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Artifact knowledge requires integration of information from different areas of human commonsense knowledge—our everyday understanding of object mechanics and our everyday psychology. Here we address the question of artifact conceptual structure, outlining evidence from tasks involving categorization, function judgments, and problem solving.

The Role of Information About "Convention," "Design," and "Goal" in Representing Artificial Kinds

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Should you take a moment to survey your immediate environment and briefly tally the relative numbers of artifacts and natural objects you see, the overwhelming likelihood is that the natural kinds are by far outnumbered (Tomasello, 1999). The wide variety, complexity, and technological sophistication of human artifacts surely make humans the ultimate tool users, despite the impressive feats of some nonhuman species ranging from distant relatives such as the New Caledonian crow (Weir, Chappell & Kacelnik, 2002) to closer relatives such as the chimpanzee (Tomasello & Call 1997). Despite our being such prolific makers and users of artifacts, the cognitive capacities underlying the nature, acquisition, and deployment of knowledge about this class of objects are not yet well understood.

Cross-disciplinary work in cognitive science has increasingly begun to focus on the question of artifact representation. Recent work has delineated formal aspects of conceptual representations of artifacts and other kinds of objects (e.g., Bloom, 1996; Prasada, 2000), aspects of artifact conceptual representation that may be shared across cultures that differ widely in their access to a use of technology (German & Barrett, 2005), the brain circuits dedicated for representing tools and tool use (Johnson-Frey, 2004), and the role that artifact conceptual representations plays in categorization and problem solving across development (Defeyter & German, 2003; Kelemen & Carey, in press). In this chapter, we consider these specific questions:

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What is the nature of artifact concepts? How do these concepts organize and deploy knowledge in the situations where we are in the presence of artifacts and their users?

A Framework for Artifact Representation

Recent research and evidence in cognitive development has suggested that developing commonsense understanding of the world is based on what Cosmides and Tooby (2001) call systems of dedicated intelligence: rapid learning guided by specialized domains of core knowledge, allowing perception of, attention to, and reasoning about important classes of entities in the children's environment such as numbers, objects, and people. According to this framework, one possible route by which humans understand artifacts is through mechanisms dedicated to just this process and no others—an intuitive engineering (Pinker, 2002) that represents the categories of tools and artifacts and underlies the capacity for tool use and artifact understanding.

An alternative possibility, also consistent with the core knowledge framework, proposes representation of artifacts that reflect an improvised intelligence integrating different domains of dedicated intelligence (Defeyter & German, 2003). But what special systems of knowledge are involved? First, the representation of artifacts requires the capacity to represent and reason about the mechanical properties of objects (its material kind, the specific structure into which this material has been arranged, and so forth) and the constraints that those mechanical properties place on its motions and possible interactions with other objects (e.g., Gibson, 1979). While information about material kind and mechanical structure constrains the possible functions that an artifact can perform, such information underdetermines function in many cases. Imagine for a minute the vast numbers of intricate mechanical devices on display in a kitchen store, and consider whether for each item an unambiguous reading of its function is immediately apparent. For some items at least, we contend, more than one plausible function might spring to mind.

Some objects can be similar enough in shape and structure and material kind to afford exactly the same set of activities (an ashtray and a soup bowl, for example), and because some artifacts have mechanical properties inherent in their structure to allow more than one possible and plausible function, further sources of information must be relevant to determining the precise functions of a given object. We have argued that functions for artifacts are further constrained by information drawn from our understanding of the domain of social agents who create and use artifacts to fulfill their goals: information provided by our intuitive psychology. Thus, information from two core knowledge domains would appear to be integrated in artifact representations (Defeyter & German, 2003; German & Johnson, 2002; Kelemen, 1999; Kelemen & Carey, in press; Matan & Carey, 2001).

