An embodied cognition perspective on quantum logic

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> "The words of language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined. [...] The above mentioned elements are, in my case, of visual and some of muscular type."

(Einstein quoted in Hadamard, 1996, The mathematician's mind: The psychology of invention in the mathematical field. Princeton, NJ: Princeton University Press (original work published 1945), as cited in Diezmann, C. M., & Watters, J. J. (2000). Identifying and supporting spatial intelligence in young children. Contemporary Issues in Early Childhood. 1(3), 299-313).

How do people think about things they cannot see, hear, touch, smell or taste? The ability to think and communicate about abstract domains such as emotion, morality, or mathematics is presumably uniquely human, and one of the hallmarks of human sophistication. Hitherto, the question how people represent these abstract domains mentally has not been answered definitely. Earlier classical cognitive models act on the Cartesian assumption of the disembodiment of mind (or soul, in Descartes terms). These models assume that neurological events can explain thought and related notions to the full extent. This view conforms to the computer metaphor of the mind in which thinking is solely based on brain activity or, in computer terminology, based on the central processing unit, also more commonly known as CPU (Seitz, 2000). When the body is put back into thought (embodied cognition) a very different perspective on human thinking emerges, namely, that we are not simply inhabitants of our body; we literally use it to think. Perhaps sensory and motor representations that develop from physical interactions with the external world (i.c., vertical dimensions) are recycled to assist our thinking about abstract phenomena. This hypothesis evolved, in part, by patterns observed in language. In order to communicate about abstract things, people often utilize metaphors from more concrete perceptual domains. For example, people experiencing positive affect are said to be feeling "up" whereas people experiencing negative affect are said to be feeling “down”. Cognitive linguists studying cognitive semantics (e.g., Gibbs, 1992; Glucksberg, 2001) have argued such articulations reveal that people conceptualize abstract concepts like affect metaphorically, in terms of physical reality (i.c., verticality). It has been argued that without such links, abstract concepts would lack common ground and would be difficult to convey to other people (Meier & Robinson, 2004). This approach helped scholars to draw significant links between embodied experience, abstract concepts, and conceptual metaphors. Conceptual Metaphor Theory (Lakoff & Johnson, 1980) defines two basic roles for conceptual domains posited in conceptual metaphors: the source domain (the conceptual domain from which metaphorical expressions are drawn) and the target domain (the conceptual domain to be understood). Conceptual metaphors usually refer to an abstract concept as target and make use of concrete physical entities as their source. For example, morality is an abstract concept and when people discuss morality they recruit metaphors that tap vertical space (a concrete physical concept). In colloquial language a person who is moral is described as “high minded”, whereas an immoral person might be denominated as “down and dirty” (Lakoff & Johnson, 1999). Following theory the human tendency for categorization is structured by imagistic, metaphoric, and schematizing abilities that are themselves embedded in the biological motor and perceptual infrastructure (Jackson, 1983). Supporters of this view suggest that cognition, rather than being amodal, is by nature linked to sensation and perception and consequently inherently cross-modal (e.g., Niedenthal, Barsalou, Winkielman & Krauth-Gruber, 2005). Furthermore, those researchers argue for the bodily basis of thought and its continuity beyond the infantile sensorimotor stage (e.g., Seitz, 2000). Indeed, some researchers suggest that the neurological processes that make abstract thought possible are intimately connected with the neurological processes that are responsible for representing perceptual experiences. Specifically, they argue that conceptual thought is based on sensory experience, but sensory experience is not based on conceptual thought (e.g., love is a rose, but a rose is a rose) (Meier & Robinson, 2005). Why is an abstract concept like affect so frequently linked to concrete qualities like vertical position? One possible explanation for this perceptual-conceptual connection comes from developmental research. Early theorists of sensorimotor learning and development emphasized the importance of movement in cognitive development (e.g., Piaget, 1952). According to this perspective, human cognition develops through sensorimotor experiences. Young children in the sensorimotor stage (from birth to about age two) think and reason about things that they can see, hear, touch, smell or taste. Motor skills emerge and the infant cultivates the coordination of tactile and visual information. Later researchers postulated that thinking is an extended form of those skilled behaviours and that it is based on these earlier modes of adaptation to the physical environment (Bartlett, 1958). For example, it has been suggested that gesture and speech form parallel systems (McNeill, 1992) and that the body is central to mathematical comprehension (Lakoff & Nunez, 1997). When children get older they develop the skills to think in abstract terms. These skills maybe built upon earlier sensorimotor representations. For example, a warm bath leads to a pleasant sensory experience and positive affect. In adulthood, this pairing of sensory and abstract representations may give rise to a physical metaphor (e.g., a warm person is a pleasant person) that continues to exert effects on representation and evaluation (Meier & Robinson, 2004). Transferred to the vertical representation of affect one can only speculate. Tolaas (1991) proposes that infants spend much of their time lying on their back. Rewarding stimuli like food and affection arrive from a high vertical position. The caregiver frequently appears in the infant's upper visual-spatial environment (Meier, Sellbom & Wygant, 2007). As children age, they use this sensorimotor foundation to develop abstract thought, as recognized by developmental psychologists (e.g., Piaget & Inhelder, 1969). This early conditioning leads adults to use the vertical dimension when expressing and representing affect. These considerations suggest that the link between affect and vertical position may develop early in the sensorimotor stage (see Gibbs, 2006; for sophisticated considerations).

