar words (Hauser et al., 2002). A more direct test of relational ability comes from a series of studies with a chimpanzee (Pan troglodytes). Sarah successfully completed a number of different analogy and relational tasks, with up to 5 distracters, and was able to spontaneously generate analogies to solve problems (Oden, Thompson & Premack, 2001). This evidence
suggests that very young infants and non-human primates are clearly able to solve relational tasks—something that Piaget suggested eight-and nine-year-old children could not do.

Additionally, findings from various studies have demonstrated children’s ability to generalize based on relational similarity (Brown & Kane, 1988; Gelman, 2003; Gentner & Toupin, 1986; Springer, 1992). Children aged four-to-six-years-old were highly successful at recounting stories when similar looking characters had similar roles (~90% correct). Young children successfully recounted stories even when provided with different looking characters in similar roles (perceptual mismatch, relational match, 70% accuracy). They were also successful when different looking characters were presented in dissimilar roles (perceptual mismatch, relational mismatch, 65% accuracy). This demonstrated that very young children could generalize based on relational similarity in the face of perceptual differences (Gentner & Toupin, 1986). Further evidence suggested that children could generalize based on internal, non-obvious properties. By four- or five-years-old, children recognized that an animal could not be transformed into another kind of thing (for example, a zebra putting on a costume or painting its hide cannot become a horse). Instead, category membership appears to be stable over physical transformations (Keil, 1989; Gelman & Wellman, 1991). These non-obvious properties are accessible to young children and determine their categorization. These studies provided further support for the notion that even young children can generalize using relational similarity.
1.4 Development of Generalization: The Cue Validity Hypothesis

Here I offer an alternative explanation for the perceptual-to-relational shift that stands as a general rival hypothesis to a maturational view of the development of generalization and to a comparison-based epistemological shift in the development of generalization. I then discuss what it is that changes in the development of generalization. Rather than children inflexibly generalizing over similar appearances, labels, or relations, I expect that individual children will generalize using both types of similarities over a period of many years; with age and experience, children will use highly predictive relations (e.g., causal ones) to generalize in an increasing range of domains; and the relations children use within a domain will depend largely on the predictive accuracy of the relation in that context. Thus, within this view, what changes in the development of generalization is sensitivity to the cue validity of competing similarities.

Given Piaget’s class-inclusion example, my cue validity hypothesis claims that children’s sensitivity to predictive accuracy of various dimensions and features change with age and experience. With experience, the child becomes sensitive to the subordinate dimension – in this case, that the subset (primroses) is always smaller than the set (flowers) – rather than relying on the dominant dimension – that there are more members in subset A (primroses) than in subset B (roses). In particular, my cue validity hypothesis claims that children will become sensitive to accuracy on a subordinate dimension.

Indeed, children’s increased sensitivity to relations facilitated correct responses in a class-inclusion task (Goswami and Pauen, 2005). In this task, children were tested on a class-inclusion task using the “family” as a relation.
For example, after learning the base relation – a family with two parents and three children – children were shown a set of big balloons and little balloons and asked, “Who has more balloons to play with, someone with the little balloons or someone with the whole bunch of balloons?” If children failed this class-inclusion task, they were reminded of the families, “Who would have more balloons to play with, someone with the baby balloons or someone with the whole family of balloons?” Five-year-olds were successful on this class-inclusion task. When provided with a hint, almost all four- and five-year-olds used the family relation. In comparison to Piaget’s findings which demonstrated that children could not solve the class-inclusion tasks before they were eight-years-old, this finding suggests that familiar relations provide contextual cues that bootstrap successful generalization. Thus, what changes with experience is not a general cognitive maturation or a necessarily domain-specific comparison mechanism but rather is an increasing sensitivity to elements that predict accurate generalization.

The cue validity hypothesis can explain evidence provided in favour of the domain-general maturational account of the perceptual-to-relational shift. Evidence contrary to the domain general, maturational account of the perceptual-to-relational shift comes from a study that reported that four-year-olds could perform relational matching tasks in which the relations among three tones, for example, were mapped onto varying size relations. However, three-year-olds performed correctly if they were first told the story of Goldilocks and the Three Bears and then taught that the large item was the daddy, the medium, the mummy and the smallest, the baby (Goswami, 1992). Even three-year-olds,
with support, could perform a fairly difficult relational task. If very young children can be trained up to succeed at such a task at an early age by the addition of cues to assist their sensitivity to predictive accuracy, then it is unlikely that this is strictly a maturational process.

The cue validity hypothesis can also explain evidence provided in support of the domain-specific comparison mechanism. For instance, when children are given implicit feedback following each trial (finding the sticker or not), they quickly learn which cues will maximize their accuracy under which conditions. Furthermore, in these studies of analogy (Gentner & Ratterman, 1991; Ratterman & Gentner, 1998), the relational match often has high cue validity. In this case, then, the observed shift in use of relations might be better conceptualized as children’s learning about the relative cue validities of object matches and relational matches. The question remains as to whether there is, indeed, a relational shift and if so, how early it occurs, as well as the role of cue validity in children’s generalization.

This general hypotheses are consistent with evidence of the importance of predictive accuracy in producing changes in children’s thinking in other domains (e.g., Klahr & Wallace, 1976; Opfer & Siegler, 2004; Siegler, 1983) and with Siegler’s (1996) overlapping waves theory more generally. However, they differ considerably from the perceptual-to-relational shift perspective in that they depict children’s choice of similarities as being opportunistic and as depending on the accumulated evidence regarding the predictive accuracy of a given relation, label, or set of perceptual features.
Central to my account is the assumption that children’s sensitivity to relevant information increases with age (Siegler, 1981). For example, on balance scale problems, most five-year-olds predict that the side of the balance scale with greater weight will fall regardless of distance from fulcrum; more importantly, they fail even to encode distance of weights from the fulcrum, thereby failing to reproduce distance information when asked to recall the problems they encountered (Siegler, 1976). Older children, in contrast, do encode information about distance from the fulcrum, but they fail to integrate this information appropriately.

Another developmental difference in sensitivity to relevant dimensions is seen across a wide range of tasks that pit one dimension with another. On number conservation tasks (Piaget, 1952), young children ignore the (relevant) density of the objects in a row in favor of the (irrelevant) length of a row. On shadow-projection tasks (Inhelder & Piaget, 1958), young children ignore the (relevant) distance of the object from the light source in favor of the (irrelevant) span of the bar. On probability tasks (Piaget & Inhelder, 1951), young children ignore the (relevant) number of undesired colored marbles in favor of the (irrelevant) number of desired marbles. Across these tasks, young children’s answers were sensible given that the dominant dimensions tended to be those that maximized accuracy on the tasks that they ordinarily faced (i.e., where dominant and subordinate dimensions were not put into conflict by creative experimenters). However, older children provided better responses—not because of an overarching weight-to-distance, length-to-density, bar span-to-distance to light source, or desired-to-undesired shift—but because they knew
when to switch from commonly predictive to less commonly predictive dimensions. Consistent with this interpretation, children typically adopt premastery strategies in order of predictive accuracy (Siegler, 1983).

This same analysis can be applied to the “career of similarity” in development of analogical reasoning and category-based induction. For the same reasons that young children attend initially to weight on balance scale tasks (or length of row on number conservation tasks), their choice of perceptual matches in generalization tasks may reflect use of information that, although generally highly predictive, is less so on problems that pit (unreliable) perceptual similarities against (reliable) relational similarities. What distinguishes older children from younger children on these tasks, in this view, is simply their sensitivity to the situational reliability of less commonly predictive information (i.e., relational and taxonomic similarities). Moreover, this same principle can also explain why perceptual similarities with low inductive potential are given low weight by children when generalizing novel properties (Gelman & Coley, 1991) and why relational similarities that license almost no generalizations, such as *can be taken out of a burning house*, are seldom used by children of any age (Barsalou, 1985). Children are acquiring sensitivity in a subordinate domain that is more predictive of accuracy than the dominant domain to which they have previously been attending.

The most direct implication of this analysis is that *when* the perceptual-to-relational shift occurs—like *when* the acquisition of conservation concepts occurs—should vary greatly depending on the relation in question, with highly predictive relations showing the earliest resistance to overshadowing by
perceptual similarities. Research on development of analogical reasoning has demonstrated this point elegantly. For example, in children’s early experience, the father/mother/baby relation predicts many novel facts, which three- to five-year-olds can map onto novel transitive relations (Goswami, 1992, 1995). For relations that less reliably predict new facts in young children’s experience, relational reasoning appears much later, sometimes at age eight (Rattermann & Gentner, 1998), sometimes in college (Sternberg & Nigro, 1980; Sternberg & Downing, 1982).

