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ARE DEVELOPMENTAL THEORIES OF LEARNING PAYING ATTENTION TO ATTENTION?

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ABSTRACT

Currently available empirical evidence is often insufficient to distinguish among developmental theories of word learning, categorization, and induction. This paper argues that theories of conceptual development should be evaluated not only on the basis of their ability to account for empirical findings, but also on the basis of their consistency with a broader body of knowledge, particularly with the known properties of developing selective attention. The paper presents a brief overview of the behavioral and neurophysiological findings on the development of selective attention. These findings are argued to be inconsistent with the approaches assuming that early in development learning is driven by conceptual knowledge and naïve theories, but provide support to the approaches arguing that early learning may be impervious to conceptual influences.

KEYWORDS: cognitive development, categorization, induction, word learning, attention.

Current theories of conceptual development can be broadly characterized as those arguing that early learning relies predominantly on the low-level domain-general mechanisms of perception, attention, and memory (Sloutsky & Fisher, 2005; McClelland & Rogers, 2003; Rakison, 2003; Sloutsky, 2003; Samuelson & Smith, 2000a) and those arguing that low-level mechanisms alone are insufficient to account for learning early in development (Jaswal, 2004; Gelman, 2003; Booth, & Waxman, 2002; Woodward, 2000). Existing empirical evidence often has been consistent with both approaches, or as Smith and Samuelson (2006, p.1342) put it, “proponents of both sides can conduct nearly identical experiments and see the

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same results as being for and against [the attentional learning account]”. This problem is illustrated below using examples of empirical findings coming from two different tasks – a biological induction task and a word learning task.

In a typical induction task children are presented with a Target item (e.g., a brown starfish which is labeled “a starfish”) and two Test items, Test A (e.g., a brown pinecone labeled “a pinecone”) and Test B (e.g., a red starfish labeled “a starfish”). Children are then familiarized with unobservable properties of each Test item (e.g., “this cone has little seeds inside” and “this starfish has little eggs inside”) and asked whether the Target item is more likely to share the property with Test A or Test B. For the stimulus set depicted in Figure 1, 4-year-old children are likely to respond that Test B rather than Test A shares the property with the Target (Gelman & Markman, 1986; Sloutsky & Fisher, 2004a). Proponents of alternative approaches to early induction propose markedly different explanations to account for this pattern of responses. According to the Similarity-Based approach, early in development induction is a process of automatic similarity-based generalization, with similarity computed over automatically detected perceptual and linguistic features. In other words, common labels contribute to the overall perceived similarity of presented entities, therefore, children under certain circumstances (e.g., when test objects are equally similar to the target object; cf. Sloutsky & Fisher, 2004a) may be more likely to generalize the property from the Test item that shares a label with the Target (in the above case Test B).

According to the Naïve Theory approach, “children’s categories are theory based: They are constructed not merely on the basis of perceptual characteristics and regularities but on the basis of children’s beliefs and assumptions about the
world and the way language works … children assume that a label provides direct access to an object’s kind, and that an object’s kind determines what nonobvious properties it is likely to have” (Jaswal, 2004, p. 1872). In other words, it is assumed that for children as young as 2.5 years of age (Gelman & Coley, 1990) common labels indicate membership in the common category, therefore children are likely to generalize the property from Test B to the Target. This explanation clearly differs from the explanation proposed by the Similarity-Based approach, yet both are commonly invoked in the literature to explain the same pattern of results.

Now consider a common finding stemming from research on word learning. In a typical word learning task 2½-year-old children are presented with a novel Target Object that is labeled with a novel pseudo-word. Children are then presented with several novel Test Items, some of which are identical to the Target Object and some of which differ from it on a single dimension, such as shape, texture, or size (see Figure 2 for examples). Children are then asked which of the Test Items is likely to share the name with the Target Object.