From theory to experimental applications Affective metaphors and related associations apply to a multitude of perceptual dimensions such as, for example, spatial location, brightness and tone pitch. A plethora of studies investigated the link between abstract concepts (i.c., affect) and physical representation (i.c., verticality). For example, in a study by Meier and Robinson (2004) participants had to evaluate positive and negative words either above or below a central cue. Evaluations of negative words were faster when words were in the down rather than the up position, whereas evaluations of positive words were faster when words were in the up rather than the down position. In a second study, using a sequential priming paradigm, they showed that evaluations activate spatial attention. Positive word evaluations reduced reaction times for stimuli presented in higher areas of visual space, whereas negative word evaluations reduced reaction times for stimuli presented in lower areas of visual space. A third study revealed that spatial positions do not activate evaluations (e.g., "down" does not activate "bad"). Their studies give credit to the assumption that affect has a physical basis. Moreover, an often cited study by Wapner, Werner, and Krus (1957)examined the effects of success and failure on verticality related judgements. They found that positive mood states, compared to negative mood states, were associated with line bisections that were higher within vertical space. In a recent study Meier, Hauser, Robinson, Friesen and Schjeldahl (2007)reported that people have implicit associations between God-Devil and up-down. Their experiments showed that people encode God-related concepts faster if presented in a high (vs. low) vertical position. Moreover, they found that people estimated strangers as more likely to believe in God when their images appeared in a high versus low vertical position. Another study by Meier and Robinson (2006) correlated individual differences in emotional experience (neuroticism and depression) with reaction times with regard to high (vs. low) spatial probes. The higher the neuroticism or depression of participants, the faster they responded to lower (in contrast to higher) spatial probes. Their results indicate that negative affect influences covert attention in a direction that favours lower regions of visual space. In second experiment the researchers differentiated between neuroticism and depression. They argued that neuroticism is more trait-like in nature than depression (which is more state-like). The researchers concluded from their analysis that depressive symptoms were a stronger predictor of metaphor consistent vertical selective attention than neuroticism. Similar results emerged when dominance-submission was assessed as an individual difference variable and a covert spatial attention tasks was used to assess biases in vertical selective attention (Robinson, Zabelina, Ode & Moeller, in press). Linking higher levels of dominance to higher levels of perceptual verticality they found that dominant individuals were faster to respond to higher spatial stimuli, whereas submissive individuals were faster to respond to lower spatial stimuli. Further support for the Conceptual Metaphor Theory comes from a study investing the extent to which verticality is used when encoding moral concepts (Meier, Sellbom & Wygant, 2007). Using a modified IAT1 the researchers showed that people use vertical dimensions when processing moral-related concepts and that psychopathy moderates this effect. As mentioned above, affective metaphors and related associations apply multitudinous perceptual dimensions. Recent research examined the association between stimulus brightness and affect (Meier, Robinson & Clore, 2004). The investigators hypothecated that people automatically infer that bright things are good, whereas dark things are bad (e.g., light of my life, dark times). The researchers found that categorization was inhibited when there was a mismatch between stimulus brightness (white vs. black font) and word valence (positive vs. negative). Negative words were evaluated faster and more accurately when presented in a black font, whereas positive words were evaluated faster and more accurately when presented in a white font. Furthermore, a series of studies showed that positive word evaluations biased subsequent tone judgment in the direction of high-pitch tones, whereas participants evaluated the same tone as lower in pitch when they evaluated negative words before(Weger, Meier, Robinson & Inhoff, 2007) . Moreover, cognitive psychologists have shown that people employ association between numbers and space. For example, a by study Dehaene, Dupoux and Mehler (1990) showed that probe numbers smaller than a given reference number were responded to faster with the left hand than with the right hand and vice versa. These results indicated spatial coding of numbers on mental digit line. Dehaene, Bossini and Giraux (1993) termed the mentioned association of numbers with spatial left-right response coordinates the SNARC-effect (Spatial-Numerical Association of Response Codes). Another SNARC-effect related issue is that empirical data indicates that associations between negative numbers with left space exist. For example, in a study by Fischer, Warlop, Hill and Fias (2004) participants had to select the larger number c to 9. The results showed that negative numbers were associated with left responses and positive numbers with right responses. The mentioned results support the idea that spatial association give access to the abstract representation of numbers. As mentioned above, mathematicians like Einstein