The questions addressed in my research are non-trivial. At stake is a very basic conceptualization of human intelligence. Those who support a perceptual-to-relational shift tend to be those who conceptualize the brain as a general purpose processing mechanism that tracks frequencies in the environment and derives meaning from the outside. Those who suggest that perceptual matching is not a prior process generally support a model of the brain that has innate biases that direct attention and, in some cases, provides actual knowledge. I take a stand slightly different from either of these theories. Instead, I favor the view that perceptual processing is not necessarily easier or earlier but rather that, with knowledge, some relations come online very early and, thus, are as robust as perceptual similarities. Over time, what changes with development is the sensitivity to which particular contexts are appropriate for deploying perceptual or relational matching. With much experience, perceptual matching becomes more practiced than relational matching and we become biased to make perceptual matches rather than relational matches in ambiguous settings.
1.5 The Present Studies

The present studies tested the cue validity hypothesis in a series of six experiments. In the first study, I asked if children were able to solve tasks using either perceptual or relational matching depending on the task, when perceptual and relational similarities were in conflict. This is particularly important, as previous work demonstrated that young humans and animals could use either perceptual or relational matching but not whether they could flexibly choose to use the appropriate similarity in the appropriate context. Before I address whether or not children shift from using primarily perceptual similarity using relational similarity for generalization, I first ascertained that children could actually use both types of similarity and chose the similarity with the highest predictive accuracy when the two types of similarity were in conflict. The second experiment served as an important control for the first experiment.

The theoretical motivation for the third experiment was provided by Sloutsky and Fisher’s (2004) SINC (Similarity-based Induction, Naming and Categorization) model, in which shared category labels increased similarities between different sets of perceptual features. For example, the model predicted that by using category labels such as “dax” and “fep” in Experiments 1 and 2, I increased the discriminability of exemplars, leading to children paying greater attention to adult insects in the offspring condition (where adults were labeled) than to adults in the prey condition (where adults were unlabeled). To control for the likely role that labels might have played in the previous experiment, I removed labels and used consistent terms, such as “that one” or “this bug” for all stimuli.
In the fourth study, I investigated the developmental trend in using perceptual and relational matching to generalize. Specifically, was there indeed a perceptual-to-relational shift as has been conceptualized by a number of researchers? A perceptual-to-relational shift was not supported, in contrast to much research on the development of generalization.

The first four studies, then, determined that children could generalize over both perceptual similarity and relational similarity; both with and without category labels and that their patterns of generalization were predicted by the cue validity hypothesis. The next two studies investigated the possible mechanics of these processes.

In Experiment 5, I looked at perceptual and relational matching in three-year-olds when provided with feedback. It appeared that a learning paradigm accounted best for their ability to use a particular kind of similarity to generalize in a particular situation. Indeed, three-year-olds performed similarity to adults when they were taught which cues predicted accuracy on each task. This provided a very direct test of Halford’s maturational hypothesis.

Finally, in Experiment 6, I investigated adults’ and preschoolers’ ability to switch between tasks requiring either perceptual or relational similarity. The purpose of this experiment was to ascertain if there was an age-difference in the ability to inhibit one similarity over the other. The cue validity hypothesis predicts that children are not initially biased toward perceptual matching but can use both perceptual matching and relational matching from early in development. That said perceptual matching is clearly a robust and highly accurate strategy in most situations. I predicted that the costs of switching from
using perceptual matching to solve a task to using relational matching would be higher for adults, who have learned the value of this generalization strategy, than for children, who are still learning. By measuring the costs of task switching, I determined that generalizing over one type of similarity is more difficult to inhibit than the other, and that there is an age difference in these inhibitory differences.

In all experiments, I presented children with two problems where use of relational and perceptual similarity generated opposite predictions. These two problems were: offspring problems, which could be solved accurately using relational matches, and prey problems, which could be solved accurately using perceptual matches. In the offspring problems, the relational match provided the most reliably accurate choice because the identity of a juvenile generally can be determined by the identity of its parents. That is, in order to solve the offspring problems, the child must first recognize the importance of the offspring’s causal relation to their parents. This causal relation must be understood before the child will infer that the target is the same kind as the exemplar because it has the same parents. In the prey problems, however, the relational match provided the less accurate choice because the identity of an individual cannot be reliably determined by the identity of its predators. That is, in order to solve the prey problems, the child must understand that predators do not provide relevant information to solve the problem. Once the child realizes that responding over perceptual similarity – not relational similarity – increases accurate responding, she will answer that the target and the exemplar are the same kind because they look the same.
CHAPTER 2

CUE VALIDITY AND GENERALIZATION

Differences in the predictive accuracy of relations, labels, and perceptual features within the biological domain suggested an interesting first test of my cue validity hypotheses. Among living things, the correlation between appearance and kind is never perfect; cases of homologies, camouflage, mimicry, sexual dimorphism, injuries, surgery, and aging are but a few of the many exceptions to the rule, “Same looks, same kind” (Gelman, 2003). Also, the correlation between label and kind is not perfect either; cases of homonyms, homophones, synonyms, and parent/teacher mislabeling are but a few of the many exceptions to the rule, “Same label, same kind” (Sloutsky & Fisher, 2004). In contrast, there is an unusually high correlation between causes and effects, and so following the rule, “Same causes, same kind” would likely generate more accurate generalizations of novel properties than use of either appearances or labels. This difference in predictive accuracy, in turn, may lead children to weight the similarity of causal relations over the similarity of non-causal relations and the similarity of appearances and thereby lead children to generalize using similar causal
relations earlier in development than other relations and also in situations where perceptual similarity would otherwise lead them to generalize in the other direction.

Previous research demonstrated that young humans and animals can use either perceptual or relational matching but not whether they can flexibly choose to use the appropriate similarity in the appropriate context. Before I can address whether or not children shift from using primarily perceptual similarity to obtaining the ability to use relational similarity for generalization, I must first ascertain that children can actually use both types of similarity and choose the similarity with the highest predictive accuracy when the two types of similarity are in conflict.

If young children generalize based on perceptual similarity alone, then there should be no difference between their responses on the prey and offspring problems. Such a finding would support the perceptual-to-relational shift hypothesis. However, should children treat the prey and offspring problems differently, using perceptual similarity to generalize when presented with a prey/predator problem and using relational similarity to generalize when presented with an offspring/parent problem, my hypothesis – that children choose different similarities to generalize based on different predictive accuracies – is supported.

2.1 Experiment 1: Cue Validity and Relational Matching

The purpose of Experiment 1 was to test whether children preferred to generalize using similar appearances or relations.
2.1.1 Method

2.1.1.1 Participants. Thirty-two kindergartners and first graders (mean age = 6.7 years) participated in this experiment.

2.1.1.2 Stimuli and Procedure. A laptop computer presented children with illustrations of juvenile and adult insects and with questions about the juvenile insects. Figure 1 depicts a question given to children assigned to the offspring problems; Figure 2 depicts a question from the prey problems.

Figure 1: Offspring problem used in Experiment 1. Notice that using the similarity between adults-TT and adults-XX increases accurate generalization about juvenile-t.
Figure 2: Prey problem used in Experiment 1. Notice that correct generalization arises from matching perceptual similarity of juvenile-t and juvenile-b.

For every question, juvenile-a appeared first with accompanying auditory stimuli (e.g., a voice saying “This is a dax.”), followed by adults-XX (“It was born to these two daxes here” / “These two bugs want to eat the dax”), juvenile-b (“This is a fep.”), adults-YY (“It was born to these two feps here” / “These two bugs want to eat the fep”), adults-TT (“These two bugs gave birth to…” / “These two bugs want to eat…”), juvenile-t (“…this one here. Is this one a dax or a fep?”). Children were instructed to answer by pointing to either the left or right side of the computer screen, and no feedback was given. On each of four trials, children were asked four questions—whether the target shared a category label with a or b, whether it would look like a or b in the future, whether it had a property inside its blood like that of a or b and what its parents looked like. The final question was included initially to serve as a control question but later dropped from analysis due to its inherent ambiguity.
Similarities of adults and juveniles were manipulated by matching the segments of insects according to Tversky’s (1977) contrast rule. Juvenile insects had six vertical segments, which were colored either dark or light. Adult insects also had 6 segments (antennae, head, thorax, wings, legs, and abdomen), which could take 5 possible forms. Similarities were varied within-subjects and counterbalanced from trial to trial using the same Latin-square design in both conditions. The relative similarity of the adults (Sim[XX,TT] / Sim[XX,TT]+Sim[YY,TT]; “adult similarity” henceforth) was never equal to the relative similarity of the juveniles (Sim[a,t] / Sim[a,t]+Sim[b,t]; “juvenile similarity” henceforth). For example, on trial 1, adult similarity was 100%, juvenile similarity was 0%; on trial 4, adult similarity was 0%, juvenile similarity was 100%). Trial to trial, the difference between adult and juvenile similarity varied from 67- to 100-points; however, the sum of differences for a child always equaled 0% to control for perseverative biases.

