Embodied Knowledge

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Abstract

In theories of grounded cognition, mental representations (concepts) share processing mechanisms with systems for perception and action. In this view, mental representations are simulations of embodied experiences. This view is supported by empirical data showing that concepts, linguistic processing, and emotion processing interact with perception and action. Key issues for further research are the question how abstract concepts are grounded in sensory-motor processing, how language and concepts are related, and the development of formal models.

INTRODUCTION

Experiences leave traces in people's memory, forming mental concepts. These mental concepts constitute the knowledge that people use to recognize objects, reason, make inferences, and thus shape human behavior. To take a simple example, people have many experiences with objects such as apples. These experiences leave traces in memory that allow the formation of the concept of apples. This concept includes knowledge about perceptual and motor features—what an apple looks like; how it feels, smells, and tastes; and how one grasps an apple and takes a bite. When a person thinks about the concept *apple*, for example, after reading the word *apple*, features from the concept are activated and form the mental representation of *apple*. In the past decade, more and more research has suggested that mental concepts do not take the form of abstract symbols but are grounded in perception and action.

FOUNDATIONAL RESEARCH

As Harnad (1990) noted, theories of mental representation need to solve the grounding problem. If mental representations consist of arbitrary, abstract symbols, a mechanism is needed that relates those symbols to real experiences. In most models, symbols get their meaning from their relations to

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other symbols. However, if symbols refer only to other symbols, they have no intrinsic meaning but need an interpreter who knows the meaning of the symbols. In this respect, understanding a set of symbols without grounding is like learning a language from a dictionary. One can look up a word, but only finds other words. To understand the words, or symbols, one needs to ground them in something familiar and meaningful. A good candidate for such grounding is the sensory-motor experiences that people have in the world. For example, the symbols for *red*, *round*, *tart*, *juicy*, *can-be-bitten*, *has-a-stem* need to be linked to the perceptual and motoric experiences of those properties in the real world. Once the concept *apple* is grounded in such sensory-motor experiences it can be said to be meaningful.

The Perceptual Symbols Theory (Barsalou, 1999) was developed to solve this grounding problem. Basically, Barsalou argues that the same processes that are used for perception and action are also used for higher level cognition such as mental representations and language understanding. His theory states that mental concepts are represented by perceptual symbols. Perceptual symbols are the neural states that underlie perception and action. People learn these perceptual symbols through many perceptual and motor experiences with things in the world. Different sensory-motor experiences are connected via association areas similar to Damasio's (1989) idea of convergence zones. Association areas in modality-specific sensory-motor systems such as the visual system and the motor system capture these experiences. Higher order association areas integrate experiences from different sensory-motor systems into multimodal experiences. Together, these association networks at different levels activate the conceptual knowledge that is used during all kinds of cognitive operations such as categorization and language comprehension. In order to create the mental representations needed for processing, simulators reactivate partial experiences across different instances of a concept. Such simulations are activated top-down, from the higher level association areas all the way to the modality-specific sensory-motor systems. Importantly, in this view, the higher level association areas by themselves do not actually represent any meaning. Rather, the sensory-motor systems provide the content for mental representations. This is fundamentally different from symbolic, amodal accounts of cognition, which assume that concepts can be sufficiently represented by higher level abstract symbols.

EMPIRICAL SUPPORT FOR THE GROUNDING OF CONCEPTS

The Role of Perception. As briefly described above, grounded theories assume that concepts share mechanisms with sensory-motor processing. In this view, a concept, for example, *apple*, is represented by the simulation of potential interactions with apples, such as seeing a round, red object, grasping it with the hand and experiences of its firm feel, the sweet, tart, and juicy experience of tasting it, and so on. This idea that concepts are supported by sensory-motor systems makes the prediction that representational processes and perceptual processes should interact. This prediction has been empirically tested in several ways.

In our laboratory, we have shown that modalities contribute to representation (Pecher, Zeelenberg, & Barsalou, 2003). During conceptual processing switching between sensory modalities incurred a processing cost. Participants were slower and less accurate to verify that a concept has a particular property (e.g., *apple-red*) when the previous trial contained a property from a different modality (e.g., *airplane-noisy*) than when it contained a property from the same modality (e.g., *diamond-sparkling*). The same effect was obtained if, instead of verifying a concept-property pair, on the previous trial participants indicated the location of a perceptual stimulus such as a burst of noise or a light flash (Van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008). Such findings indicate that the mental simulation of a concept can be focused on the relevant modality as if the observer is experiencing the concept in a way that allows perception of the property. To verify that an airplane is noisy, one must run a simulation of hearing an airplane, and to verify that a diamond sparkles, one must run a simulation of seeing a diamond. As is also found with actual perception (Spence, Nicholls, & Driver, 2000), switching between modalities incurs a cost because attention has to switch from one modality to the other.

