

Stegosaurus and Spoonbills: Mechanisms for transfer across biological domains

Joyce M. Alexander

Indiana University

Kathy E. Johnson

Indiana University-Purdue University Indianapolis

Brianna Scott

Indiana University

Rhonda D. Meyer

Alliance for School Choice

In (2008) M. F. Shaughnessy, M. V. Veenman, & C. K. Kennedy (Eds.), Metacognition: A Recent Review of Research, Theory, and Perspectives. (pp. 63-83). Happaug, NY: Nova Publications

This research was supported by grants BCS-9907865 and BCS-0217466 from the National Science Foundation. We thank Shannon Brown and numerous research assistants at IUPUI and IU for their assistance on this project. We also wish to thank the children and parents who participated in this study, Mudge Morris for her expertise on dinosaurs, and Allison Douglas for her expertise on dolphins, whales, and sharks. Correspondence and requests for reprints should be directed to Joyce Alexander, Department of Counseling and Educational Psychology, 201 N. Rose Ave., Bloomington, IN 47405 (joalexan@indiana.edu).

Abstract

This chapter examines the state of the literature regarding transfer across domains built primarily of declarative knowledge, with a particular emphasis on domains related to biology. We propose that expertise in declarative knowledge domains can transfer to other related domains but not through typical strategy use or procedural knowledge platforms. Transfer between domains related to biology seems to be facilitated by an increased level of attention to perceptual and behavioral features in the expert domain. Although there is a significant literature documenting transfer across declarative knowledge domains in adults, evidence for transfer in children has been more difficult to obtain. The present chapter presents a model of the types of knowledge which would be prone to transfer effects in children and reviews research on the factors that most likely facilitate that transfer. We argue that transfer in children, when it does occur, is often implicit and unaccompanied by metacognitive awareness, and we provide relevant evidence through an analysis of children's performance on a referential communication task. Finally, methods for supporting the development of metacognitive knowledge about concepts are explored, as well as future directions for research.

Stegosaurus and Spoonbills: Mechanisms for Transfer Across Biological Domains

Although children frequently are depicted as universal novices (Brown & DeLoache, 1978), there are groups of child experts who, because of interest or experience, have come to know more about a domain than many adults will ever know (e.g., Alexander, Johnson, & Schreiber, 2002; Chi, 1978). A child expert's superior performance is facilitated by a well-organized and rich semantic network of domain-specific knowledge (e.g., Gobbo & Chi, 1986). Attempts to glean evidence that components of expert skill transfer to unfamiliar domains have invariably met with failure in the adult and child skilled performance literature (e.g., Chi, Glaser, & Farr, 1988; Glaser, 1987). These failures may be attributable to the types of domains that have been investigated. Research on expertise has been devoted predominantly to domains dependent on strategic performance and procedural knowledge (e.g., chess, computer programming, Go). In domains such as these, the strategies that are used to increase proficiency are inextricably linked to conceptual knowledge pertaining to the domain.

Mastery of domains characterized by knowledge of object categories (e.g., dinosaurs, rocks) is rooted in category differentiation and the learning of features and dimensions along which category members may be grouped, rather than in the development of knowledge-dependent heuristics. As such, it is possible that expertise may exert effects on categorization and perceptual discrimination in less familiar but related domains, particularly if such domains share theoretical similarity (e.g., two different biological domains). The potential role of metacognition and other individual difference variables in facilitating such transfer is not known, particularly for young children.

The present chapter will review evidence from studies of child experts and explore questions such as: What types of knowledge transfer from one biological domain to another? How extensive is the transfer? What factors facilitate this transfer? The remainder of the chapter addresses these questions through 4 sections. In the first, we review the literature surrounding the effects of expertise and the extent of transfer typically seen. Next, we review the literature that

examines child experts and the transfer of their knowledge, proposing a model for the transfer of expertise across domains. Following, we review the literature on factors that support transfer across domains such as IQ and metacognitive knowledge. Finally, we examine our model with a set of data from 4- to 9-year-old dinosaur experts and conclude with future directions for research.

Expertise

Although expertise exists along a continuum, individuals who are considered to be experts typically have acquired vast amounts of domain-specific knowledge and the ability to perform domain-relevant pattern-based retrieval in their area of expertise (Chase & Simon, 1973; Ericsson & Lehman, 1996). Experts display highly organized knowledge (Chi, Glaser, & Rees, 1982; Hoffman 1992) and generally represent problems in their domain of expertise in terms of general principles rather than surface elements (Chi, Feltovich, & Glaser, 1981). For example, research on expertise effects in the domain of physics has shown that novices tend to focus on the explicit information given in a problem (objects, surface structure of the problem, etc) while experts tend to focus more on nonobvious principles acquired through inferences, classifying physics problems in terms of physical principles aligned with problem solutions. In addition, the automaticity of access to information within the domain reduces the role of memory search and general processing skills in experts' problem solving (Glaser, 1987).

Experts also understand the conditions under which their knowledge might be useful and know how to regulate problem solving within the domain (Chi et al., 1981). Importantly, however, performance quality is not solely related to time spent in the domain but instead likely relates to the role of deliberate practice and the factors that lead some individuals to engage in sustained, deliberate practice more than others (Ericsson & Charness, 1995; Ericsson, Krampe, & Tesch-Romer, 1993). Interestingly, expertise in a domain is not necessarily related to high scores on measures of general intelligence (Chase & Simon, 1973).