2.1.2 Results and Discussion

As a preliminary analysis, I examined proportion of relational matches for each of the questions independently. Across all conditions and experiments, the number of relational matches did not differ by question (ps > .1), so I collapsed the three questions into one measure of relational matches (0-100%).

To determine whether there was an effect of problem type in my findings, I first performed repeated-measures ANOVA on proportion of relational matches (Figure 3).
Figure 3: Results of Experiment 1. Here the percentage of matches refers to generalizing based on the similarity of the base to target. For the prey problems, young children are generalizing based on similarity of the base to target (juvenile). For the offspring problems, they are generalizing based on the causal origins (parents).

As expected, I found a main effect of condition, indicating that relational matching was more frequent in offspring problems than in prey problems, $F(1, 127) = 88.23, p < 0.0001$. Individuals made relational matches approximately 80% of the time in the offspring condition. That is, children generalized from the
novel target to the juvenile that was not perceptually similar, but was the offspring of parents who were perceptually similar to the parents of juvenile-t. Children made more relational matches when the parents, the relational match in the offspring problems, were more perceptually similar, \( F(3, 63) = 17.26, p < 0.0001 \). This finding is interesting because it reflects a novel pattern of generalization, one in which generalization follows the attributes of the causal origin of a target rather than the target itself. Could this pattern of generalization have resulted from there being something more salient about the adults’ appearance than the appearance of the offspring? Evidence from the prey condition, in which the appearances of the adults and offspring were identical to the offspring condition, allowed me to test this hypothesis.

In the prey condition (where juveniles were introduced as prey), I found the opposite effect. Individuals made relational matches approximately 25% of the time, as would be expected if children generalized category labels (e.g., “a dax”) and other properties (e.g., “has golgi in its blood”) to targets based on their similarity to other exemplars. Furthermore, perceptual similarity among the prey increased children’s generalizations based on the prey insects, \( F(3, 63) = 12.77, p < 0.0001 \). This finding is important in the present context for both a broad and a narrow reason. Broadly, it indicates that having a target share a relation with an exemplar (i.e., both being the prey of a similar predator) was not itself sufficient to affect generalization, at least not when targets looked more like another exemplar. More narrowly, it demonstrates that the similarity of the adults was not sufficient to distract children from the perceptual similarity of the juveniles, which children were apparently able to follow.
2.2 Experiment 2: Generalization without Relational Matching

Children in Experiment 1 generalized properties to a target juvenile using adult similarity when the adults were in a causal relation to the juveniles and using juvenile similarity when the adults bore a non-causal relation. The purpose of Experiment 2 was to test the effect of causal information by presenting children with the same problems presented in Experiment 1 but without information about relational similarity. In this case, the model predicts generalization by perceptual similarity for both the offspring and prey problems.

Experiment 2 also allowed me to test an alternative explanation for the results of Experiment 1. Specifically, in Experiment 1, I manipulated the relation of juveniles to adults by orienting juveniles above adults to depict a predator/prey relation and by orienting juveniles below adults to depict a parent/offspring relation. Because this difference in orientation placed the juveniles near the eyes of the adults in the predator/prey condition, it is possible that the gaze of the adults drew children’s attention to the visual features of the juveniles, and thereby led to generalization by juvenile similarity. If this alternative explanation were correct, removing adults would lead to greater generalization by juvenile similarity for the prey problems than for the offspring problems.

2.2.1 Method

2.2.1.1 Participants. Thirty-two kindergartners and first graders (mean age = 6.6 years) participated in this experiment.
2.2.1.2 *Stimuli and Procedure.* The stimuli and procedure used were identical to those used in Experiment 1, except the adults labeled TT were removed (see Figures 4 and 5).

![Stimuli Diagram](image)

1. This [a] is a dax. It was born to these two daxes [XX] here.
2. This [b] is a fep. It was born to these two feps [YY] here.
3. Is this one [t] a dax or a fep?

Figure 4: Offspring problem for Experiment 2. Notice that the relational match is missing. That is, the parents of the target juvenile are not present and therefore, I expect children to generalize over perceptual similarities.
2.2.2 Results and Discussion

As predicted, there was no difference in performance on the two problems, $F (1, 127) = 3.03, p = ns$. These results are consistent with the prediction that generalization follows exemplar-to-target similarity in the absence of information about the causal origins of the target, which was present in the offspring condition of Experiment 1 but absent in the offspring condition of Experiment 2 (Figure 6).
Figure 6: Results of Experiment 2. Notice that children generalized using perceptual similarity of juvenile-t in both Prey and Offspring problems.

It appears that children’s generalization by adult similarity in Experiment 1 reflected their interpretation of the adults as causal origins, and lacking that, in Experiment 2, they generalized quite strongly on the basis of exemplar-to-target similarity.
2.3 Experiment 3: Effects of Labels on Relational Matching

The purpose of Experiment 3 was to replicate the results of Experiment 1 under conditions in which children were not given category labels for the exemplars and associated adults. The theoretical motivation for this test is provided by Sloutsky and Fisher’s (2004) SINC (Similarity-based Induction, Naming and Categorization) model, in which shared category labels increase the similarity of different sets of perceptual features. For example, the model predicts that by using category labels such as “dax” and “fep”, I may have increased the discriminability of the exemplars, leading to a higher level of attention to adult insects in the offspring condition (where adults were labeled) than to adults in the prey condition (where adults were unlabeled). I test this alternative hypothesis in Experiment 3, in which I presented the same prey and offspring problems but did not provide category labels for any of the adult or juvenile exemplars.

2.3.1 Method

2.3.1.1 Participants. Thirty-two kindergartners (M = 5.7 years) participated in this study.

2.3.1.2 Stimuli and Procedure. The tasks were identical to that used in Experiment 1, except I replaced novel category labels (e.g., “dax”) with a general descriptive term (e.g., “this bug”) (see Figures 7 & 8).
Figure 7: Offspring problems used in remaining experiments. Notice that labels like “fep” or “dax” are not present. This provides a critical test of the role of labels in generalization.

Figure 8: Prey problems. These stimuli were used in the remaining experiments. As above, labels are not present in this experiment.

Additionally, rather than asking children to choose between two category labels for a target (e.g., “is this a dax or a fep?”), I asked them to choose between two categories for the target (e.g., in offspring condition, “is this one the same kind as the one these two gave birth to or the same kind as the one these two
gave birth to?"; in the prey condition, “is this one the same kind as the one these two want to eat or the same kind as the one these two want to eat?”).

2.3.2 Results and Discussion

As in Experiment 1, I examined the effect of juvenile similarity by conducting repeated-measures ANOVA on condition (prey, offspring) on the proportion of relational matches. Results indicated that the proportion of relational matches were strongly affected by experimental condition in the absence of labels, $F (1, 127) = 47.64, p < 0.0001$. Individuals made approximately 79% relational matches in the offspring task and approximately 40% relational matches in the prey task.

2.4 General Discussion

In this chapter, I examined whether young children would generalize from exemplars to targets on the basis of how similar the entities looked or on the basis of their shared relation to other entities (e.g., effect-of-X, goal-of-X). I hypothesized that the greater predictive accuracy of causal origins would lead young children to ignore target-to-exemplar perceptual similarity when the countervailing relational similarity was causal but to rely on target-to-exemplar perceptual similarity when the countervailing relational similarity was non-causal. The results of Experiments 1 – 3 confirmed this prediction.

These results are not consistent with previous reports (e.g., Gentner & Toupin, 1986; Smith, 1989; Sloutsky & Fisher, 2004) that young children lack the processing capacities to simultaneously ignore holistic similarity and generalize on the basis of non-obvious information. However, results are consistent with claims that children’s category-based induction relies on use of causally central
information (Ahn et al, 2000; Gelman, 2003; Springer, 2001) and with the more
general developmental claim that predictive accuracy affects how early children
will use a particular kind of information (Siegler, 1983, 1996).