Within this framework for understanding artifact function, two central questions have emerged. First, what is the nature of the information from the social domain that is integrated with object mechanical knowledge to determine adult representation of artifacts? Second, are there changes across development in the sensitivity to different kinds of information in the representation of artifacts? While all scholars within this area of cognitive science agree that some information from outside object mechanics is required to form representations of artifacts, there has been disagreement over the nature of the information derived from intuitive psychology (and even beyond) that might play a role.

Sources of Information Relevant to Decisions About Artifact Category and Artifact Function

A common guiding idea about the representation of artifacts is that information about an artifact's designed function (the use intended by the designer) is central to its representation, sometimes characterized as our employment of an abstract explanatory stance—the "design stance" (borrowing from Dennett, 1987)—guiding reasoning in the domain of artifacts. This captures the intuition that should I stir my coffee with my fountain pen rather than a spoon, this act does not change the nature of the pen or its function; it is still a pen (not a spoon), and it is still for writing (not for stirring). Experiments posing this essential question to adult participants confirm this intuition. In typical experiments, participants are given vignettes where an object is described as having two potential functions, one assigned by its maker and the other by the current user, and they are asked to decide the category or function of the object (German & Johnson, 2002; Kelemen, 1999; Matan & Carey, 2001).

Developmental results have been more mixed. Some scholars find evidence for children reasoning from design, as indexed by choices of the design function over the current alternative use, from age four years (Kelemen, 1999), and others show that children are not sensitive to design until perhaps age six or later. Prior to this age, design and current functions are assigned equal weight (German & Johnson, 2002; Matan & Carey, 2001). As German and Johnson (2002) point out, the latter pattern is what one might expect. Since access to information about current use is a reliable cue to the design function in most cases and much more easily accessible than historical information about design or observations of artifacts actually being made, it makes sense that children should attend to the current uses to which artifacts are put in order to learn their functions. Children begin to imitate the everyday uses of objects from the end of the first year (Abravanel & Gingold, 1985), and recent demonstrations show that children as young as age two prefer a tool that has been used by an adult to achieve a goal over alternative tools that are equally functional, even after just one demonstration by an adult model (Casler & Kelemen, 2005). Interestingly, at twenty-four months, children do not restrict the uses to which the object is put in this paradigm; they tend to use the same tool to solve other tasks for which it is suitable (Casler & Kelemen, in press).

Shared Conventions and Artifact Representation

Although the notion of design has assumed center stage in much work on the nature and development of artifact knowledge, artifact functions also have a conventionalized nature. The intuition is that there is shared agreement among a community of users about "proper" artifact functions. Perhaps what makes the pen, in the example above, retain its categorization and function is not a matter of its design so much as a matter of the fact that my solitary idiosyncratic use cannot overturn a shared conventional agreement on its proper function. Just as linguistic representations depend on agreement among the users of a given language as to what will be the appropriate linguistic form for a given referent (see Clark, Chapter Two, this volume), so it goes that artifact functions depend on such agreement within a community of users of the artifact (Callanan, Chapter Seven, this volume).

To test this idea, the case of the "stirring pen" needs to be modified such that the current alternative use occurs not just at the hands of a single user but rather at a minimum by many users, and perhaps preferably as a result of explicit or implicit agreement among them.

Siegal and Callanan (2005; see also Callanan, Chapter Seven, this volume) and Kelemen (2005) presented the first tests of this hypothesis, varying the standard task described above such that the current alternative use was described not as idiosyncratic to the current owner of the object but rather shared by many people. Although the methods were in many respects similar, the results conflicted. Siegal and Callanan showed that adults were likely to judge the artifact's function according to information about shared convention in preference to information about design in this case, while Kelemen found the opposite result.