![Figure 2](image)

It has been demonstrated that when novel Target Objects possess cues indicating animacy (such as eyes or shoes) children rely on the similarity in both shape and texture to generalize novel labels, whereas in the absence of animacy cues children rely solely on the similarity in shape (Booth & Waxman, 2002; Jones & Smith, 1998). Proponents of alternative approaches to early word learning propose markedly different explanations to account for this pattern of responses. Some researchers have argued that since human learners are sensitive to bundles of correlated properties of objects (such as the fact that beaks, feathers, and wings are...
likely to co-occur, or that entities that have eyes are likely to possess tendency for self-propelled motion and other attributes of living things), “these correlations provide a means for shifting attention among object properties in category relevant ways” (Jones & Smith, 1998, p. 331). In other words, different correlated structures, or different contexts, automatically shift attention to the attributes that are most predictive in these contexts (such as shape alone or shape in conjunction with texture in the example above). However, other researchers have argued that “eyes (and shoes) play an important role in word extension not because they automatically trigger attention to both shape and texture, but because they each signal the ontological status of the object being named (i.e., animacy). This conceptual knowledge of animacy then guides attention to the most relevant object properties.” (Booth & Waxman, 2002, p. 493).

As is clear from the above examples, empirical evidence may sometimes be insufficient to distinguish between the two accounts of learning early in development. However, theories can be evaluated not only on the basis of whether they can generate supporting evidence, but also on the basis of their consistency with a broader body of knowledge. Consider, for example, the area of visual perception, in which researchers have been trying to account for humans’ ability to interpret light and shade patterns on a surface in terms of 3-D geometry (Langer & Bülthoff, 2000), a problem traditionally referred to as perceiving shape-from-shading. The first algorithm for extracting shape information from shading was proposed by Horn in 1975. Despite being successfully applied in machine vision, some assumptions of Horn’s algorithm (e.g., that the lighting conditions are known or can be accurately estimated) made it implausible as a psychological theory (Langer & Bülthoff, 2000; Todd & Mignolla, 1983; Horn, 1975). Similarly, I propose that it is necessary to evaluate theories of conceptual development based on whether their assumptions are plausible given the known properties of the organisms these theories purport to apply to, namely – young children. Therefore, the goal of the present paper is to align theoretical assumptions of different approaches with the known properties of processing early in development.

Conceptual Development: Theoretical Approaches

According to one theoretical approach, associative learning mechanisms alone are insufficient for sophisticated learning exhibited early in development, because the number of associations that could be acquired is potentially infinite. Therefore, in addition to the low-level domain-general learning mechanisms, infants and young children are hypothesized to rely on a variety of domain-specific constraints limiting dimensions of the environment learners attend to. There have been proposed a number of such constraints, among them naïve theories (“…children’s categories are theory based: they are constructed not merely on the basis of perceptual characteristics and regularities but on the basis of children’s beliefs and assumptions about the world and the way language works” (Jaswal, 2004, p. 1872) and conceptual knowledge [(“…infants as young as 1.5 years of
age … bring their conceptual knowledge (however rudimentary it may be) to bear in word learning” (Booth, Waxman, & Huang, 2005)]. It is important to note that there is no agreed-upon definition of “conceptual knowledge”. Some have argued that conceptual knowledge as well as naïve theories can be implemented as connection or attention weights, or systems of learned associations (McClelland & Rogers, 2003; Sloutsky, 2003; Samuelson & Smith, 2000a). Others, however, advocate the position that conceptual knowledge and naïve theories are not associative in nature (Booth, Waxman, & Huang, 2005; Jaswal, 2004), and the latter meaning is assumed in this article.