Child experts. Children who are experts on domains such as dinosaurs and chess, while not likely to reach the pinnacle of consistent performance described by Ericsson and Lehman (1996) or Glaser (1987), still know more about a domain than most adults will ever know. Research in this area has suggested that child experts possess, a) improved memory for domain-relevant information; b) better understanding of causal relations; c) knowledge of many words denoting concepts learned within the relevant domain; d) improved processing efficiency, and e) hierarchically-organized domain knowledge (e.g., Chi, 1978; Chi, Hutchinson & Robin, 1989; Chi & Koeske, 1983; Gobbo & Chi, 1986; Johnson & Mervis, 1994).

Child experts present a unique opportunity for studying the relation between developmental processes and the increased processing efficiency that accompanies the acquisition of expertise. Typically age and knowledge levels covary throughout childhood. Thus, older children know more than do younger children. In addition, older children have more strategies available to support their learning than do younger children, as well as higher levels of metacognitive knowledge. The availability of child experts allows researchers to test the degree to which increases in domain-specific knowledge can account for changes in performance normally attributed to cognitive developmental processes (Carey, 1985). Researchers can capitalize on the availability of child experts to address a range of questions pertaining to knowledge effects, transfer, and potential mechanisms for such transfer.

Expertise on domains related to biology. The term “domain” is used by different groups of researchers to mean different things (Hirschfeld & Gelman, 1994). Some researchers use this term to refer to extremely broad areas of cognitive competencies, such as the representation of number or causal relations. Others use the term "domain" to denote theories, or coherent clusters of beliefs pertaining to areas such as biology, physics, or music (Carey, 1985; Gopnik &

Meltzoff, 1997; Karmiloff-Smith, 1992). We have adopted the use frequently seen in the expertise literature, where "domain" tends to have a considerably narrower focus, typically referring to particular areas of specialization such as chess, numerical digit span, or birds (Ericsson & Smith, 1991).

Domains that are related to biological concepts are composed primarily of declarative knowledge. These domains are organized taxonomically through hierarchical inclusion relations that support induction (Berlin, Breedlove, & Raven, 1973; Malt, 1995; Waxman, Lynch, Casey, & Baer, 1997), and they encompass a rich array of perceptual and behavioral features that vary in terms of the degree to which they are extended across categories or category members (Shipley, 1993; 2000). Mastery of domains related to biological concepts thus requires category differentiation and the learning of features and dimensions by which members can be grouped. Across most object domains (whether related to biology or not), concepts may be represented at multiple levels of specificity: *superordinate* (e.g., animal, vehicle); *basic* (e.g., bird, car); *subordinate* (e.g., sparrow, sedan), and *sub-subordinate* (e.g., chipping sparrow, Pontiac sedan). *Basic* level concepts are most perceptually and pragmatically salient and have been shown to be the most common level at which items are categorized (e.g., Gelman, 2003; Neisser, 1987; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976).

Domains related to biological knowledge consist primarily of *subordinate* concepts (e.g., kinds of dinosaurs, kinds of birds). Categorization at subordinate levels is considerably more difficult for young children than categorization at the basic level because of the similarities among category members (e.g., all kinds of dinosaurs look alike and function similarly relative to basic level contrasts among dinosaurs, birds, and cetaceans; Callanan, 1989; Mervis & Crisafi,

1982; Mervis, Johnson, & Mervis, 1994). This difficulty in subordinate level categorization is one of the first obstacles that must be overcome by a developing child expert.

At an even deeper and more abstract level, biological concepts are embedded within larger knowledge systems or theories (Keil & Lockhart, 1999; Medin, 1989; Murphy, 2001) – most notably a framework theory of biology (Barrett, Abdi, Murphy, & Gallagher, 1993; Carey, 1985; Johnson, Scott, & Mervis, 2004; Wellman, 1990). Framework theories help to define the ontology of domains by highlighting causally relevant properties that lend organizational structure to the knowledge base. Such theories also help to specify the kinds of theoretical explanations that are appropriate. For example, it would be appropriate to attribute an increase in the size of an animal to growth processes, but inappropriate to attribute an increase in building size to growth.

Much research related to the issue of how expert knowledge impacts categorization has been focused on biological concepts, such as trees (Lynch, Coley, & Medin, 2000; Medin, Lynch, Coley, & Atran, 1997; Proffitt, Coley, & Medin, 2000), birds (Bailenson, Shum, Atran, Medin, & Coley, 2002; Boster, 1988; Boster, Berlin, & O'Neill, 1986; Johnson & Mervis, 1997, 1998), and fish (Boster & Johnson, 1989; Medin et al., 2006). A sizeable literature from the field of cognitive anthropology precipitated much of this work, beginning with Berlin, Breedlove, and Raven's (1973) seminal explorations of folk classification of plants and animals, and the extent to which people's everyday categorization converges with scientific taxonomy (see Malt, 1995 for a review).

Generally this research has provided evidence that for experts, the subordinate level of categorization begins to function as the basic level, in that it is the preferred level for identifying and categorizing objects (Johnson & Mervis, 1997; Tanaka & Taylor, 1992). Furthermore,

experts' knowledge has been shown to reorganize (Johnson & Mervis, 1994), such that experts are essentially freed from relying predominantly on perceived similarity when classifying and reasoning about objects (Coley, Shafto, Stepanova, & Baraff, 2005). Knowledgeable experts can use a variety of causal, thematic, and ecological relations to guide inductive inferences. Abstract goals or ideals also become increasingly salient in determinations of prototypicality (Lynch, et al., 2000). In general, expertise tends to increase one's understanding of multiple relations among entities, and the ability to apply this understanding in context-specific ways (Shafto & Coley, 2003). Whether these tendencies remain constrained to the domain of expertise, or whether they generalize to other domains related to biology will be considered throughout the remainder of this chapter.