Before we get to presenting new evidence on this question, it is worth pointing out that one issue that is often obscured within this debate has been the possible difference between the information that might be important for categorizing artifacts (for example, deciding to which kind an item belongs, what category label should be used to refer to it) versus that which might be important to determining the function of artifacts (for example, deciding what an item is for). German and Johnson (2002) demonstrated a dissociation between the information that preschool children use in answering these two questions. When presented with two plausible candidate functions for a novel artifact, one described as its design (what it was made for), and the other described as its current use (what its owner uses it for). Five-year-old children were split between the candidates when asked to judge function (German & Johnson, 2002). When provided with candidate novel names for the same artifacts and under the same conditions (one provided by the designer, one by the current owner), children favored the label provided by the designer (German & Johnson, 2002).

Although this is a subtle difference, there are important consequences of this difference in considering the types of information that might be brought to bear in answering each question. Specifically, the relationship between the function that an object has and its material kind, its structure, and its mechanical properties is not an arbitrary one: mechanical properties in the end constrain the possible functions an object can perform (Christie, Markson, & Spelke, 2005). So although mechanical structure underdetermines artifact function, there are clearly functions that certain objects cannot perform, no matter what the intentions of their designers.

In the case of category labels and their referents, the same relationship is far weaker: there are no constraints placed on the form of the category label by the material kind and mechanical structure of its referent. It is in this sense that word meanings are arbitrary. Communication using category labels thus would appear to depend on shared agreement among a community of language users. So although it is true that we tend to have conventions about the "proper uses" of certain objects, it may also be that the role of convention is less pronounced for decisions about the functions of artifacts than it is for decisions about what kind of thing it is. In one sense, a successful intentional action with an object that achieves a goal other than that for which it was designed and other than that which its conventionalized function is not wrong, or at least not wrong in quite the same way that intentionally referring to a category using a different label might be—so at least, we argue here.

This idea predicts that information about design and current use (either idiosyncratic or conventional) might have different consequences for categorization and judgment of function. In particular, we might find that information that people currently use an item for a particular purpose is more relevant to what category it should be assigned to than to a decision about what it is for. We need to agree about categorization, but not necessarily about function.

In a recent study, members of our research team addressed this prediction (Defeyter, German, & Hearing, in press). Adults and children four to six years old were provided with vignettes in which two candidate functions were described for novel objects that were presented as line drawings. Each function had been pretested to ensure it was equally plausible given the structure of the object. One function was introduced as assigned by the maker of the object (the design function), and the other was described as its current function. For some participants, this current use was described as idiosyncratic (for example, performed by the owner; German & Johnson, 2002; Matan & Carey, 2001; Kelemen, 1999). For others the current use was described as conventional (performed by "everybody"; Siegal & Callanan, 2005). In addition, some participants were asked to assign functions to the novel artifacts, and others were asked to assign the artifacts to categories.

The results of this study showed that adults tended to assign both function and category based on the function assigned by the maker (the design function). Children's responses were more complex, but showed a pattern consistent with the idea that convention information might be more important for decisions about category than about function. First, when asked to assign function, children were split between the design and the current use, and this pattern held regardless of whether the current use was idiosyncratic to the current user or a shared convention. However, when asked to assign category on the basis of the exact same information, children's judgments of category were based on the function assigned by the designer if the current function was idiosyncratic. This replicates German and Johnson's finding (2002) that information about design is critical for categorization but also qualifies it: design information is used only if the alternate current category label is idiosyncratic. When the current function was shared by many people, children's use of design information was attenuated; they selected the category based on the function assigned by the designer just as often as that based on the function shared among the current users.

The results therefore do not replicate the finding that adult decisions about function or category rely on information about shared convention (Siegal & Callanan, 2005). They provide further evidence that decisions about category labels ("What is it?") and decisions about function ("What is it for?") are dissociated in development (German & Johnson, 2002). These results also provide evidence that although decisions about category and function are dissociable, children can make inferences from function to category. Participants in this study were given information about functions only, not information about the label or category intended by the maker or currently in use. Children who were asked about artifact categories used information about function to generate their answers. Interestingly, this result complements another recent study showing that children also can make the reverse inference, from category to function. Jaswal (2006) showed that when presented with objects that resembled one thing (for example, a key) but had functional features allowing another function also (for example, to be used as a spoon), children assigned function on the basis of the label provided by an adult if that adult was described as having made the object. If the adult was described as having found the object, the function selected was based on the overall appearance (for example, to open doors).