Reports of children ignoring perceptual similarities in favor of relational ones have been subjected to a number of methodological criticisms that do not apply to the present studies. For example, one concern has been that evidence of early category based induction derives exclusively from children’s responses to familiar naturalistic stimuli (e.g., photographs, colored drawings, and toy models), where it is difficult to manipulate similarity with mathematical precision (see also, Sloutsky & Fisher, 2004; Jones & Smith, 1993; Deák & Bauer, 1996). This issue is important in evaluating claims about children overriding perceptual similarity because generalization typically decays exponentially with object-level similarity (Shepard, 1987); thus, effects of perceptual similarity are expected to become vanishingly small when comparing targets that differ greatly versus only moderately from exemplars. In the current studies, I was able to control similarity with precision, as well as other perceptual features that might given an “illusion” of abstract generalization, including presence of category labels, specific exemplar features, and feature-feature correlations. With these variables equated within and across conditions, children consistently ignored target-to-exemplar perceptual similarity in favor of similarity of causal origins, suggesting that children’s generalizations cannot be explained by their using some subtle perceptual cue.

Rather than children relying invariably on exemplar-to-target perceptual similarity in generalization, another processing account may explain results. In
this account, young children process two kinds of similarity and use the more predictive one to generalize. The first kind of similarity is the perceptual similarity that exists between exemplars and targets, which children interpret as a *surface similarity* (in the sense that they are ready and willing to override the information). The second kind of similarity is the similarity that exists between the causes of exemplars and causes of targets, which children interpret as an *explanatory similarity* (in the sense that they believe similarity to be the best predictor of other similarities). In the current experiments, when children perceived a match between exemplars and targets, they assumed the surface similarity to be an effect of a cause shared between targets and exemplars, which motivated them to generalize using perceptual similarity. Consistent with this interpretation, children who were given no information about target origins (i.e., children in the prey conditions) reported that similar-looking targets had similar-looking parents. More direct evidence for this account, however, came from the offspring conditions of Experiments 1 and 3, where children had access to both surface and explanatory similarities, and children reliably used the latter to generalize.
CHAPTER 3

EFFECTS OF CUE VALIDITY ON RELATIONAL MATCHING

The results of Experiments 1-3 established that young children could generalize using both perceptual and relational similarity. In the following two experiments, I tested to see if there was a developmental trend in this ability (i.e., was there an age where children preferred perceptual similarity over relational similarity or vice versa) and if I could induce accurate perceptual matching and relational matching in the youngest group that did not use it spontaneously (i.e., could this be explained by a learning mechanism).

The two types of problems – prey and offspring problems—invite competing predictions from the perceptual-to-relational shift hypothesis and my cue validity hypothesis. Specifically, the perceptual-to-relational shift hypothesis predicts that young children will initially use perceptual similarity to generalize from exemplar to novel stimuli and with age and experience later acquire the ability to use perceptual similarity and relational similarity on both types of problems. In contrast, my cue validity hypothesis predicts that relational matching should increase with age and experience on the offspring problems (where relational similarity is most reliable) and relational matching should decrease with age and experience on the prey problems (where perceptual similarity is most reliable).
3.1 Experiment 4: Developmental Changes: The Effects of Cue Validity

In Experiment 4, I examined developmental changes in the ability to use perceptual similarity and relational similarity for generalization. Specifically, I looked at the effects of cue validity on making perceptual and relational matches. I tested these two competing predictions in Experiment 4, where I examined age differences in generalization, and in Experiment 5, where I examined trial-to-trial differences in generalization as children gain information about the accuracy of their choices.

3.1.1 Method

3.1.1.1 Participants. Participants comprised 31 undergraduates (mean age = 20.8 years), 32 five-year-olds (mean age = 5.4 years; 11 girls and 21 boys), 32 four-year-olds (mean age = 4.5 years; 12 girls and 20 boys), and 32 three-year-olds (mean age = 3.6 years; 19 girls and 13 boys). One undergraduate was eliminated due to failure to complete the task.

3.1.1.2 Stimuli and Procedure. A computer presented participants with illustrations of juvenile and adult insects (see Chapter 2, Figures 7 and 8 for stimuli layout), with scripts presented by pre-recorded audio to prevent experimenter bias. Perceptual similarities among stimuli presented in a single trial were varied within subjects and counterbalanced from trial-to-trial using the same Latin-square design in both conditions. Juvenile insects had six segments, colored either dark or light. Adult insects had six segments (antennae, head, thorax, wings, legs and abdomen), each of which could take five possible forms. The relative similarity of the adults \( \frac{\text{Sim}[XX,TT]}{\text{Sim}[YY,TT]+\text{Sim}[YY,TT]} \) (adult similarity) was never equal to the relative similarity of the juveniles.
(Sim[a,t] / Sim[a,t] + Sim[b,t]; juvenile similarity). That is, if juvenile-\(a\) were 100% similar to juvenile-\(t\), then adult insects-XX were 0% similar to adult insects-TT. Thus, on any given trial, I could determine whether participants used juvenile or adult insect similarity to solve the problems.

Individuals received either offspring or prey problems, as described previously and displayed in Figures 7 and 8. For every question, juvenile-\(a\) appeared first with accompanying auditory stimuli (“Look at this one!”); next, adults-XX appeared, forming a triad with juvenile-\(a\), (offspring condition: “These two bugs gave birth to this one here” / prey condition: ”These two bugs want to eat this one here”). Juvenile-\(b\) next appeared (“Look at this one!”), followed by adults-YY to complete the second third triad (offspring condition: “These two bugs gave birth to this one here.” / prey condition: “These two bugs want to eat this one here.”). Finally adults-TT (offspring condition: “These two bugs gave birth to…” / prey condition: ”These two bugs want to eat…” ) and juvenile-\(t\) (“this one here.”) completed the triad. On each of eight trials, participants were asked three questions about juvenile-\(t\), the target– whether the target was the same kind as juvenile-\(a\) or \(b\) (categorization), whether it would look like juvenile-\(a\) or \(b\) in the future (projection), and whether it had a property (\(golgi\)) inside its blood similar to juvenile-\(a\) or \(b\) (induction). Participants were instructed to answer by pointing to the left or right side of the computer screen.

3.1.2 Results and Discussion

I first examined the proportion of relational matches for each of the three questions independently. Across all conditions, trials, and age groups, the proportion of relational matches did not differ by question (\(ps > .10\)); therefore, I
collapsed the three items into one summary measure of relational matching. Subsequent analyses were performed on proportion of relational matches over four trials, and post-hoc comparisons were performed using Fisher’s PLSD unless otherwise indicated. Results are depicted in Figure 9 and Table 1.

Figure 9: Developmental trend in relational matching. Notice that with age, both relational matching and perceptual matching increase.
Table 1: Relational matching by Condition in Experiment 4

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Offspring Problems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adults</td>
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</tr>
<tr>
<td>5-year-olds</td>
<td>79.47%</td>
<td>23.28</td>
</tr>
<tr>
<td>4-year-olds</td>
<td>72.13%</td>
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<td>3-year-olds</td>
<td>61.25%</td>
<td>20.84</td>
</tr>
<tr>
<td><strong>Prey problems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>7.23%</td>
<td>17.85</td>
</tr>
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</tr>
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</tr>
<tr>
<td>3-year-olds</td>
<td>55.92%</td>
<td>20.76</td>
</tr>
</tbody>
</table>

To determine whether there was a developmental trend in my findings, I first performed a 2 (condition: offspring, prey) X 4 (age: 3-, 4-, 5-year-olds and adults) repeated-measures ANOVA on proportion of relational matches. As expected, there was a main effect of condition, indicating that relational matching was more frequent when juveniles were in the role of offspring rather than prey, $F(1, 119) = 71.16, p < 0.0001$. Further, the overall proportion of relational matches decreased with age $F(3, 119) = 5.10, p < 0.01$. Finally, age and condition produced interactive effects on relational matching $F(3, 119) = 14.83, p < 0.0001$. To examine this interaction further, I analyzed relational matching in each condition separately.

On offspring problems, where juvenile insects were in the role of offspring, relational matching increased with age, $F(3, 62) = 2.92, p < 0.05$. Post hoc analysis indicated that adults and five-year-olds were more likely than three-
year-olds to generalize using relational matches \((ps < 0.05)\). Further, one-group t-tests indicated that all age groups were more likely to generalize to relational matches than expected by chance \((ps < 0.05)\).