Transfer of Expertise

Expertise is generally thought to be largely domain-specific. Ericsson and Charness (1999) have argued that the acquisition of expertise depends upon approximately 10 years of deliberate practice and study. Interestingly, Glaser (1987) has suggested that certain domains may lend themselves more to generalizability than others. When domain structures are sufficiently similar such that structural alignment and analogical thinking are tenable, aspects of expertise might transfer to the structurally similar domain (Gentner & Gentner, 1983). In general, however, transfer from the domain of expertise to other domains is very rare.

The basic assumption behind transfer is that knowledge or skills from the expert domain is directly applied to other domains (DeCorte, 2003). *Near transfer*, or the transfer of skills or knowledge between very similar contexts (as when a garage mechanic transfers knowledge of a particular car model's engine to a newer model) occurs fairly readily (Perkins & Salomon, 1988). However, evidence for *far transfer*, or the transfer of skills across contexts that on the surface seem very dissimilar (as in the application of chess strategies to political or military campaigns), has consistently been difficult to obtain (Bransford & Schwartz, 1999; Thorndike & Woodworth,

1901). Though the transfer of knowledge across domains that are related to biology would seem more challenging than generalizing from one car model's engine to that of a newer model, it fits more closely with Perkins and Salomon's (1988) notion of near transfer. Clearly, examples of near and far transfer exist along a continuum of opportunities for transfer (Barnett & Ceci, 2002).

Perkins and Salomon (1988) have argued that any type of transfer is more likely under certain conditions. First, the initial knowledge or skills should have been thoroughly learned and already practiced across multiple contexts. Transfer can also be facilitated through an explicit abstraction process whereby the learner reflects on underlying principles that are acquired in one situation and then applies those de-contextualized principles to a new situation, otherwise known as "high road transfer." Typically the learner's metacognitive knowledge or the explicit use of analogies by a teacher can play a significant role in facilitating high road transfer.

Bransford and Schwartz (1999; p. 66) have noted that, "prevailing theories and methods of measuring transfer work well for studying full-blown expertise, but they represent too blunt an instrument for studying the smaller changes in learning that lead to the development of expertise. New theories and measures of transfer are required." Bransford and Schwartz go on to propose that these new theories of transfer need to concentrate on the effects of current learning on the subsequent learning of new information, not on the direct application of information from one situation to another. In other words, how well are the individuals "prepared for future learning?" They argue that a focus on preparation for future learning (PFL) may enable researchers to notice instances of positive transfer that would normally be hidden. Transfer may also need to be studied through the implicit transfer of information between domains (Alexander, Johnson, Albano, Freygang, & Scott, 2006; Johnson & Mervis, 1998), which we turn to next.

Transfer across domains related to biology. Previous research with adults has revealed a clear attentional shift with expertise from relying on surface features to relying on more abstract behavioral features or even features supporting causal/ecological reasoning (Coley, Shafto, Stepanova, & Baraff, 2005; Proffitt, et al., 2000; Shafto & Coley, 2003). Work by Johnson and

Mervis (1998) suggests that this attentional shift may generalize to other biological domains. They found that adult bird experts based similarity decisions on deep features related to taxonomic membership for both familiar (bird) and less familiar (tropical fish) stimuli. Bird experts also rated perceptual features indicative of taxonomic categories in fish (e.g., fin shape) as perceptually more salient than did novices. In a separate study involving both adults and children, Johnson, Scott and Mervis (2004) found that adult dinosaur experts were significantly more likely to infer correct functional correlates for shorebird features than were adult dinosaur novices. Adult dinosaur experts also were likely to accept morphed, hypothetical dinosaurs with novel combinations of features as plausible, providing reasonable explanations for why such features could have co-evolved. Finally, although not based in a biological domain, research by Smeeton, Ward, and Williams (2004) found that experts in field hockey are more likely to transfer pattern recognition skills to similarly structured sports such as soccer but not to sports with different structures such as volleyball (Smeeton, et al., 2004). Thus, some evidence suggests that adult experts are capable of extending at least some aspects of their category-based knowledge to other similar domains.

Assessments of child experts generally have not revealed evidence for direct application of information from one domain to another. Instead, the evidence suggests that high levels of domain-specific knowledge may culminate in the child's better preparation for future learning of related information and an increased likelihood of focusing on diagnostic features in the new domain. This typically happens without the child being explicitly aware of their relative advantage. For example, Johnson and Mervis (1994) reported a case study in which one 4-year-old child's existing knowledge of passerine birds facilitated his rate of learning about (unfamiliar) shorebirds, relative to other children who began with less knowledge. Chi et al.

(1989) found that child dinosaur experts were more likely than novices to transfer their dinosaur knowledge to novel dinosaurs by comparing the novel dinosaurs to known dinosaurs and families in order to draw inferences about expected behaviors. Finally, Johnson and Eilers (1998) found that children with expertise on dinosaurs described differences between unfamiliar shorebird pairs more analytically by emphasizing more subtle perceptual differences than did children with less knowledge.

On the other hand, very little evidence exists in support of explicit transfer of knowledge-dependent strategies in children. Alexander, et al. (2002) found that children with high levels of dinosaur knowledge did not deploy strategies more effectively within a less familiar, but related, biological domain (sea creatures). Their task involved presenting children with pairs of 3-dimensional models behind a screen – children were free to explore the models haptically, but could not see the models. Children were asked to simply decide whether the pair included identical creatures (e.g., 2 tyrannosaurs) or not (a tyrannosaur and an allosaurus). While child experts demonstrated an advantage within the expert domain on haptically identifying the initial model in the pair (even being seen to “count” the number of toes on models using their fingers), younger child experts performed very similarly to same-aged novices (and more poorly than older novices) when completing the cross-model comparison task within both the expert and novice domain. In other words, high levels of knowledge did not override 4-to 6-year-old children’s tendency to perform poorly on the strategy-laden comparison between difficult pairs on the haptic exploration task.