The results support the idea that different information in acquired semantic memory for artifacts can be made explicit under different conditions or when faced with different kinds of problem (German & Johnson, 2002; Jaswal, 2005; see also Hammer & Diesendruck, 2005), whether that be judging an artifact's function, what kind of thing it is, or how it can be used to solve a problem (e.g., Defeyter & German, 2003; German & Defeyter, 2000). We turn now to consider evidence on the question of artifact representation that is drawn from a different domain: evidence from tasks requiring the use of artifacts to solve novel problems.

Deployment of Artifact Representations in Problem Solving

Although categorization and function judgments provide a window into early knowledge about artifacts, they nevertheless may fail to reveal important aspects of artifact knowledge—aspects relevant to problem solving. Indeed, from a core knowledge perspective, conceptual systems ought to promote action and problem solution, not just the mere contemplation of knowledge for its own sake (Cosmides & Tooby, 1994). Although the development of means-end problem solving has been studied (Brown, 1990), this research has only recently been linked to the conceptual representation of artifacts.

This link was make explicit by German and Defeyter (2000; Defeyter & German, 2000), who studied the impact of artifact concepts on children's performance on a class of object-use problems made popular by the Gestalt school of psychology (e.g., Duncker, 1945). In these tasks, the subject needs to solve a problem using a particular object of known function (variously, a box, a paper clip, a screwdriver). However, to solve the problem, the tool must be used in an unusual way. For example, in the candle problem (Adamson, 1952), subjects are presented with a candle, a book of matches, and a box of tacks and asked to fix the candle to a vertical screen. To solve the problem, the tack box must be used as a platform. Adults are far more likely to arrive at this solution—indeed, to find it obvious—when the box is presented without the tacks inside than when the box is presented full of tacks. In other words, priming the box's typical function (containment) makes it more difficult to see that the problem can be solved by using the box in an atypical manner. This phenomenon is called *functional fixedness.*

We propose that functional fixedness arises when mechanical properties relevant to the object's design function are activated by the demonstration of that function, blocking the activation of properties that might be relevant for alternative uses to which the object might be put, which otherwise would come easily to mind (Defeyter & German, 2003; German & Defeyter, 2000). Note that it does not follow from this model that flexible tool use is impossible or rare, just that typical uses are promoted at the expense of unusual uses. Note that while this may be suboptimal for flexible problem solving, it stems from a cognitive architecture that likely provides advantages in promoting the rapid deployment of mechanical knowledge in cases where artifacts are used for typical purposes. Consistent with this idea, it is worth noting that priming an atypical function does not cause similar delay in generating standard functions of artifacts in problem solving (Van de Geer, 1957).

Taking this proposal as a simple model for the interaction between conceptual structure and task conditions that gives rise to the phenomenon of fixedness can allow us to generate several interesting predictions that stem from the interaction between artifact conceptual structure and the specific conditions under which those artifacts are presented to participants. Some of those predictions have been tested in our recent work.

Development in Function-Based Problem Solving. German and Defeyter (2000) extended this analysis, proposing that given this model for the explanation of functional fixedness, the phenomenon could be used as an index of conceptual structure: fixedness should occur only if artifact representations are centered around information about the object's design function. If younger children's representations of artifact functions are improvised on the basis of representations of an object's mechanical properties, on the one hand, and representations of the goals of agents, on the other, rather than being centered on design, then younger children should be less susceptible than older children to functional fixedness.