On prey problems, where juvenile insects were in the role of prey, relational matching decreased with age, \(F(3, 63) = 16.58, p < 0.0001\), with children more likely to generalize over relational matches than adults \((ps < 0.0001)\). Further, only adults were less likely than expected by chance to generalize to relational matches, \(t(15) = 9.59, p < 0.0001\).

These findings support my cue validity hypothesis. That is, with age and experience, perceptual and relational matching increased. It is important to note here that all groups made correct relational matches whereas only adults performed perceptual matching. This is similar to findings in Experiment 3, where five-year-olds were more correct performing relational matches than perceptual matches. Given these non-intuitive findings, I next attempted to induce perceptual and relational matching in the youngest group of children, three-year-olds.

### 3.2 Experiment 5: Manipulation of Cue Validity on Relational Matching

In Experiment 4, I found increases and decreases in relational matching, depending on whether the juvenile insects played the offspring or prey role in the relation. I hypothesized that this pattern would emerge over development as children learned that the parent-offspring relation predicts category membership, whereas the predator-prey relation does not. To test this hypothesis more directly, I provided feedback to three-year-olds according to this rule, and observed its impact on generalization patterns of three-year-olds,
whose answers in Experiment 4 did not differ by problem type (offspring vs. prey). If the overall developmental trend in Experiment 4 reflected the learning history of children, I reasoned a similar trend would emerge as young children learned about the predictive accuracy of the two different relations for generalization. Furthermore, I could compare the results of Experiment 5 to prior analogy tasks (e.g., Gentner and Rattermann, 1991), which typically provide children feedback as well. Finally, as a follow up to this learning study, I tested the same children’s generalization at a later date to examine the durability of the experimentally-induced developmental change.

3.2.1 Method

3.2.1.1 Participants. Participants comprised 16 three-year-olds (mean age = 3.79 years; 8 girls and 8 boys).

3.2.1.2 Stimuli and Procedure. Children participated in a feedback phase when they received feedback on their responses and a retention phase, two days later, when they were retested without feedback. As a point of comparison, data from three-year-olds in Experiment 4 was included as pretest data in Experiment 5.

Stimuli and procedure were identical to that of Experiment 4 except that feedback was provided following every response. For correct responses, the experimenter said, “That’s right. That one is the same kind as that one,” and pointed at the target and appropriate exemplar. For incorrect responses, the experimenter said, “Actually, that’s not right. That one is the same kind as that one,” and pointed at the correct target and appropriate exemplar. Participants were not told why the exemplar/target match was correct. In the retention
phase, two days following the feedback phase, the experimenter returned and tested the same 16 three-year-old children on the same conditions they previously viewed in the feedback phase. This testing was done without feedback.

3.2.2 Results and Discussion

To determine if a similar developmental trajectory occurred when three-year-olds were provided with feedback on their answers, I first performed a 2 (condition: offspring, prey) X 2 (test phase: pretest, feedback/retention) ANOVA on proportion of relational matches (Figure 10). As in Experiment 4, relational matching was more frequent when juveniles were in the role of offspring rather than prey, $F(1, 44) = 18.48, p < 0.0001$. More importantly, problem and test phase produced interactive effects on relational matching, indicating that young children learned the predictive accuracy of the two different relations for generalizing category judgments, $F(1, 44) = 11.63, p < 0.001$. To test this interpretation, I examined performance in the feedback/retention phase separately.
Like older children and adults in Experiment 4, three-year-olds’ relational matching in the feedback phase differed by problem type, \(F(1, 14) = 12.13, p < 0.01\), with relational matching occurring more frequently on offspring (M = 74%) than on prey problems (M = 36%). Most of the differences between three-year-olds’ relational matching in Experiment 4 and 5 occurred as a result of learning after the first trial of feedback. After this point, relational matching did not increase, \(F(3, 42) = 0.48, p = ns\). Further, three-year-olds’ relational matching remained flexible in the retention phase, when they again chose relational
matching much more for offspring than prey problems, \( F(1, 14) = 28.16, p < 0.0001. \)

### 3.3 General discussion

The purpose of this chapter was to examine the generality of the “perceptual-to-relational shift” across relations that differed in their reliability as predictors of category membership. For the parent-offspring relation, where identity of adults predicted category membership of juveniles, I replicated the previously observed perceptual-to-relational shift. In contrast, for the predator-prey relation, where identity of adults did not predict category membership of juveniles, I found that relational matches decreased with age. Further, when three-year-olds were provided with feedback on their judgments, a similar trend emerged from trial to trial, i.e., increasing relational matches for problems involving a parent-offspring relation and decreasing relational matches for problems involving a predator-prey relation.

These experiments do not provide support for a universal perceptual-to-relational shift. Children in my study did not use perceptual similarity overall and then abruptly shift to using relational similarity overall—neither as they aged nor as they acquired feedback. In my view, these findings raise questions about theories of relational development that posit the primacy of perceptual similarity in situations where children recognize relations and percepts to conflict. If perceptual similarity were the default mode of generalization, I should have seen a high rate of perceptual matching among three- and four-year-olds regardless of condition. In fact, their overall rate of perceptual matching was lower than adults, and even the youngest children were more likely than not
to make relational matches in the offspring condition (cf. Goswami, 1992). Moreover, if relational similarity were the preferred developmental endpoint, I should have seen older children and adults making relational matches more often in both the offspring and prey conditions. However, I instead observed adults and older children making perceptual matches more often in the prey conditions, but not in the offspring condition. These results highlight the susceptibility of young children to irrelevant similarities overall, but argue against the primacy of mechanisms that focus attention on just irrelevant perceptual similarities (Keil, 1995; Keil & Batterman, 1984; Gentner, 1988; Rattermann & Gentner, 1998).

Far from requiring that I assume a context-general perceptual-to-relational shift, my pattern of results can be understood instead from the assumption that relational matches are just one possible developmental endpoint that typically ends with high rates of overall accuracy. In this account, children in Experiments 4 and 5 learned to maximize accuracy by using the relevant similarity for each type of problem. This account differs from the perceptual-to-relational shift account in accurately predicting that young children’s initial rate of perceptual matching would be even lower than adults’ when solving prey problems. Also consistent with this account, feedback led to three-year-olds in Experiment 5 quickly learning to generalize over perceptual and relational similarities as the context required. This fast learning was also quite durable, with three-year-olds retaining their new knowledge about relevant similarities when tested at a later date. Thus, my learning study in Experiment 5 replicated both the perceptual-to-relational shift and the relational-to-perceptual shift observed in Experiment 4.
One possible objection to my account is that the relational shift I found was not as dramatic as might be expected. I suggest that the relational shift that occurred over time in Experiment 4 was not pronounced because children came to my task knowing the predictive value of the parent-offspring relation. Origin relationships are generally important to young children, and they have a certain amount of expertise in these, particularly in contrast to predatory relationships. Indeed, previous work on analogy (Gentner & Rattermann, 1998; Goswami, 1995; Goswami & Pauen, 2005) demonstrated that the “Father, Mother, Baby” triad provided a good analogy for three- to five-year old children to solve a variety of problems.

My explanation of the perceptual-to-relational shift as a function of sensitivity to cue validity points to an integration of statistical and symbolic approaches (which seem necessary for analogical reasoning) in understanding the development of generalization. Within this account, it is entirely possible (as in the present studies) for children to fail to generalize over relations that they represent merely because they fail to realize that the relation is a reliable predictor of the property, name, or category that they are asked to induce. Computational approaches to such developmental phenomena might be profitably modeled by cognitive architectures such as DORA (Doumas & Hummell, 2005; Doumas et al., submitted), which is able to discover new relations on the basis of observation alone. In my view, an architecture that is capable of discovering relations from distributional information is, at least in principle, also capable of tracking which relations are and are not reliable for making generalizations, and thus to accommodate the relational-to-perceptual
shift that I observed in Experiments 4 and 5, as well as the perceptual-to-relational shift commonly highlighted in the developmental literature.