According to the alternative approach, early learning is an automatic process largely impervious to conceptual influences. Within this approach conceptual knowledge and beliefs are viewed as a potential outcome rather than a prerequisite for learning (Sloutsky & Fisher, 2005; Sloutsky, 2003; McClelland & Rogers, 2003; Samuelson & Smith, 2000a). Proponents of this approach argue that early learning is constrained by the regularities in the input and information processing properties of the organism rather than conceptual knowledge. For instance, most cup-shaped objects are called “cups” and most ball-shaped objects are called “balls”, so children first (slowly) learn these simple object-label correlations. Once children learn many simple object-noun correlations (i.e., approximately one hundred nouns in the case of word learning (Gershkoff-Stowe & Smith, 2004), they can learn a higher-order correlation that most solid objects are named in English according to their shape (Samuelson & Smith, 1999). Learning this higher-order correlation is argued to result in an automatic increase in the allocation of attention to predictive dimensions (i.e., shape in the case of early word learning), and decrease in the allocation of attention to non-predictive dimensions (i.e., color), thus promoting rapid word learning (Smith, 2000; see also Fisher & Sloutsky, 2006, and Sloutsky & Spino, 2004, for similar results in inductive generalization tasks).

To summarize, both approaches predict that some object properties are more important than others for word and category learning, and therefore assume some sort of attentional selectivity allowing learners to preferentially allocate processing resources to objects and object dimensions relevant to the task at hand. However, assumed mechanisms of this selectivity are radically different. On the one hand, Smith and colleagues argue that early selectivity is automatic and “may be relatively inaccessible to deliberative and strategic controls” (Smith, Jones, & Landau, 1996, p. 144; see also Sloutsky, 2003; Sloutsky & Fisher, 2005; Samuelson & Smith, 2000a). On the other hand, Gelman and Medin urge to consider “the logical possibility that change in weighting is the result of a slower, more conscious and deliberate weighting and ignoring of different aspects of the situation” (Gelman & Medin, 1993, p. 164). However, relevant findings on the development of selectivity have not been brought to the debate, and while both approaches are internally consistent, it is unclear whether they are consistent with the basic properties of children's selective attention.
Some form of attentional selectivity is present from birth: newborns are not indifferent to what they attend to, preferring to look at some visual stimuli over others (Fantz, 1963). However, this selectivity can be characterized as stimulus-driven or automatic, rather than person-driven or voluntary: early selectivity has been shown to be driven by the properties of the stimulus, such as its brightness, intensity, and novelty (see Ruff & Rothbart, 1996, for review) rather than by infants’ intentions. For instance, once a stimulus “grabs” attention, one-month-olds often find it difficult to voluntarily disengage attention from this stimulus, and unlimited exposure to a patterned stimulus may result in prolonged looking that ends in considerable distress, a phenomenon referred to as obligitory looking (Stechler & Latz, 1966). This behavior exemplifies immaturity of executive control – “the ability to orchestrate thought and action in accordance with internal goals” (Miller & Cohen, 2001, p. 167).

Although obligatory looking diminishes by two months of age, it is not until later in development that people can voluntarily engage and disengage their attention. The question then becomes: is voluntary selective attention sufficiently developed to support conceptually-driven learning in infancy and early childhood? In other words, do young learners have sufficient control to inhibit attention to perceptually salient but conceptually irrelevant cues, allocate their attention to conceptually relevant cues, and deliberately switch attention among cues (since different cues can be relevant in different contexts)?

Research suggests that transition from stimulus-driven to person-driven selectivity is gradual and takes place during the preschool years (Rueda, Posner, & Rothbart, 2005; Ruff, & Rothbart, 1996). Immaturity of executive control of attention early in development has been shown in a variety of tasks requiring participants to respond based on specified stimuli dimensions. For example, in the dimensional-change-card-sorting (DCCS) tasks participants are presented with a set of cards depicting familiar objects that differ on two dimensions (e.g., color and shape). Children are first asked to sort cards according to one dimension (e.g., shape), and upon completing the task, they are asked to sort cards according to a different dimension (e.g., color). This task is analogous to word learning tasks in which children have to flexibly shift their attention among different object dimensions when learning names for animate and inanimate objects (Booth & Waxman, 2002; Jones & Smith, 1998) or rigid and deformable objects (Samuelson & Smith, 2000b; Soja, Carey, & Spelke, 1991). However, despite being successful in switching attention among object dimensions in the word learning tasks by age 2 ½, 3-year-old children perseverate in their sorting by the original dimension in the card sorting tasks, even though they understand and remember sorting rules. Performance on the DCCS task does not improve until 4 or 5 years of age (Zelazo, Frye, & Rapus, 1996), suggesting that young children have limited control over switching their attention among task-relevant stimulus dimensions and thus making...
it unlikely that differential weighting of various dimensions in the course of
generalization tasks occurs in a “conscious and deliberate” manner (Gelman &
Medin, 1993).