Similarly, Johnson et al. (2004) found little evidence of transfer on a task that depended more heavily on explicit conceptual knowledge as bases for relations among dinosaur features. Children aged 7 to 9 years were presented with two tasks. In the first, they viewed pictures of

hypothetical dinosaurs created by “morphing” dinosaur species together to create feature combinations that were either plausible (e.g., a sauropod with a horned structure on its head; many scientists believe that the horned structures played a communication function, meaning any species of dinosaurs could have evolved with them) or not plausible (e.g., a carnivore with a set of spikes on its back; large predatory dinosaurs rarely would have needed defense mechanisms as they were typically the animal at the top of the food chain). During a series of interview questions, children were asked to decide whether the hypothetical dinosaurs could have evolved, and to justify why or why not. Invariably children indicated that the hypothetical dinosaurs could not have evolved – typically because they had never seen a dinosaur like that before. This is in keeping with Inhelder and Piaget’s (1958) assertion that school-aged children have difficulty with reasoning about the hypothetical – in this case, even when relevant knowledge is quite high. In the second task, children were asked to explain why features of both dinosaurs and shorebirds were functionally important. Although children regularly mentioned relevant properties for dinosaurs (linking body parts to behavioral correlates involving diet, defense, or thermoregulation), children had difficulty making similar inferences for less familiar shorebirds. It may be that the attentional shift described for similarity judgment tasks (Johnson & Mervis, 1994, 1998) precedes the development of explicit awareness concerning why such features are functionally significant. Of course it is also possible that children understand something about the functional significance of the perceptual features that they construe as most salient – yet they have difficulty verbalizing what they know.

In sum, we offer these preliminary conclusions regarding expertise and transfer across object domains. First, what evidence there is for transfer between expert and novice object domains in children appears to be due to a shift in attention to more subtle attributes of objects.

Research by Sheya and Smith (2006) suggests that surface perceptual features may play a significant role in the understanding of behavioral or role properties of basic level objects, beginning early in childhood. In fact, Rakinson (2003) and Booth and Waxman (2002) have suggested that highly diagnostic features at the basic level may be important anchors in the conceptual system that serve to focus attention and memory and link the instance in question to relevant conceptual knowledge beginning in infancy. For child-experts, this shift in attention to more subtle attributes of *subordinate* kinds is likely driven by a low-level perceptual learning mechanism and seems to operate largely outside the realm of explicit awareness, though the role of metacognition in this process has not been tested thoroughly.

It seems possible that this perceptually-driven learning mechanism could facilitate transfer between domains at multiple levels. First, an expert in one domain who is just beginning to learn about a second domain might notice how clusters of surface features tend to co-occur in the new domain in ways that are analogous to feature covariation in the expert domain. For example, sharp teeth and two-leggedness tend to co-occur in the dinosaur domain while a median notch in the tail tends to co-occur with flukes and not caudal fins when comparing sea creatures. Second, experts might begin to notice that surface features tend to relate to behaviors or functions similarly across the two domains. The presence of sharp teeth tends to co-occur with eating meat in the dinosaur domain and with eating fish in sea creatures. Experts might also notice that clusters of behavioral properties also tend to co-occur. Eating meat tends to be associated with running fast (as predators must outrun their prey) and preying on relatively large fish also tends to co-occur with faster swimming speeds. Developing experts might also begin to notice that certain properties tend to form a cohesive set of explanations for behaviors such as diet, thermoregulation, and locomotion. These explanations might eventually cohere into a causal

underlying framework or theory in the expert domain that could be applied to the newly learned domain. Any of this knowledge might facilitate preparation for future learning in the transfer domain

Table 1 summarizes these possibilities. It is plausible that the aspects of expertise listed may transfer to other related domains, at least implicitly. We have organized the table such that transfer is more likely to occur at the lower levels of complexity of knowledge (those rows at the top of the table). In other words, current literature suggests that transfer of the understanding of the importance of diagnostic features in domains related to biology (Johnson & Mervis, 1998) would be more likely than transfer of causal relations inherent within an underlying framework theory (Johnson, et al., 2004)

Factors that Facilitate Transfer

A second aim of this chapter is to consider the effects of individual difference factors on transfer between biological domains - with a particular emphasis on IQ and metacognition. We first define metacognition and briefly review the literature on IQ and its relation to metacognition and transfer. We then concentrate particularly on the role of one type of declarative metacognitive knowledge - metaconceptual knowledge – in facilitating transfer effects.

The exact definition of metacognition has been debated in the literature for decades (c.f. Brown, Bransford, Ferrara, & Campione, 1983; Flavell, 1979). Alexander, Carr, and Schwanenflugel (1995) suggested a definition that includes three elements: 1) declarative metacognitive knowledge; 2) cognitive monitoring; and 3) regulation of strategies. Each of these elements has been shown to improve with age (Alexander et al, 1995). Metacognitive knowledge is an umbrella term typically encompassing “meta” information about many different types of

cognitive processes. The current chapter focuses on the role of declarative metacognitive knowledge about concepts in predicting transfer across conceptual domains.