In conclusion, I think that what makes humans so smart is not just the ability to shift from generalizing over common features to generalizing over common roles. Instead, the flexibility of cognition that makes human cognition so adaptive – that allows me to classify dolphins as perceptually similar to swordfish but biologically similar to bears, or to draw analogies when they are warranted and to ignore them when they are not – is an increased sensitivity to different types of similarities (concrete as well as abstract) as reliable predictors of novel properties. This adaptive flexibility is not always evident in young children, but often these failures may reflect an insufficient base of knowledge about which type of information to use rather than any inherent bias toward perceptual over relational similarity.
CHAPTER 4

FLEXIBILITY OF RELATIONAL MATCHING OVER DEVELOPMENT

Different theories of generalization predict different patterns of flexibility and automaticity. For instance, a maturational hypothesis has been proposed to account for differences between childlike and adult-like patterns of generalization. These theories typically posit a shift from generalizing over perceptual similarities to generalizing over relational similarities. Rarely, however, is the role of real-time flexibility addressed. That is, there is ample evidence that children can generalize over both perceptual similarities and relational similarities; however, there is little evidence regarding what happens when they are asked to switch from generalizing over perceptual matches to generalizing over relational matches. Assessing this flexibility is important because, whereas much is known about inhibiting one feature for another, very little is known about inhibiting a feature for a relation, or vice versa.

What, then, do we know about costs of task switching when asked to inhibit one feature that was previously used for generalization and use a different feature? Previous research has demonstrated the utility of task switching costs as a measure of inhibition, asymmetry of interference and cognitive complexity (Kirkham, Cruess & Diamond, 2003; Monsell, 2002; Wylie & Allport, 2000; Zelazo, 2004; Zelazo, 2006). Re-engaging attention to previously inhibited stimuli has been interpreted as an indicator of automaticity (Monsell, 2002; Monsell et al, 2000). The more time spent practicing a task, or the more
recently the task was practiced, the easier to enable a task set. Costs of task switching, then, are a measure of the time it takes the control process to reconfigure the task set, as Monsell (2002, p. 135) puts it, a kind of mental ‘gear changing’. For instance, with the Stroop task, the display color of a word interferes much more with naming the display color than naming the word. This effect is due to the stronger task-set for word naming given the frequency with which we read words compared to the frequency with which we name colors. Additional inhibition is needed to suppress the urge to read the word than to enable performance of naming the color.

Larger costs of task switching occur when switching to a dominant language from a second language (Meuter & Allport, 1999). Slower response latencies when participants switched from their second language to their dominant language might be the result of differences in relative strength of the two languages and need to actively inhibit the dominant language. In this scenario, cost of task switching is a measure of the carry-over of positive priming from the currently irrelevant dimension from its use on the earlier trials and the release of inhibition of the now relevant dimension. This suggests, then, that when an automatic task is followed by a non-automatic task, the need to inhibit the stronger task-set of the automatic task during the non-automatic task interferes with performance on the automatic task.

Some theories of generalization posit that perceptual matching occurs necessarily prior to relational matching. For instance, perceptual matching is an “easier” task requiring less cognitive control and can be performed by children with less developed cognitive architecture. Evidence from work by Halford
(1992, 1995) suggested that, with maturation, children first could use only binary relations before acquiring ternary, and then more complex, quaternary relations. Other evidence suggested that children are able to perform relational matches after mapping similarities from base to target using first perceptual similarities before recognizing relational similarities. For example, recall the experiment described previously in which preschool children watched an experimenter hide a sticker under one object within a triad of objects arranged in increasing size. Three-year-olds successfully found the sticker when the objects were perceptually and relationally identical. However, these children ignored the size relation (e.g., middle) and chose based on perceptual similarity when objects were cross-mapped (Gentner & Rattermann, 1991).

These theories about a perceptual-to-relational shift in generalization posit that matching by perceptual similarity is initially automatic: thus, with maturation of executive functioning or experience, children learn to ignore highly salient perceptual matches and use more predictive relational matching. For instance, Kirkham, Cruess and Diamond (2003) investigated the role of inhibition salient perceptual matches using the Dimensional Change Card Sort (DCCS) with three- and four-year-old children. Children were asked to sort cards based on color (red or blue) into two boxes, the “blue boat” box and the “red train” box. Mid-task, participants were asked to switch sort dimension to shape (boat or train). On one hand, three-year-olds failed to sort correctly in the standard experimental set up described above, and when the cue to the sort dimension was both visible and not visible. On the other hand, four-year-olds were successful on all permutations of the task except when cards were put face
up in the boxes. Kirkham and her colleagues interpreted the failures of three-year-olds to indicate a deficit in their inhibitory control. This deficit is largely overcome by the age of four when children have gained the ability to inhibit their attention to previously relevant perceptual aspects of the stimulus and can disengage attention to currently relevant aspects. Thus, three-year-olds appeared inflexible in their ability to change tasks, whereas four-year-olds, in contrast, were able to flexibly apply different rules to the task, suggesting that flexibility increases with age.

Increasing flexibility with age is predicted by another theory of switching costs, Zelazo and colleagues’ (Muller et al, 2006) Cognitive Complexity and Control (CCC) theory, in which increasing self-reflection and higher order rule use allows for greater cognitive control. With age, participants’ ability to represent more complex rule structures affords greater task success. To the card sort task described above, Zelazo and colleagues added a negative priming paradigm to investigate the role of inhibition and rule structure. Participants initially sorted red rabbits and blue boats by shape. The original exemplars were removed and participants were asked to sort by a different dimension. As exemplars, participants were provided with red trucks and blue horses and asked to sort by color. In this case, the original shapes (i.e., rabbits and boats) have changed and so, given that they have not previously seen trucks and horses, inhibition of representations of “truck” and “horse” cannot interfere with performance on the subsequent task, as “rabbit” and “boat” might have. Three-year-olds failed this negative priming task. Rather than only being unable to inhibit previously relevant aspects of the task, Zelazo argued that, in addition,
three-year-olds have difficulty paying attention to the currently relevant aspects of the situation when they have been previously irrelevant. That is, it is not only that three-year-olds failed the card sort task because they were unable to inhibit attention to one aspect of the stimuli but also that they failed to engage attention to the currently important aspects. It appears then that failure to solve a negatively primed switching task indexes inhibition, as well as engaging attention to previously inhibited stimuli – in short, flexibility.

The perceptual-to-relational shift hypothesis predicts that children will use perceptual matching more often than relational matching and therefore, will be more practiced at a perceptual matching task. Due to this practice, they will have more difficulty inhibiting perceptual matches to perform relational matches. Adults, on the other hand, will use both perceptual matching and relational matching flexibly and not incur difficulties inhibiting either perceptual matching or relational matching.

My cue validity hypothesis, in contrast, predicts that children’s attention is drawn equally to both perceptual matches and relational matches, and that they use these two types of similarities more flexibly than optimally. That is, children can make both perceptual and relational matches, however, they have not yet learned which cues to attend to in order to maximize their accuracy using either perceptual matching or relational matching. Because perceptual matching maximizes accuracy in many contexts, children and adults rarely learn to inhibit perceptual matches. However, they do need to inhibit irrelevant relational matches. Consequently, my central prediction is that, with experience, relational
matching becomes easy to inhibit whereas perceptual matching becomes difficult to inhibit as it is less practiced.

4.1 The Present Studies

I assessed flexibility of solving these two types of problems—prey and offspring—by examining performance on a block of problems that either followed a block of similar problems (no switch condition) or followed a block of different problems (switch condition). These two conditions invite competing predictions from the perceptual-to-relational shift hypothesis and my cue validity hypothesis. Generally, the perceptual-to-relational shift hypothesis suggests that perceptual matching is initially automatic, but that age and experience leads to greater cognitive control and thus flexibility in performance. For the present study, this hypothesis predicts (1) that perceptual-matching should be more frequent in children than adults across both prey and offspring problems, and (2) that perceptual-matching initially will be more automatic than relational-matching, leading to a large cost in accuracy when switching from prey to offspring problems.

In contrast, my cue validity hypothesis generates different predictions about both initial biases and how children respond to switches in blocks of problems. Regarding initial biases, the hypothesis predicts that relational matching should increase with age and experience on offspring problems (where relational similarity is most reliable), whereas relational matching should decrease with age on prey problems (where perceptual similarity is most reliable). Regarding task switching, the hypothesis predicts that flexibility of perceptual-matching will decline as the automaticity of perceptual-matching
increases. Thus, as perceptual-matching becomes more automatic with age, adults’ performance will suffer large costs in accuracy when switching from prey to offspring problems, whereas children’s performance for the same switch will be more accurate. This prediction is not a trivial one: children’s perseverative biases are ubiquitous in cognitive development, thereby providing a particularly strong test of the cue validity hypothesis.

To sum, by investigating the costs of task switching to generalization strategies, I can determine if (a) there are shifting costs, (b) there is a developmental difference in these costs and (c) whether one age group is biased to use one type of matching over another.