Similar findings emerge from a go-no-go task (an age-appropriate
analogue of the Continuous Performance Test), in which participants are asked to
attend to a stream of visual stimuli and to selectively respond to some items. For
example, participants might be presented with a series of images depicting ducks
and turtles, and instructed to press a button every time they see a duck (i.e., “go”
trials) and avoid pressing the button when they see turtles (i.e., “no-go” trials)
(Akshoomoff, 2002). Findings indicate that those 3-year-olds who can complete
the task (thus demonstrating their ability to focus on a task for prolonged periods of
time) exhibit high rates of both misses and false alarms, thus exhibiting difficulty
with the voluntary control of selectivity. Marked improvement on this task (in
terms of proportion of children completing the task, response time, and accuracy)
is observed between 4 and 5 years of age.

However, behaviors observed in the described above tasks could be
interpreted as evidence for dissociation between knowledge and action, rather than
immaturity of executive control. In other words, it could be argued that age-related
improvements on these tasks are primarily due to the improved ability to inhibit
prepotent motor responses. Therefore, findings from a task that requires executive
control over selective attention but not a motor response can be particularly
informative, and one such task is a modified version of the switch task (Robinson
& Sloutsky, 2004; Napolitano & Sloutsky, 2004). In this task participants are
presented with two bimodal compounds, each consisting of an auditory and a
visual stimulus. Each compound predicts a particular outcome, and participants
are asked to learn the compound-outcome association. Four-year-old children often
exhibit auditory modality preference, evident in their tendency to selectively rely
on the auditory part of the compound to predict future outcomes. This tendency is
clear from participants’ performance on a follow-up recognition test, during which
visual and auditory components of the “trained” compounds are paired with novel
visual and auditory stimuli: children tend to notice the change only in the auditory,
but not in the visual part of the compound. When instructed (at the onset of each
trial) to rely only on the visual part of the compound to predict outcomes, children
are able to learn compound-outcome associations, but at testing they still tend to
notice the change only in the auditory part of the compound. These findings
suggest that 4 year-old children may be unable to voluntarily switch their modality
preference, even though automatic shifts in modality preference can be obtained
under appropriate stimulus conditions (Napolitano & Sloutsky, 2004).

Difficulties in performing tasks requiring voluntary control of attention
have been often attributed to the immaturity of the prefrontal cortex (PFC) (Bunge,
Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Miller & Cohen, 2001). In
particular, prefrontal lesions in adults and non-human primates lead to impaired
performance on the tasks requiring executive control. For example, patients with
PFC damage exhibit deficits on the Wisconsin Card Sort Task similar to those of
healthy 3-year-olds on a DCCS task: they have no difficulty in discovering the rule for initial card-sorting, however are unable to adjust their responses when the sorting rules change. Similarly, monkeys with PFC lesions are impaired on the analogue of this task (Miller & Cohen, 2001). In addition, neuroimaging and post-mortem analyses of the brain structures of humans and non-human primates indicate that PFC is one of the last brain areas to mature. Evidence for delayed maturation of PFC comes from the measures of myelination, synaptogenesis, gray matter reduction, and resting levels of glucose metabolism (Bunge et al., 2002; Durston, Thomas, Yang, Uluğ, Zimmerman, & Casey, 2002; Casey, Giedd, & Thomas, 2000). Overall, it has been argued that while mature PFC is not critical for performing automatic behaviors, it is crucial “when behavior must be guided by internal states or intentions” (Miller & Cohen, 2001, p. 168).