German and Defeyter (2000) presented five-, six-, and seven-year-old children with a task analogous to the candle problem. The children's task was to help a puppet reach a high shelf, and the solution was to use a box as a platform (rather than as a container) in order to raise a tower of bricks to the required height. In the key function demonstration condition (when function was primed), the box was presented in use for its typical function: containment. The bricks and several other inappropriate items (for example, a coin, pencil eraser, and toy car) were presented inside the box. In the baseline condition (the function was not primed), the box and other items were presented separately.

The results showed that in the baseline condition, the problem was trivially easy for all of the children. Like adults in the candle problem, six- and seven-year-olds showed evidence of functional fixedness: they were slower in reaching the solution when the box's typical function was primed than when it was not. However, five-year-olds showed no evidence of functional fixedness: they solved the problem just as fast when the box's typical function was primed as when it was not. Moreover, the five-year-olds actually were faster than both six- and seven-year-old groups to solve the problem when the containment function of the box was first demonstrated. Defeyter and German (2003) replicated this finding with an improved task and more sensitive measures of fixedness. They also went on to show that these results extended to a case where children were presented with novel objects with newly taught functions, thus demonstrating that this finding was not accumulated knowledge of or experience with specific objects' actual functions, but rather appears to stem from something about the organization of artifact knowledge around the design function.

Cross-Cultural Differences in Access to Technology. Does mature organization of artifact concepts in terms of a design or conventionalized function reflect a universal property of human semantic memory? To date, all investigations of the conceptual representation of artifacts have been undertaken in technologically sophisticated cultures, where artificial objects with highly specific functions are prolific—cultures with such items as olive pitters, book ends, and staple guns (Tomasello, 1999). Artifact concepts embodying a central design or conventional function as a core property may therefore reflect this technological promiscuity. What might we expect to see in a culture where there is more sparse access to technology and artifacts are simpler? Indeed, what about a society in which artifacts have a range of conventionalized functions rather than being seen as "for" just one thing?

Lévi-Strauss (1962) argued that people in nonindustrial societies may enjoy more technological flexibility than people in industrial societies precisely because they are less constrained by narrow conceptions of what an artifact or object is for. A key idea is improvisation: constraints in generating a novel use for an object are placed only by the physical properties of the materials at hand, not by prior knowledge of function. Such improvisation is observed to occur frequently in nontechnological cultural settings (Berry & Irvine, 1986).

On the view that conventions are critical to artifact representations, one might therefore expect less fixedness when a design function is primed. However, an alternative possibility is that despite the differences between such cultures and technologically rich cultures, priming design functions still induce impaired problem solving, suggesting that certain mechanical features of artifacts, arranged such that it functions well for its designed purpose, can be activated by demonstrations of that function.

German and Barrett (2005) tested this prediction in the Shuar, a society of hunter-horticulturalists of the Amazon region of Ecuador. Although industrially manufactured artifacts have been present among the Shuar for many decades and various others are manufactured from forest materials, most artifacts familiar to people in industrialized societies have never been present. In general, Shuar people are exposed to only a small set of manufactured artifacts, and the set of artifacts to which they are exposed tend to be of a low-tech nature; specialized devices such as olive pitters, corkscrews, and saws are absent from this culture.

German and Barrett (2005) found in two separate problem-solving tasks that Shuar adolescents with a mean age of sixteen, for whom the design function of an artifact was demonstrated during problem presentation, were slower both to select the object for use in the problem and solve the problem than adolescents for whom the function was not primed. Thus, although the convention within the culture is one in which objects can be pressed into multiple uses, priming one specific function causes fixedness in much the same way as it does in more technologically promiscuous cultures, where many objects with highly specific functions exist.

How Specific Is Function Information in Artifact Representations? One assumption of the simple model of fixedness already described is that because the design function of an object is the core property around which artifact knowledge is based, impairment in generating an alternative function in problem solving should be limited to (or at least maximal in) cases where the object's design function alone is demonstrated, and not extend to or be attenuated when demonstrations of other nonstandard functions occur. Despite a long history of work in this area, this question has received little investigation. Although Van de Geer (1957) showed that priming an atypical function does not impair performance in a subsequent problem-solving task requiring the object to be used for its design function, just one study has looked at the effect of priming nonstandard functions on later generation of another non standard function (Bond, 1955).