4.2. Experiment 6: Flexibility of Inhibition

4.2.1 Method

4.2.1.1 Participants. Participants included sixty-four preschoolers (mean age = 5.2 years; range = 4.39 to 6.69), 25 girls and 29 boys. Thirty-two adults (mean age = 19 years; range = 18 to 25), 18 women and 14 men, participated in this study.

4.2.1.2 Stimuli and Procedure. On a computer, participants were presented with illustrations of juvenile and adult insects and pre-recorded information and questions. The relative similarity of the adults \(\frac{Sim[XX,TT]}{Sim[YY,TT]+Sim[YY,TT]}\); adult similarity) was never equal to the relative similarity of the juveniles \(\frac{Sim[a,t]}{Sim[a,t]+Sim[b,t]}\); juvenile similarity).

Participants were randomly assigned to one of four conditions (Table 2): no-switch offspring (two blocks of offspring problems), no-switch prey (two blocks of prey problems), switch offspring (one block of prey problems followed
by one block of offspring problems) or switch prey (one block of offspring problems followed by one block of prey problems).

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<th>Table 2</th>
<th>Experiment 6</th>
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<td>Prey no switch</td>
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Table 2: Design of Experiment 6. Blocks have four trials each.

Offspring problems and prey problems, as described previously, are displayed in Figure 7 and 8 (Chapter 2). For every question, juvenile-\(a\) appeared first with accompanying auditory stimuli (“Look at this one!”), followed by adults-\(XX\) (offspring condition: “These two bugs gave birth to this one here”/prey condition: ”These two bugs want to eat this one here”), juvenile-\(b\) (“Look at this one!”), adults-\(YY\) (offspring condition: “These two bugs gave birth to this one here.”/prey condition: ”These two bugs want to eat this one here.”), adults-\(TT\) (offspring condition: “These two bugs gave birth to…”/prey condition: ”These two bugs want to eat…”) and juvenile-\(t\) (“this one here.”). Participants were instructed to answer by pointing to either the left or right side of the computer screen. On each of the trials, participants were asked three questions – whether the target was the same kind as \(a\) or \(b\) (categorization), whether it would look like \(a\) or \(b\) in the future (projection), and whether it had a property (\textit{golgi}) inside its blood similar to \(a\) or \(b\) (induction).
4.2.2 Results and Discussion

All analyses, unless otherwise stated, were performed on the second block of trials, which provide participants’ responses to a task having been primed with a previous block of tasks. When accuracy on the second block of trials were analyzed using a three-way ANOVA (age: adults, preschoolers; condition: no-switch, switch; task type: offspring, prey), I found a three-way interaction of age, condition and task, $F(1, 88) = 7.9, p < 0.01$. To explore this interaction further, I analyzed the data for each task separately.

4.2.2.1 Prey problems: The effect of switching differed for preschoolers and adults, $F(1, 44) = 5.88, p < 0.05$ (Figure 11). For preschoolers, switching led to a large decrease in accuracy, $F(1, 31) = 16.05, p < 0.0001$, Cohen’s $d = 1.33$, reflecting a failure to inhibit relational matching from the previous block of offspring problems. In contrast, adults were not affected by the switch, $F(1, 15) = 0.074, p = ns$, reflecting the inability to inhibit relational matching from the previous block of offspring problems. Thus, performance on prey problems revealed a development in the ability to inhibit relational matching.
Notice that adults were highly successful on prey problems. Preschoolers, on the other hand, were successful on the no-switch task but not on the switch task. Children were unable to inhibit relational matching responses when switching to a task requiring perceptual matching.

4.2.2.2 Offspring problems On offspring problems, the effect of switching was similar for preschoolers and adults, $F(1, 44) = 2.36, p = 0.13$ (Figure 12). Overall, switching led to a large decrease in accuracy, $F(1, 44) = 25.74, p < 0.0001, \ d = 1.546,$ reflecting a general inability to inhibit inaccurate perceptual matching. Far from adults improving their ability to inhibit inaccurate perceptual matching, the nominal age difference in costs of switch came from slightly larger switch
costs in adults, $F(1, 15) = 19.44, p < 0.001, d = 1.595$, than in children, $F(1, 31) = 13.06, p < 0.001, d = 1.27$. Thus, performance on offspring problems revealed no development in the ability to inhibit perceptual matching.

**Offspring Problems**

![Graph showing accuracy of task switching between preschoolers and adults.]

Figure 12: Offspring problems. Notice that adults incurred a large cost of task switching when switching from using perceptual matching to using relational matching on offspring problems.

These findings do not support an increase in the ability to inhibit inaccurate perceptual matching. These findings do, however, support an increase in the ability to inhibit inaccurate relational matching. Whereas adults had no difficulty in switching from relational matching to perceptual matching,
children’s accuracy suffered when switching from relational matching to perceptual matching (Figure 13).

Figure 13: Costs of task switching. Notice that adults easily inhibited relational matches but not perceptual matches. Preschoolers, on the other hand, had equivalent costs of task switching on both tasks.

To sum, a three-way interaction indicating that the costs of task switching differed by age group (preschoolers, adults), problem type (offspring, prey) and condition (switch, no-switch) suggested that the cost of task switching and generalization is more complex than perceptual-to-relational shift theorists have
concluded. Contrary to predictions that would have the development of perceptual matching preceding relational matching, I found that children were not biased to generalize based on perceptual similarity. As predicted by my cue validity hypothesis, preschoolers could not use a particular similarity more automatically than another in their use of different cues for generalization. Furthermore, children appeared equally flexible in their context specific generalizing as demonstrated by the equivalent switching costs for both prey switch and offspring switch tasks. Adults, on the other hand, evinced a large cost when inhibiting perceptual matches but not with relational matches.

4.3 General Discussion

These findings are important to understand the development of generalization. If, as my data demonstrated, children lack perceptual automaticity when generalizing, how can they, simultaneously, be perceptually bound, or generalize based on perceptual cue before relational cues (Gentner & Ratterman, 1998; Ratterman & Gentner, 1998; Springer, 2001)? Moreover, the pattern that I have found, whereby adults, but not children, are able to easily inhibit relational matches but not perceptual matches, suggests that adults are responding to stimuli using automatic choices. This pattern makes sense when generalization is looked at in a learning context. When in doubt, perceptual matching strategies indeed do yield accurate results much of the time. To this end, adults have learned to respond based on perceptual similarity. This bias, however, does not require that perceptual similarity matching is either the dominant mode of matching or the automatic mode. Instead, it is a strategy that works well in a variety of settings and is a useful tool that we have learned.
Looked at this way, the adults in my study were biased to respond using perceptual-matching because employing a good, general learning mechanism, in an effort to maximize accuracy on the task. Adults incurred the greatest costs when switching from an automatic task, perceptual matching, to a less automatic, relational matching, task. In offspring problems where relational matching is the dominant strategy, adults’ performance suffered when shifting from matching based on perceptual features to relational features.

Furthermore, looking at these results in light of Allport and colleagues’ work suggests that there is a cost to practice and increased knowledge that is measured in task switching costs. It follows that the more practiced the task, the more automatic the task, the more difficult it might be to switch. Just such an asymmetry has been found in language tasks, whereby additional inhibition is required of automatic tasks but not more difficult ones (Meuter & Allport, 1999; Wylie & Allport, 2000; Waszak, Hommel & Allport, 2005). That is, the asymmetry of inference as evidenced by the ease or automaticity of task is determined by the need for extra inhibition of easy tasks versus more difficult tasks. In this study, I have demonstrated that the asymmetry is not what perceptual-to-relational shift theorists might expect; indeed, the picture appears to be developmentally opposite. Rather than preschool children automatically generalizing by perceptual matches and obtaining the flexibility to use relations with age, I found that children are far more flexible and less automatic in their ability to generalize. Adults’ generalize more automatically and less flexibly than children—as evidenced by their perceptual biases—thus, demonstrating a similar asymmetry as Allport and colleagues have described previously.
The importance of context specificity to maximize accuracy is not limited to categorization, similar results have been found with word learning (Smith & Samuelson, 2006). The Attentional Learning Account (ALA) of early noun learning stipulates that learned associations create contextually cued attentional biases. That is, in the moment of learning, children automatically attend to similarities that have previously predicted accuracy in linguistic and perceptual contexts in the child’s learning history. Learned associations drive this top-down control of children’s attention in the moment of learning from the child’s past, which then modulates her attentions. As this automatic attention is reinforced, it becomes an automatic process. According to Smith and her colleagues, through this dynamic binding of context cues, children can attend to linguistically and perceptually irrelevant similarities. These contextually cued attentional biases are similar to what we see in this paper with the adults’ bias to perceptual matching. Like contextually cued attentional biases, however, perceptual matching is not a privileged process that comes online prior to relational matching or results in a whole-scale shift from use of one strategy to another.