Another line of research has shown effects of mental representations on processing of visual stimuli (Stanfield & Zwaan, 2001; Zwaan, Madden, Yaxley, & Aveyard, 2004; Zwaan, Stanfield, & Yaxley, 2002). The idea is that representation of an object and perception of that object might use (partly) overlapping perceptual features. Visual perception is facilitated by such overlapping features. In several studies people read sentences in which an object's orientation, shape, or motion was implied. For example, the sentence *There was an eagle in the sky* implies an eagle with its wings out, whereas the sentence *There was an eagle in the nest* implies an eagle with its wings folded in. Processing of a subsequent picture was facilitated when the relevant dimension matched the one implied by the sentence (e.g., the shape of the wings) compared to when it mismatched. The effect of visual overlap does not only occur between a currently activated concept and perception, but was also observed when there was an hour-long interval between sentence reading and picture processing (Pecher, Van Dantzig, Zwaan, & Zeelenberg, 2009). Thus, implied visual features are not only represented during online language processing, but also more available at longer delays. Both short and long-term effects indicate that concepts not only contain perceptual features but also that the particular features that are represented (e.g., orientation) are context dependent. Context-dependent activation of visual properties has been observed even when no visual information is presented in the entire task. When participants are asked to list properties of concepts, they are more likely to name properties that are visible from an implied perspective than properties that are not visible (Wu & Barsalou, 2009). For example, *seeds* is named more frequently as a property of *half a watermelon* then as a property of *a watermelon*. In our own laboratory, priming effects have been observed between words that refer to objects with similar shapes (*banjo-tennis racket*), but only when the experimental context has made shape relevant (Pecher, Zeelenberg, & Raaijmakers, 1998). Thus, perceptual features are relevant for concepts even in linguistic contexts. This indicates that participants have visual representations of concepts.

The Role of Action. Equally important for concepts are actions. Glenberg (1997) has proposed that the main function of concepts is to support interactions with the environment. Therefore, in his theory action is central to mental representations. Two types of information are important for concepts. First, objects have affordances. Affordances are actions that are possible given the constraints of the environment and our bodies. For example, the shape of an apple and the characteristics of our hands afford grasping the apple with one hand. Research indicates that affordances are activated by visual object information. Second, patterns of previous actions are stored in memory. We have memories of bringing apples to our mouth and biting them and in some cases these memories are activated when the object or a reference to it is encountered. Concepts are formed by the combination of current affordances and memories of previous actions. The affordances of a particular apple are combined with memories of previous actions such as biting the apple, giving the concept *apple* meaning. Support for this idea is provided by interaction between concepts and action. For example, when people judge sentences describing actions, their judgment is facilitated when they have their hand shaped in a way that is appropriate for grasping the object mentioned in the sentence (Klatzky, Pellegrino, McCloskey, & Doherty, 1989) or when they move their hand in the direction that is implied by the sentence (Glenberg & Kaschak, 2002). These and similar findings have been obtained for different types of stimuli, such as object pictures, words, and sentences. The effects occur in both directions, that is, actions are affected by concepts and concepts are affected by actions. Moreover, interactions between actions and concepts are even observed when the concept is irrelevant for the action or vice versa (e.g., Bub & Masson, 2010).

Thus, these results strongly suggest that the motor system is involved in representing concepts.

Flexibility. The view that concepts are grounded in sensory-motor systems also implies that concepts are flexible. A major reason why concepts are flexible is that they are embedded in a context. People may encounter apples in a variety of contexts: they may inspect apples in the store, looking for exemplars without blemishes or they may bite an apple, feeling the firmness of its skin and the juice running into their mouth, taste its sweetness and tartness, and chew its flesh. There is evidence that linguistic context affects which aspects of concepts are activated (Barsalou, 1993; Zeelenberg, Pecher, Shiffrin, & Raaijmakers, 2003). Context can affect which sensory modalities are relevant, and this in turn affects the strength of activation of features from those modalities. Our studies on conceptual modality switching (Pecher *et al.*, 2003) suggest that attention can be focused on specific modalities if the concept is presented in the context of a feature from that modality. Properties from a specific modality are more accessible if the prior context focuses on that same modality than if it focuses on a different modality. These results show that the context of the immediately preceding trial affects processing on the current trial.