Brief review of the literature on development of executive control indicates that young children are limited in their ability to voluntarily disengage attention from salient information and switch attention among stimulus dimensions, suggesting that executive control of selective attention is unlikely to be sufficiently developed early in life to support conceptually-driven learning. However, one could counter argue that conceptually-driven learning may be consistent with the evidence on the development of voluntary selective attention under certain conditions. In particular, one could argue that young children may be more successful in controlling their attention when it is driven by conceptual knowledge (e.g., in word learning tasks) rather than experimenter’s instructions (e.g., in DCCS tasks). Furthermore, one could argue that internal states (such as conceptual knowledge and naïve theories) are more salient and attention-grabbing than perceptual information. In this case, attending to conceptual rather than perceptual information is the prepotent response, and thus conceptual knowledge presumably guiding early learning (e.g., knowledge of an ontological status of an object) is deployed automatically rather than deliberately.

First of all, currently there is no evidence in the literature on the development of executive control suggesting that attention guided by conceptual knowledge is more successful that attention guided by external instructions. Furthermore, current theories of executive control do not hypothesize separate mechanisms for internally- and externally-driven control of attention (Miller & Cohen, 2001). Therefore, while it is possible that internally-driven and externally-driven executive control are subserved by different neural mechanisms and the former matures faster than the latter, this possibility is not grounded in available empirical evidence.

Second, the possibility that conceptual knowledge rather than perceptual information is the prepotent response is inconsistent with the growing body of evidence about the nature of generalization in young children. In particular, recent findings suggest that children are unlikely to spontaneously rely on conceptual knowledge in generalization tasks, even when they possess such knowledge and this knowledge does not conflict with perceptual information. For example, there is evidence that 5 year-old children are likely to rely on perceptual information rather
than knowledge of category membership when performing inductive generalization about familiar entities (such as cats, bears, and birds), and as a result exhibit accurate performance on a post-induction recognition memory test (Fisher & Sloutsky, 2005; Sloutsky & Fisher, 2004a). Adults, on the contrary, spontaneously rely on their knowledge of category membership when performing induction about familiar entities, and as a result exhibit chance performance on the follow-up memory tests. Similar findings emerge from a task in which 5 year-olds were taught novel natural-kind-like categories, and later were asked to perform an inductive generalization task about members of these categories. Despite accurate categorization performance (with the categorization test administered both before and after the induction task), children did not rely on their knowledge of category membership to perform induction, even when category membership did not conflict with appearance information (Sloutsky, Kloos, & Fisher, 2007). Therefore, there is little evidence that for young children conceptual information is more salient than perceptual information.

Furthermore, an attempt to reconcile the findings on the development of voluntary selective attention with conceptually-driven learning raises several important questions. How do naïve theories and conceptual knowledge become the prepotent response? Is the prepotent status of conceptual information innate or acquired? If it is acquired, are low-level domain-general processes sufficient to acquire conceptual knowledge? If yes, what are the differences between this position and the proposal that conceptual knowledge and naïve theories can be implemented as attention or connection weights, or systems of learned associations (McClelland & Rogers, 2003; Rakison, 2003; Sloutsky, 2003; Samuelson & Smith, 2000a)? If not, what are the mechanisms whereby conceptual knowledge and theoretical beliefs are acquired and become the prepotent response? Until these questions are addressed, findings on the development of voluntary selective attention and conceptually-driven learning early in development are difficult to reconcile.

CONCLUSIONS

Aligning assumptions of the theories of cognitive development with behavioral and neurophysiological findings on executive control may provide a useful metric in evaluating competing theories of conceptual development. Evidence reviewed in this paper suggests that executive control of attention and brain structures supporting this ability are insufficiently developed in infants and young children to support learning that is deliberate and conceptually-driven in nature. Therefore, this evidence is inconsistent with the theoretical approaches assuming that early learning relies on intentionality, conceptual knowledge, and naïve theories. Conversely, this evidence supports the approaches that do not rely on executive control of attention to account for learning early in development.
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