Individuals with higher IQ scores consistently have been found to be more apt to transfer what they know – particularly across more disparate domains (Alexander, et al., 1995). In addition, children with higher IQs tend to have higher declarative metacognitive knowledge throughout development. Thus, we assume IQ would facilitate the transfer of knowledge from one biological domain to another. Unfortunately, this has typically been difficult to test. Most of the child expert studies we have reviewed have reported above-average IQ scores in children with the highest levels of knowledge (e.g., Alexander, et al., 2002; Johnson & Mervis, 1994, Johnson & Eilers, 1998). Thus, the exact nature of the relation between these variables may present a unique measurement dilemma for the field. Data we will present below are from a more representative sample, though the average IQ is still one standard-deviation above the normed mean.

Work by Veenman, Wilhelm, and Beishuizen (2004) has been aimed at understanding the interplay of IQ and metacognition developmentally in more knowledgeable and less knowledgeable domains. Their work suggests that metacognition is independent of IQ and tends to play a larger role in task performance when individuals are performing in a novice domain. They argue that the metacognitive skills of experts in a domain are well integrated with domain-specific knowledge whereas the metacognitive skills of novices are not as well integrated with domain knowledge. They also advance the idea that metacognition can be a person-related characteristic, not just dependent on domain knowledge. In fact, metacognitive skillfulness is one important factor that contributes to transfer.

Unfortunately, the majority of studies examining the role of metacognition in transfer have addressed the transfer of skills rather than knowledge and online monitoring of performance rather than declarative metacognitive knowledge. Virtually no work has concentrated on knowledge of domains of object categories or whether domain knowledge in an expert domain could enhance preparation for future learning (PFL) in related domains. Indeed, Alexander, et al. (2006) suggest that when examining performance within conceptual domains, using declarative *metaconceptual* knowledge as a predictor of later performance is more appropriate than using a general metacognitive knowledge measure. Metaconceptual knowledge, as defined by Alexander, et al. (2006), is a series of related meta-information concerning the structure and function of taxonomically-organized concepts (e.g., prototypicality, feature centrality, inclusion relations; Murphy, 2002). It also includes one's knowledge concerning how an entity representation can be affected by high levels of knowledge.

Alexander, et al. (2006) found that metaconceptual knowledge develops steadily between the ages of 5 and adulthood. In addition, IQ is consistently related to metaconceptual knowledge scores throughout development. Finally, although finding a direct connection between high levels of declarative metacognitive knowledge and appropriate task behaviors has been difficult (Veenman, et al., 2004), Alexander et al (2006) found that metaconceptual scores significantly predicts performance on a twenty-questions task designed to tap categorical knowledge. Alexander et al. (2006) argue that the development of metaconceptual knowledge might reflect a transitional step between implicit understandings of conceptually-related strategies, and explicit, on-line articulation of knowledge pertaining to the deployment of such strategies. Interview items assessing metaconceptual knowledge seem to tap some level of general knowledge about conceptual issues, even if it cannot be articulated verbally after the completion of a task. In the

next section, we report data that explores the potential role of metaconceptual knowledge and IQ in facilitating transfer across biological domains on a referential communication task for which knowledge of category structure should be quite salient.

Exploring Transfer between Biological Domains: The Case of Referential Communication

Young children's referential communication skills tend to be relatively poor (Whitehurst & Sonnenschein, 1985). In referential communication situations, the speaker constructs a message in order to direct the listener's behavior, ideally tailoring the message to the particular characteristics of the listener. Referentially precise messages should meet the intent of the speaker and be comprehensible to the listener. Research has shown that the content knowledge of the least knowledgeable partner constrains what can be shared (Whitehurst & Sonnenschein, 1985). Domain-specific knowledge has also been shown to be related to the kinds of communication questions asked in the game of twenty questions (those that address surface characteristics versus deep-level characteristics; Alexander, et al., 2006; Alexander, Johnson, Leibham, & DeBauge, 2004). Metaconceptual knowledge and IQ have both been shown to play important roles in communication tasks (Alexander et al, 2006), though metaconceptual knowledge has been found to be a more important predictor of good communication among children whose IQ is average or slightly below average than for children whose IQ are above average.

Task procedures. We examined performance on a referential communication task across two domains – one “expert” for which children were reported by parents to be highly familiar (dinosaurs), and one novice (sea creatures). Participants included 35 children (mean age 6,9, range 4,9 to 9,8). Children were recruited through newspaper advertisements and through a Children's Museum exhibit on dinosaurs. During the task, the child sat at a low table on which 2

rows of 4 museum-quality models were randomly placed. One model was placed on a brightly colored mat that designated it to be the “target.” Models ranged from 8 to 21 cm long and from 5 to 14 cm high and were readily graspable. Children completed 3 trials involving models from each of the 2 domains (dinosaurs and sea creatures), with trials matched across domains in terms of difficulty level. Difficulty level was reflected in the degree of feature overlap between the target and the other models in the array, with more difficult trials involving higher proportions of shared features.

Referential communication tasks typically entail both a speaker and a listener. Because of the logistical difficulties of scheduling a second child to serve as the “listener”- coupled with our inability to experimentally control that listener’s level of domain knowledge - we adapted the task by having each child provide messages to a tester, who then proceeded to type the message into a laptop computer. The researcher told the child that the computer knew which 8 dinosaurs/sea creatures were laid out on the table and was going to try to guess which model had the mat under it based on the child’s clues. The researcher encouraged the child to pick the best possible clues so the computer could figure out as quickly as possible which model was placed on the mat. The researcher told the child that they could not use the model’s name but could tell the computer anything else about the animal. In addition, the children were free to explore and pick up any of the models in front of them if they thought it would help them create better clues. The child completed one training trial followed by three trials in both domains. For each trial, children were permitted up to three attempts at helping the computer to guess the correct model (with determinations of success actually made by the tester, who pressed a programmed key at that point to make the computer appear to “guess correctly”). Only the data from the last attempt

for each trial are reported here, though the number of attempts required for successful differentiation of the target model was recorded.