To sum, in this chapter, I investigated the costs of switching generalization strategies. In doing so, I determined that there are shifting costs that differ both by task and by age. Adults appear to have more difficult inhibiting their use of perceptual matching than relational matching, whereas children have equivalent difficulties in their ability to inhibit either type of matching.
CHAPTER 5

CONCLUSION

This dissertation reports a series of experiments that test an alternative explanation for the roles of perceptual and relational similarity in the development of generalization. Rather than development proceeding from generalizations over perceptual similarities to generalizations over relational similarities, the dominant developmental pattern appears to be towards generalizing over highly predictive similarities, regardless of whether the similarities are perceptual or relational. Within this latter view, the important developmental question is not when children learn to ignore irrelevant perceptual similarities in favor of relational ones, but how children learn the contexts in which they should ignore irrelevant perceptual similarities and irrelevant relational similarities. Moreover, if my account is correct, there are interesting implications for problems where perceptual and relational similarities conflict. Specifically, it predicts increasing use of relational matches with age for relations that reliably predict novel properties and decreasing use of relational matches with age for relations that do not reliably predict novel properties. Finally, I have provided a possible mechanism behind these findings: a learning mechanism.

In this series of studies, I first demonstrated in Experiment 1 that young children were able to make both perceptual and relational matches to correctly solve generalization tasks and, in the control study, Experiment 2, that they are,
indeed, using the relation to solve this task. Additionally, in Experiment 3, children’s performance on this task was not driven by the label serving as a salient, shared property. In Experiment 4, I found that there is a developmental trend in participants’ ability to make perceptual and relational matches. That is, with age, accuracy on both perceptual matching and relational matching increased. Whereas this might suggest a maturational effect, in Experiment 5, I was able to induce this change in the youngest age group, three-year-olds, to demonstrate that this effect was due to learning, not simply maturation. Finally, in Experiment 6, I demonstrated that adults, rather than children, were perceptually bound. Adults had larger costs of task switching from perceptual matching to relational matching problems. Children had equivalent switching costs both from perceptual matching to relational matching problems and vice versa.

5.1 Contributions of this research

This work provides a valuable contribution to the research on the development on generalization. First, it joins a growing literature demonstrating the early use of relations in young children. The finding that children use different relations to select the perceptual features by which to categorize suggests an interesting perspective on Gelman and Markman’s (1986) findings and on Sloutsky and Fisher’s (2004) failure to replicate them. In this work, I provided a conceptual replication of Gelman and Markman’s work; children ignored perceptual similarity and used relational information to infer category membership. Further, in Experiment 2, labels did not enhance category-based induction compared to Experiment 1, suggesting that young
children’s bias to attend to auditory information (Napolitano & Sloutsky, 2004; Robinson & Sloutsky, 2004; Sloutsky & Lo, 1999; Sloutsky, Lo, & Fisher, 2001) cannot explain their category-based induction, as it might have in Gelman and Markman (1986). Most generally, these results are consistent with claims that children’s category-based induction relies on use of causally central information (Ahn, Gelman, Amsterlaw, Hohenstein, & Kalish, 2000; Springer, 2001), which is a central tenet of Gelman’s (2003) theory of early categorization.

Secondly, this finding appears to be generalizable beyond the specific relations and features tested. Whereas one might ask how widely children use the parent/offspring relation to generalize in their everyday lives, without detailed information about the frequencies that children even encounter origin information, any answer to this question is admittedly speculative, and sharply different answers have been aired (Gelman & Wellman, 1991; Oakes & Madole, 2003; Rakison, 2003). My view is that both direct and indirect information about origins might be present to some degree. First, children have direct experience with offspring that are not clones of their parents and thus could learn that parent/offspring relations are more predictive of category-membership than appearances. For instance, two seeds may look similar, but since they come from different fruit their properties differ substantially; two chicks may look similar, but since they are hatched from eggs laid by different birds, their properties also differ; and so on. These contexts of direct origin information could provide indirect information about origins. Thus, that kin tend to cohabitate (Lieberman, Tooby, & Cosmides, 2003), engage in nepotism (Agrawal, 2001; Hamilton, 1964), and avoid engaging in incest (Lieberman et al., 2003), infanticide (Struhsaker &
Leland, 1987; Watts, 1989; Watts & Mitani, 2000) and cannibalism (Bilde & Lubin, 2001; Watts & Mitani, 2000) potentially provides a rich source of indirect information about origins and thus its importance in category-judgments. The importance of causal relations is not limited to biology. Evidence of origin-based generalization is reported in literature from social psychology (Rothbart & Taylor, 1992) and cognitive anthropology (Gil-White, 2001), where descent affects generalizations within social groups.

Thirdly, it offers an alternative hypothesis, utilizing learning theory, to account for the putative perceptual-to-relational shift in contrast to the maturational hypothesis and the epistemological general-purpose mechanism. These findings stand in contrast to the conceptualization of generalization as a maturation shift from the ability to use binary to using ternary and quaternary relations. That is, given that three-year-olds were successful at this task with feedback, suggests that the putative perceptual-to-relational shift is due to learning, not maturation. Additionally, the costs of task switching accrued by adults when inhibiting perceptual matching to perform relational matching suggests that adults are matching using perceptual cues automatically. That the pattern of children’s performance did not demonstrate such a lack of inhibition suggested that children are neither perceptually bound nor relationally bound.

These findings also stand in contrast to the conceptualization of generalization as an epistemological shift due to a general-purpose comparison mechanism. That is, specifically, I do not find evidential support for the primacy of perceptual matching over relational matching. Instead, these studies support a theory that predicts learning over both perceptual and relational
similarities, with a view to maximizing accuracy. In particular, in Experiment 4, I found a developmental shift from chance performance on both tasks by three-year-olds, to more successful performance on both perceptual matching and relational matching tasks by five-year-olds and adults. Additionally, it was the adults in the task-switching task that used perceptual matching as a default, easier strategy, not children. Instead, children were equally bound by both perceptual similarity and relational similarity.

In contrast, these findings clearly support the cue validity hypothesis. As predicted by the cue validity hypothesis, children can make early use of relations to solve problems in which relations have high cue validity. With feedback, three-year-olds learn to use different similarities in the tasks to solve generalization problems successfully. Rather than the “relational shift” that I expected to find, with age and experience, children learned to use both perceptual matching and relational matching appropriately to solve generalization questions. Finally, I have provided evidence that perceptual matching becomes more automatic with practice. This finding in particular stands in contrast to previous hypotheses predicting that children automatically use perceptual matching and only become adept at relational matching with age.

5.2 Future directions

This research suggests future directions for study. In the experiments reported here, I used a relation that is well known to young children. It is well known that young children can use the offspring/parent relation to solve class-inclusion problems and has been predicted to be relevant to young children by
Halford (1993), Goswami (1995) and Gentner (Gentner & Rattermann, 1998). Further study using different relations is important to demonstrate the generalizability of the findings presented here.

I have provided evidence that children can track cue validity. Indeed, when provided with feedback, three-year-olds were able to use perceptual matches and relational matches quite accurately. An interesting test of this hypothesis would be to manipulate the predictive accuracy of relational matches. That is, children would be provided with feedback mapping onto different rates of accuracy – 80 percent, 50 percent, and 20 percent – to discern if participants’ rates of generalization change accordingly. This study provides a strong test of the cue validity hypothesis.

Whereas the cue validity hypothesis does not address origin states of perceptual matching or relational matching, it posits that the cognitive ability to do both is present early, needing only outside information to track relative accuracy. If relational matching does not necessarily precede perceptual matching, as I have argued here, then accounts that rely on comparison to derive relations out of perceptual similarities will not account for the ability to use relations to generalize. Nor will maturation accounts relying on changes in cognitive control. Thus, in a much broader context beyond this work, it behooves us to ask about the origin states of generalization.

To conclude, I maintain that we start out neither matching by fins nor matching by something unseen like “mammalhood.” Instead, we learn when matching by either perceptual similarity or relational similarity increases our likelihood of being correct. Thus, when asked what lives in the ocean, we can
correctly induce that swordfish and dolphins live in the ocean by matching by their features – fins – and when asked which animals nurse their young, by matching by their relations – mammals – we can induce that dolphins and bears nurse their young. This cognitive flexibility is what makes humans so smart.
LIST OF REFERENCES


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