Related findings show that focusing on a specific modality can also have long-term consequences. Activation of the visual features in a prior task makes those features more available later on, possibly because of altered representations. For example, we found that almost an hour after reading the sentence *chocolate is brown* participant's recognition memory was faster for a black and white drawing of chocolate than after reading the sentence *chocolate is sweet* (Pecher, Zanolie, & Zeelenberg, 2007). Because these findings are obtained for representations that are based on linguistic input they suggest that participants simulated a visual representation of the object that has contextually relevant perceptual qualities. These properties are then strengthened selectively, making them more available on subsequent representations of the concept. Thus, concepts are flexible in the sense that the availability of properties can vary. The representation at a specific moment contains only a subset of all possible properties. Flexibility happens at two time frames. The current context influences the current content of the concept, thus having a short-term effect on representations. Information that was activated is strengthened and as a result is more likely to be activated again the next time the concept is represented. Thus, both the current context and prior contexts affect the accessibility of concept features.

The Relation between Language and Concepts. Much of the evidence for mental concepts as sensory-motor simulations comes from studies in which participants were processing language. Although language itself obviously has visual, auditory, and motoric properties, the relation between sensory-motor properties of an utterance and its meaning is quite arbitrary and abstract. An important question is how language processing and conceptual processing interact. Rather than viewing these two types of processing as separate modules or mechanisms, we can view them as aspects of the same experience. In this sense, linguistic experiences are sensory-motor experiences that are connected via association areas at different levels, just like any other sensory-motor experience. Such ideas have been worked out in formal models. For example, Plaut (2002) developed a connectionist model that consists of modality-specific and language input and output subsystems and a central layer connecting all input and output systems. His simulations suggest that both within-modality and cross-modality connections are important to represent conceptual structure. A related idea is that of the semantic hub (Patterson, Nestor, & Rogers, 2007). The semantic hub, supposedly located in the anterior temporal pole, is a single area that connects different sensory-motor and language processing areas and has some representational power. Thus, in all these proposals language and sensory-motor activations are part of the same network that supports both linguistic processing and conceptual processing.

Such a network explains how concepts are formed and how concepts and language are related. Experiences with concepts are often accompanied by language. For example, one may see the word *apple* together with a picture of an apple, or hear the word *apple* followed by the taste of an apple. Experiences in different modalities, both directly with the object and with the words that are related to the concept become interconnected. This way, coherent concepts such as *apple* are formed. Because words and concepts are related, language activates the concept and sensory-motor activations activate language.

An important role for language and the association areas or semantic hub is the formation of categories. Superordinate categories such as furniture often consist of exemplars that have little perceptual similarity with each other and might even share perceptual similarity with exemplars from completely different categories. Language helps to bind experiences with exemplars of the same category even if they do not share perceptual experience and helps to distinguish exemplars that share perceptual features but are from different categories.

Language might also play a role as a shortcut in tasks that do not require deep conceptual processing (Simmons, Hamann, Harenski, Hu, & Barsalou, 2008). Word associations are produced faster than responses that require perceptual simulations. Studies show that when a task can be performed on the basis of simple word associations, the role of sensory-motor processing is smaller than when word associations are not enough to perform a task. This suggests that when people are giving fast responses they rely on word associations and do not fully activate concepts. Word co-occurrence norms also show, however, that sensory-motor variables are captured in linguistic utterances. Although some researchers have interpreted this finding as evidence for symbolic representations of concepts (Louwerse & Jeuniaux, 2008), we think it is more likely that concepts are represented by sensory-motor activations and that these activations are reflected in their utterances.

Emotion. In addition to language processing, the role of sensory-motor activations for conceptual processing can also be clearly seen in how people process emotion. The valence of a concept is the degree to which people have positive or negative feelings about it. For example, people may have positive feelings about kittens and negative feelings about snakes. Such feelings are associated with approach and avoidance actions. If you like kittens, you have a tendency to bring them closer to yourself, for example, by taking a step in their direction or by picking one up and bringing it closer to your body. Conversely, if you do not like snakes you have a tendency to increase the distance between your body and the snake. In the laboratory, this is investigated by showing pictures or words with emotional valence and asking participants to respond to the stimuli by moving a lever toward or away from themselves, mimicking approach and avoidance actions respectively. People find it easier to make approach responses when the stimulus has positive valence than when it has negative valence and to make avoidance responses when it has negative valence than when it has positive valence (Chen & Bargh, 1999). The relation between valence and approach/avoidance actions also works in the opposite direction. People tend to like meaningless stimuli more after performing an approach action than after performing an avoidance reaction. Another important and related finding is mimicry. People have a tendency to mimic other people's facial expressions or bodily postures. Researchers have suggested that mimicry underlies understanding of and empathy with other people's emotions (Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). People may use feedback from their own expression to recognize other people's feelings. Mimicry is stronger between people who like each other than between people who do not like each other, and when people are prevented from using mimicry their performance in emotion recognition tasks drops. Thus, the close relation between emotion understanding and emotional actions suggest that action is fundamental to emotional concepts.