During a second session scheduled one week later in the child's home, we administered assessments of children's knowledge of dinosaur names and attributes (modeled after those used by Gobbo & Chi, 1986) to verify that all 35 children possessed at least moderate levels of dinosaur knowledge in the domain of expertise. IQ was then assessed with the Kaufman Brief Intelligence Test (K-Bit; Kaufman & Kaufman, 1990). Finally, metaconceptual knowledge was evaluated using a nine-item interview designed to tap children's knowledge concerning the structure and function of taxonomically-organized concepts, as described by Alexander et al. (2006). We also administered a "clue rating" task to gauge children's metaconceptual sensitivity to the relative usefulness of particular cues. The child's own clues generated for the most difficult trials in each of the two domains were embedded within a standardized list of 16 cues. Children were shown a photograph of each 8-model array along with a close-up photo of the target animal and reminded of the "game" that they had played a week earlier with the computer. Children were asked to rate how useful they thought each clue was on a 4-point scale (4 = "very good") that was anchored by faces varying in terms of level of positive affect.

Data reduction and analysis. For each child, the number of attempts required to correctly differentiate the three target models in each domain was recorded. In addition, each clue produced by a particular child was given a distinctiveness score reflecting how well it discriminated among models in the array. Scores for each clue were based on the number of exemplars present that could be eliminated with the child's clue. The maximum distinctiveness score was "7" (reflecting that all non-target models could be eliminated; in other words, a completely unambiguous clue), and the lowest score was "0" (reflecting that none could be

eliminated, or a very ambiguous clue). Distinctiveness scores were summed across the three final clues generated on each trial (composite scores could range from 0 to 21).

Children's level of strategy use was determined based on the number of trials within a domain for which either verbal and/or nonverbal evidence of contrastive behavior was observed. Videotapes of each testing session were used to code nonverbal evidence, and responses to a standard declarative metaconceptual question were used to record verbal evidence. At the end of each trial the child was asked, "How did you think of such good clues? How did you know those would be the best clues? Why were they better than other clues?" If the child responded by indicating that they had deliberately contrasted the target model with other models in the array (e.g., "It's the only one that has X." "I looked at all of them and then decided to say Y."), one point was awarded for that trial (only 5 children were this explicit in their strategy awareness, and only in the expert domain). Nonverbal evidence included cases where the child picked up more than one model and obviously engaged in contrastive exploration, or instances of the child looking back and forth between the target model and at least one of the nontargets. Children could receive up to one point for each type of evidence observed in relation to a set of 3 clues, and scores were then summed across trials within each domain (range: 0-6 points). Evidence for transfer was expected to take the form of similar levels of performance across the two domains. In addition, we were interested in whether intelligence or level of metaconceptual knowledge was predictive of children's performance in the novice (sea creature) domain.

Paired-samples t-test results indicated that strategy scores were higher and total distinctiveness scores were higher in the more familiar dinosaur domain than in the sea creature domain. In contrast, the total number of trials required to successfully differentiate the target was actually higher in the expert than novice domain (see Table 2 for descriptive information).

Further analysis revealed that this pattern was attributable to the fact that children typically concentrated their descriptions on features of dinosaurs (e.g., sharp teeth) that were perceptually and behaviorally important – yet were not unique to the target model and therefore did not uniquely discriminate it from the array.

Despite these domain differences, there were similarities between performance measures across domains. Total distinctiveness scores were positively correlated between the dinosaur and sea creature domains, $r(35) = .50, p < .01$. This correlation remained unchanged even when IQ was partialled out. Thus, there were similarities in the distinctiveness levels of the features children attended to across domains. In addition, those similarities did not seem to be solely due to advantages in central processing speed or verbal ability, as indicated by maintenance of the correlation when IQ was partialled out.

We next considered factors that were predictive of performance in each of the two domains. Neither IQ nor metaconceptual scores were related to total distinctiveness or strategy use scores in the expert domain, $r(35) = .08$ and $.18$, respectively for IQ; $r(35) = .21$ and $.25$, respectively for metaconceptual scores. Both factors, however, did help to predict transfer to the novice domain (see Table 3). IQ was related to total distinctiveness scores in the sea creature domain $r = .34, p < .05$ as well as strategy scores in the sea creature domain, $r(35) = .42, p = .01$. Metaconceptual knowledge scores were significantly related to number of trials in the sea creature domain, $r(35) = -.41, p = .01$. Interestingly, age was not significantly related to any performance measure in either domain (all r 's = $-.21$ to $.27$)

In addition, qualitative analysis of the children's clues revealed evidence that children were attempting to apply their expert knowledge to the less familiar domain. For example, one child reported that the target sea creature (orca) had "both plant eater and meat eater teeth."

Although this information is not accurate, the child is clearly relying on an important feature that discriminates meat-eating from plant-eating dinosaurs. Another child told the computer that the whale shark had a “sharp tail that can attack enemies.” Again, this is not accurate information, but the same child had recently characterized the euoplocephalus (target dinosaur) as having “spiky things on its tail.” Most children’s books clearly note that this spike was likely used for defense and attack behaviors. In fact, 39% of the children’s clues for the less familiar domain were rated by researchers as pertaining to three of the main behavioral organizing dimensions in the dinosaur domain (hunting, defense, and diet). Given that the children had little supporting biological knowledge in the sea creature domain, we would predict they would focus almost exclusively on perceptual information when generating clues. Instead, 39% of the children’s clues were related to hunting, defense, or diet, suggesting they are aware that perceptual properties are related to underlying biological functions, even if their inferences were not entirely accurate.