Using Duncker's candle problem (1945), Bond (1955) showed that no functional fixedness occurred when the test object (a box) was used as a measure or to clamp a piece of string. However, this experiment is severely limited in having used a less sensitive measure of fixedness (including the proportion of subjects solving the task and overall time to solution). Several cleaner measures are available, such as measuring the latency to select the artifact or whether the tool is the first object selected (see Defeyter & German, 2003, for discussion).

In a recent study we addressed this question by comparing the effect on problem solving of priming the design function with that of priming an atypical use, and both against a baseline with no function demonstration. The task was using a metallic object (a wrench) to complete an electrical circuit (Duvall, 1965). The results showed that using the object to tighten a bolt immediately prior to problem presentation (design function demonstration) resulted in participants' being less likely to select the object for their first solution attempt and being overall less likely to solve the problem than participants in the baseline condition, a demonstration of functional fixedness. Priming a nondesign function (using the wrench to tap in a nail) resulted in participants' being less likely to select the object first, but did not result in fewer solutions, suggesting that there was measurable fixedness but that this was not as extensive as that caused by priming the design function.

These finding suggest that functional fixedness results not just from the interaction between prior knowledge of a familiar object's designed function and conditions where that function is primed; it can occur also, at least to an extent, when other plausible functions are primed. These findings call into question the extent that susceptibility to functional fixedness can be used as a straightforward index of an organization to semantic memory in which the designed function comprises a single central (or core) property around which artifact conceptual knowledge is based (e.g., Defeyter & German, 2003; German & Barrett, 2005). Instead, the results suggest that artifact representations may be structured such that plausible, goal-directed uses of the object can also activate information within the concept structure that is related to mechanical properties relevant to the solution of the current problem. To the extent that these mechanical properties mismatch those required to solve a later task, performance will be impaired.

This speculation predicts that fixedness should be attenuated in cases where (1) an object's mechanical properties are demonstrated "accidentally" (an action with no explicit goal) and (2) the mechanical properties activated by a demonstrated function overlap those required by a later problem.

Note that even if the above idea is correct, it is not inconsistent with the idea that the design or conventionalized function may nevertheless be shown to be a more important property within artifact representations than other functional information that can be primed, as demonstrated in the experiment described above. Although similar in many respects to impairment caused by demonstration of the design function, impairment caused by priming of nondesign functions may yet be shown to differ in important respects. First, it is notable that when the proportion of solvers is the dependent variable, the novel function did not differ reliably from the control condition. This replicates the one existing study in the literature (Bond, 1955) and may reflect an important way in which priming a design function can totally block alternative uses for some subjects. Finally, because the design function explains the precise structure and combination of most of the mechanical properties that an object exhibits, it follows that the more complex the object and specific the relationship is between the design features and the function, the less likely it is that highlighting just one alternate mechanical property will lead to equivalent fixedness.

Summary

In this chapter, we have considered the nature and development of our capacities for the representation of artificial kinds. We have presented a range of evidence collected using varying methods and from our own laboratories and those of others that speaks to the question of the kinds of information that might be central to knowledge of artifacts and their functions in human semantic memory. One key argument here has been that despite the fact that information about shared convention has been argued to play an important role in understanding of the "proper" uses of artifacts, just as it does in the case of the use of linguistic symbols within language communities, there are important differences between the two cases, and indeed across development, decisions about categories and functions dissociate. We have argued here that the nonarbitrary relationship between the material kind and mechanical structure of artifacts and the functions that can be supported undercuts the force of information about convention as important to determining proper artifact function. Shared convention appears less important for determining this facet of our semantic memory for artifacts than it does in supporting the proper relationship between linguistic symbols and the categories of artifact to which they refer.

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