RECENT DEVELOPMENTS: THE GROUNDING OF ABSTRACT CONCEPTS

The grounded cognition approach has been criticized for dealing mainly with the mental representations of concrete objects and actions. For concrete objects and actions it is relatively easy to see how sensory-motor systems might be involved in their representations. As we discussed above, there is much evidence that conceptual processing and sensory-motor processing interact, providing support for the idea that perception, action, and mental representations share processing resources. In order to claim that cognition is grounded in perception and action, however, we need to show that such interactions exist not only for concrete objects such as *apples* but also for more abstract concepts such as *truth* and *problem solving*.

Several ideas have been put forward to solve the grounding problem for abstract concepts (Pecher, Boot, & Van Dantzig, 2011). The most thoroughly investigated idea has its origin in cognitive linguistics, the Conceptual Metaphor Theory (Lakoff & Johnson, 1980). On this account, people use metaphors and image schemas to ground abstract concepts in sensory-motor experiences. In language, people often use concrete domains to talk about abstract concepts. For example, people talk about *solving a problem* in terms of a *journey* that involves traveling from a starting point (the problem situation) to a destination (the solution) along a path (the method that is used to solve the problem). This can be seen in expressions such as *to have something get in one's way* or *to reach the solution*. People have very concrete experiences with journeys, full of rich sensory-motor details. These concrete experiences are mapped on the abstract situation of solving the problem, giving it concrete structure. This account explains how abstract concepts are grounded in sensory-motor systems because the mapping is based on concrete physical experiences.

Starting with this linguistic evidence, cognitive scientists have further investigated the psychological basis of Conceptual Metaphor Theory. Although metaphors are observed in language, the theory claims that metaphorical language is the expression of the underlying metaphorical concepts. Thus, metaphors are not merely a linguistic phenomenon, but are fundamental to conceptual processing. The theory distinguishes between primary metaphors, or image schemas, and secondary metaphors. Especially image schemas are relevant for grounded cognition. Image schemas are basic patterns of embodied experience, such as *up-down*, *inside-outside*, and *balance*. They are learned through multimodal experiences. The resulting image schemas are analogue representations of embodied experiences in space but they are not modality specific. Rather, they are more abstract than direct sensory-motor experiences, and in this way can form a bridge between direct physical interactions and abstract concepts.

Evidence for Conceptual Metaphor Theory is most convincing when image schemas are activated in the absence of any linguistic reference to the image schema. Studies have shown that mental representations of abstract concepts result in activation of concrete image schemas. For example, researchers have investigated whether the abstract concept *power* activates an *up-down* image schema (Schubert, 2005). When people talk about power, they often refer to powerful people as being higher than powerless people. Consistent with this mapping, participants shifted their visual-spatial attention to higher locations after reading a word referring to a person with much power (e.g., *president*) than after reading a word referring to a person with little power (e.g., *servant*). As a result, participants were better at identifying an unrelated visual stimulus in congruent locations than in incongruent locations (Zanolie *et al*., 2012). Similar findings have been reported on the activation of *spatial proximity* for the concept *similarity*, *up-down* for *quantity*, *containment* for *category membership*, *spatial movement* for *time*, and *left-right* for *valence* (see Pecher *et al*., 2011, for an overview). All these studies provide evidence for a role of image schemas for mental representations of abstract concepts in contexts that contain no direct reference to the metaphorical mapping.

Image schemas thus seem to play a role in de representation of abstract concepts. The question is to what extent Conceptual Metaphor Theory can fully explain abstract concepts. Image schemas are very basic patterns, representing a single dimension with limited values. For example, the *up-down* image schema represents only a concept's vertical relative position. This alone is not sufficient to represent the concept *power*. Rather, vertical position is an embodied representation of relative differences in power between people. It does not represent what it means to have power over someone, such as having the ability to make someone do something. A related issue is that there is no one-to-one mapping between concepts and image schemas. For example, many metaphors can be used for the concept *love*, such as *journey*, *proximity*, and *containment*. Similarly, a single metaphor can be used for many concepts. For example, the *up-down* metaphor can be used for *power*, *quantity*, *valence*, and so on. This also illustrates that image schemas have only limited representational power. In other words, an image schema represents one property of an abstract concept, and additional information is needed to represent the full meaning of a concept.