Finally, we considered whether children’s estimates of clue usefulness reflected their level of general metaconceptual knowledge. Declarative metaconceptual knowledge scores were significantly and positively correlated with children’s clue usefulness ratings for both the standardized list of clues (dinosaurs: $r = .48$; sea creatures: $r = .38$) and for their own previously generated clues (dinosaurs: $r = .38$; sea creatures: $r = .44$, all p ’s $< .05$). This suggests that the metaconceptual interview did tap into children’s understanding of the relative quality of the clues they were generating.

In summary, when children engage in message construction for a referential communication task involving highly familiar stimuli, few individual differences relate to behavior. These findings are similar to those of Veenman, Wilhelm, and Beishuizen (2004) and

suggest that expertise in a domain facilitates attention to important perceptual features regardless of level of IQ or metacognitive knowledge. Our data show that expert children generate highly distinctive referential communication clues and they tend to focus on distinctive features even when confronted with stimuli from a less familiar domain. The children can also draw inferences about distinctive features in the sea creature domain and (sometimes incorrectly) use them to differentiate the target from the other exemplars in the array. On the other hand, children's clue generation in the novice domain is predicted both by metaconceptual knowledge and IQ. Finally, age is not related to task performance measures, even though it is related to metaconceptual interview scores, $r(35) = .62, p < .001$. Although age is certainly playing a significant role in the metaconceptual scores, it is not directly playing a significant role in performance measures in the novice domain (see correlations in Table 3).

An Integration and Suggestions for Future Research

Our survey of the literature focused on expertise aligned with domains of biological kinds suggests that both children and adults acquire domain-specific vocabulary and a vast repertoire of feature knowledge that can be recruited to afford flexible bases for categorization and induction. In the context of children's referential communication, we have provided evidence that expert knowledge may support the construction of less ambiguous messages in a novel, but related domain. Our review also suggests that, although children and adults differ in terms of the potential for transfer of domain-specific knowledge, both seem to shift their attention to relatively subtle perceptual features that are particularly diagnostic of taxonomic relations (or salient behaviors). This attentional shift seems to readily generalize to biological domains that are relatively unfamiliar. Our data also suggest that children attempt to apply their knowledge of behavioral features to less familiar, but related biological domains. In the present data set, the

distinctiveness scores of these 4- to 8-year old children's referential communication "clues" were highly correlated ($r = .50$) across expert and non-expert domains and approximately 40% of their clues pertained to behavioral features in the novice domain.

This shift in attention to subtle perceptual features seems to be quite implicit for children. Admittedly, few studies have explicitly asked children or adults whether they are aware of the perceptual shift. We hypothesize that adults may more readily reflect explicitly on why such features are important across domains and use that information to guide induction. For example, Shafto and Coley (2003) found that adults restricted the use of their framework theories to the expert domain and to appropriate situations in the novice domain (reasoning about diseases instead of reasoning about blank predicates). Thus, adults seem to be able to flexibly and knowingly use their domain knowledge to assist learning at appropriate times. Data on children have not supported such flexible uses of domain knowledge in novice domains.

Similar to the suggestion by Alexander et al. (2006), the present data support the importance of metaconceptual awareness in transfer. Metaconceptual knowledge does not seem to explicitly affect task performance, as few children were explicitly aware of how to generate effective clues when asked directly after the task. Instead, metaconceptual knowledge seems to be playing an implicit role, possibly facilitating the transition from implicit awareness of diagnostic features to more explicit awareness. Alexander et al., (2006) found that metaconceptual knowledge was related to referential communication skill in a large sample of 6 year olds, with higher levels of metaconceptual knowledge resulting in less ambiguous communication messages. In addition, the present study found correlations between ratings of clue goodness and metaconceptual knowledge as well as a relation between metaconceptual knowledge and number of trials required to do well on the communication task. Both

relationships suggest an implicit role for metaconceptual knowledge in facilitating task performance. This implicit awareness may eventually lead to more explicit application and deployment of effective referential communication skills across domains, much as we see in adults.

There are at least two possible explanations for why children seem relatively unaware of the applicability of their knowledge from the expert to novice domain. Children may acquire their knowledge through the brute force of relatively effortful associative processes, whereas adults may be “prepared for learning” in a related domain by virtue of the mediated effects of related schemata. Data consistent with this hypothesis was presented in Bransford and Schwartz (1999). They asked students to generate questions about what they would need to research in order to design effective recovery plans for eagles. Although the fifth graders tended to focus on features of individual eagles, the college students focused on issues of interdependence between the eagles and their habitats. As Bransford and Schwartz concluded, “Because they had not studied eagles directly, the college students were presumably generating questions framed by other aspects of biology that they had learned. So, by this alternative form of transfer test, it would appear that the college students had learned general considerations that would presumably help shape their future learning if they chose to pursue this topic.” (p. 66-67).

It may also be the case that adults’ more pronounced transfer effects are mediated through the development of metaconceptual knowledge (a “high road transfer”) which supports the establishment of domain-general strategies for category learning and transfer. Such strategies may be executed whenever experts confront novel categories that are organized in ways similar to their expert domain. Children may be capable of such explicit strategy control only once sufficient levels of relevant metaconceptual knowledge become available.

Although it may be difficult to foster the development of metacognitive knowledge in young children, recent research has shown that metacognitive skills training can support transfer

at least with older children. Georghiades (2000) found that metacognitive instruction is feasible with primary school children under every day circumstances (though difficult and time consuming). Secondly, students who received metacognitive instruction performed better on written assessments about the topic (electricity) than those without metacognitive training. In a follow-up report, Georghiades (2004) found that 5th grade students with metacognitive training gained an even stronger advantage at a time-delay of eight months. Thus, the durability of the conceptual understandings was greater with metacognitive instruction.

It seems that there are multiple opportunities for parents or teachers to share metacognitive information about attention (“Pay attention to this, not that.”) and memory (“So, how can we remember these six things?”). But, how often do adults have metacognitively rich conversations about categories with their children? How might children acquire metaconceptual knowledge? Some feedback about concepts may come as children interact with parents about “things” in the world. For example, if a child is attempting to solicit help in reaching one of several dinosaurs from a shelf in a toy store, the helper may request more specific information such as “Which dinosaur?” (or may inadvertently retrieve a dinosaur different from the one the child wanted, thereby providing feedback that the child’s message was ambiguous). This may help the child realize that subordinate labels for objects afford precise communication, and that different people may identify the same object in different ways. Other forms of metaconceptual knowledge (e.g., inclusion relations) have been shown to take longer to master (Alexander et al., 2006). Limitations in exposure to a domain built on subordinate kinds and/or working memory limitations may contribute to these problems (Johnson et al., 1997). Additionally, some parents may include more metacognitive information about strategies in their discussions with children than others (Neitzel & Stright, 2003; Stright, Neitzel, Sears, & Hoke-Sinex, 2001); similar

findings could be true regarding the embedding of metaconceptual information in everyday activities with children.

Finally, our survey of research also has highlighted some methodological challenges associated with addressing interactions among metacognition, expertise, and knowledge transfer in children that should be considered in future research. First, declarative metaconceptual knowledge is difficult to assess reliably, as children must verbally articulate what they know in a structured interview context. This issue is pertinent to almost all evaluations of metacognition that depend on children providing verbal explanations in relation to particular vignettes. While this issue obviously does not impact children who demonstrate explicit knowledge of conceptual structure and function, it remains possible that children who demonstrate little metaconceptual knowledge are actually more capable than they seem. Limitations in verbal skills may be limiting our awareness of understandings children do have.

In addition, it remains an open question to what extent the implicit forms of transfer described in the present chapter reflect actual shifts in attentional preferences as a result of domain-specific knowledge acquisition, as opposed to more stable individual difference characteristics. For example, it may be the case that children who manifest high levels of interest in dinosaurs tend to have a more analytic cognitive style than children less interested in dinosaurs. Alternatively, one could conduct longitudinal studies in which children are evaluated across multiple domains both before and after training in the “expert” domain. While this is undoubtedly the ideal design for investigating interactions among knowledge, IQ, and metacognition and the potential for knowledge transfer, it carries with it costs associated with longitudinal research, more generally. Multiple samples would be needed to investigate patterns aligned with near vs. far transfer. It would also be difficult to evaluate developmental changes

unless longitudinal-sequential variations were implemented. Future researchers must devise novel and creative approaches to dealing with these issues.

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Table 1

Aspects of Child Expertise and Their Potential for Transfer

Type of Knowledge	Potential for Transfer
Diagnostic Perceptual Features (or Feature Clusters)	Implicitly Increases Attention to Analogous Types of Features in Related Domains
Behavioral (or Functional) Features	Implicitly Increases Attention to Analogous Types of Features in Related Domains
Causal Relations Between Perceptual and Behavioral (or Functional) Features	Implicitly Increases “Preparedness to Learn” and Analogous Relations in Related Domains
Bases for Taxonomic Relations	Implicitly Increases Attention to Analogous Bases in Related Domain
Framework Theoretical Knowledge	Aspects may Implicitly or Explicitly Generalize to Related Domains, Particularly for Older Children and Adults

Table 2

Mean Levels of Performance Across Expert and Novice Domain Trials of Referential Communication Task as well as predictor factors

Variable	Dinosaur		Sea Creature		Paired-samples
	Mean	sd	Mean	sd	t-test
Number of Trials needed (max 9) ¹	4.22	0.94	3.71	1.13	$t(34) = 2.11, p < .05$
Total of Maximum Distinctiveness Scores ²	44.65	7.79	41.63	9.37	$t(34) = 2.12, p < .05$
Strategy Score ³	2.50	1.45	1.94	1.47	$t(34) = 2.33, p < .05$
IQ	116.26	10.91			
Metaconceptual Knowledge	9.09	2.71			

¹ Lower scores represent more sophisticated performance

² Number of distractors (out of 63 across three trials) successfully eliminated with clues

³ Maximum Score = 6, Higher scores represent both verbal and nonverbal behavior reporting an examination of multiple items in the array and a contrastive strategy for clue generation.

Table 3

Correlations across Performance Variables for Transfer to Novice Domain Trials of Referential Communication Task

Performance Variable	Metaconceptual Knowledge	IQ
Number of Trials ¹	-.44**	-.32
Total Maximum Distinctiveness Scores ²	.27	.34*
Strategy Scores ³	.24	.42**

* $p < .05$, ** $p \leq .01$

¹ Lower scores represent more sophisticated performance

² Number of distractors (out of 63 across three trials) successfully eliminated with clues

³ Maximum Score = 6, Higher scores represent both verbal and nonverbal behavior reporting an examination of multiple items in the array and a contrastive strategy for clue generation.