Such additional details might be provided by situated concepts. In this view, concepts develop from entire situations. A concept is a collection of experiences that are combined into a representation. For example, the concept *power* is based on many situated experiences that a person has with power, and the representation of power likely occurs in a situated context.

Abstract concepts often derive much of their meaning from an entire situation, more so than concrete concepts. Because situations have sensory-motor properties, this proposal can also explain how abstract concepts might be grounded. The representational power of such concept can be based entirely on collections of experiences. This idea was recently further developed for the emotion concepts *fear* and *anger* (Wilson-Mendenhall, Barrett, Simmons, & Barsalou, 2011). Exemplar models of categorization (Hintzman, 1986; Nosofsky, 1986) explain how individual episodes of experience are stored. Abstraction occurs when a cue activates several experiences. These different experiences are then combined into some sort of summary representation for further processing. Thus, there is no need for the storage of abstract representations, instead, abstractions are created as a response to a cue.

Another approach to grounding abstract concepts is to combine embodied experiences with linguistic relations (Andrews, Vigliocco, & Vinson, 2009). On this account, concepts are acquired through these two sources. Embodied experiences provide sensory-motor grounding, but this may not be available for abstract concepts. Knowledge is also acquired through language, however, and the availability of linguistic information is independent of how concrete or abstract the concept is. They developed a model in which the two sources are combined. In this model, abstract concepts are represented as linguistic items that are related to other linguistic items and that, by inferences, are also related to sensory-motor information. Thus, abstract concepts are grounded, albeit indirectly, in sensory-motor activations.

KEY ISSUES FOR FURTHER RESEARCH

Clearly, the question of how abstract concepts are grounded needs further research. Although there is quite some evidence that image schemas are important for abstract concepts, image schemas may be of limited value for representations because they only represent certain properties. Richer representations might consist of situational properties. Situations play a role for all concepts, and perhaps even more so for abstract concepts than for concrete concepts. In fact, it seems impossible to represent an abstract concept such as power without the context. Thus, a theory of abstract concepts should take situations into account. Situations should likely be considered part of the concept rather than just background. For example, experiments with problem solving tasks have shown that concrete details of the situation are very important, even if they are irrelevant for the proper solution of the problem. Research on transfer in problem solving tasks such as in physics has shown that participants are more likely to use a previously learned solution if problems share superficial properties, even if the underlying structure is very different (Goldstone & Sakamoto, 2003).

One might argue that solving physics problems is a very difficult task for novices. A question for future research is whether the same is true for more automatic processes such as mental representation.

A second important issue is the role of language. First, language might be important for the acquisition and perhaps also the representation of abstract concepts. In Andrews *et al.*'s (2009) model concrete concepts are grounded directly in sensory-motor experiences but are also represented by the pattern of linguistic contexts in which they appear. Abstract concepts are mostly represented by the linguistic contexts. One might wonder to what extent representations can still be considered grounded in sensory-motor processing if the grounding is indirect through other linguistic symbols. Second, other researchers have even argued that linguistic data such as word co-occurrences show effects of sensory-motor aspects of concepts. For example, concepts that are perceptually similar occur in linguistically similar contexts. Thus, linguistic relations might be sufficient for the representation of meaning. One should take into account, however, that linguistic data are produced by humans who already have rich concepts. Models of word co-occurrences have as input texts such as internet news groups or textbooks that are used in schools. All these texts are produced by people, and thus can be expected to reflect the conceptual structure of the person producing the test. Thus, rather than concluding that conceptual representation is based on linguistic symbols, one could say they are expressions of underlying concepts and have no bearing on the nature of those underlying concepts. Attempts to use linguistic output to investigate the nature of the underlying representations should therefore be regarded with some care.

A third issue is the need for formal models of grounded cognition. The literature seems to be replete with claims that the grounded cognition framework makes certain predictions but these claims are based on verbal theories rather than detailed formal models. Formal models can give insight into the feasibility of the approach. So far, few attempts have been made at formal modeling. One important obstacle might be the operationalization of sensory-motor input. If the input to a model is derived from verbal materials, such as feature production norms, one has to be aware that this is only an approximation to actual sensory-motor representation. Computational models of human cognition have played an important role in understanding human behavior and may also help in better understanding how meaning is represented.

CONCLUSION

To conclude, as many researchers from fields such as philosophy, linguistics, and psychology have remarked, concepts need to be grounded. In the past

15 years, several ideas have been put forward on how concepts might be grounded in sensory-motor processing. Inspired by these ideas, researchers have obtained support for such ideas. Now, however, it seems we are reaching the boundaries. Some of these boundaries are mentioned above. If we can jump these boundaries, the field will make further progress toward a grounded view of cognition.

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