explicitly accentuate the role of the concrete spatial representation of numbers for the development of their mathematical ideas. Today there are a few savants which can do calculation up to 100 decimal places. They also emphasize visuo-spatial imagery as in the case of Daniel Tammet who has an extraordinary form of synaesthesia which enables him to visualize numbers in a landscape and to solve huge calculations in the head. Moreover, about 15% of ordinary adults report some form of visuo-spatial representation of numbers (Seron, Pesenti, Noel, Deloche & Cornet, 1992). However, the quantum mechanical concept of superposition transcends the dualistic representation which form the basis of so many conceptual metaphors by negating the third Aristotelian law of the excluded middle, the tertium non datur (lit. no third [possibility] is given) a.k.a. principium tertii exclusi. This "law of thought" stipulates that any given proposition can either be true or false (there is no middle ground in-between). It implies that either a proposition is true, or its negation is true. From a cognitive linguistics point of view, concepts like morality and affect are anchored in spatial representations. These are called primary metaphors, other examples include vertical metaphors like "up is more" or emotional/sensory metaphors like "affection is warmth"177, or perceptual metaphors like "good is bright" etc. These concepts are not superimposed but mentally represented as opposites (in vertical and/or horizontal space). On the basis of psychological and empirical evidence, it can be convincingly argued that mathematical concepts are inherently rooted in sensorimotor representation (Lakoff & Nuñez, 2000). Our perception of space is restricted to three dimensions. However, multidimensional Hilbert space is not grounded in our embodied neural/sensorimotor representations of mathematical concepts. Our logical inferences are based on metaphors, we take inferences from a source domain and apply them to a target domain, e.g., "happy is bright" and "sad is dark", or "up is good" and "bad is down" (Barsalou, 2008; Lakoff, 1987, 1993; Lakoff & Johnson, 1980). According to theory, the same somatic mappings underlie the cognitive foundations of logic and mathematics (Lakoff & Johnson, 1980; Lakoff & Nuñez, 2000). From this perspective our understanding of quantum logic must thus be grounded in sensorimotor representations, how else would one cognitively represent abstract thought? From an embodied cognition point of view, the notion of disembodied thinking (purely "platonic" computation) has been clearly rejected. Any form of cognition is always grounded in sensorimotor representations (Lakoff & Nuñez, 2000). However, many mathematicians implicitly subscribe to a Platonic view on abstract mathematical reality which is a disembodied form of mathematics. From a grounded cognition perspective, modal simulations of bodily states underlie cognition and hence mathematical and logical reasoning (Barsalou, 2008). It follows that mathematics is not detached and dissociated from the genetic and neuronal predispositions which underlie human cognition, as the Platonic "abstract universal mathematics" perspective would hold. The questions has been posed before as follows: "... is there, as Platonists have suggested, a disembodied mathematics transcending all bodies and minds and structuring the universe-this universe and every possible universe?" (Lakoff & Nuñez, 2000, p. 1) However, the question of how to cognitively represent superpositional states in multidimensional Hilbert spaces remains still an open one. And what role does embodied cognition play in this context or is quantum logic independent of physical representations as Platonists would believe? Conversely, we propose that the concept of superposition might be especially relevant for cognitive representations of concepts, specifically in the context of integrating multiple "binding circuits" (Lakoff, 2014). According to theory, the entire system is based on these perceptual primitives which are binary in nature (warmth vs. cold, up vs. down). The concept of superposition transcends the dichotomies which are intrinsic to these schemas. A visual metaphor superposition is provided bistable visual stimuli like the Rubin's Vase (Pind, 2014) discussed in the introductory chapter. Those ambiguous visual stimuli seem to convey much deeper epistemological information about the psychophysical nature of perception (Atmanspacher, 2002; Atmanspacher & Filk, 2010). According to theory (Lakoff, 1993; Lakoff & Nuñez, 2000), abstract thought is based on the combination of complex metaphors. We suggest that superposition (e.g., bistable perception) is a perceptual schema in itself and it follows its own logic which sets it apart from classical visual metaphors (e.g., the spatial logic of containment which underlies set theoretical reasoning processes). An interesting question is whether other cultures have metaphors for superposition. We already discussed Bohr and the Yin & Yang symbol before. For an article on "the role of metaphor in information visualization" see (Risch, 2008). The role of neuro-cognitive linguistics is to make the unconscious embodied architecture of cognition visible. Given that most of cognition occurs at an unconscious level, cognitive linguistics has to deal with mainly unconscious concepts and frames (and how these are embodied from a neuronal point of view).

Footnotes

177 From an embodied cognition perspective, warmth is associated with early experiences of affection during the sensorimotor stage of development. Interestingly, the insular is involved in the underlying neuronal ciruit, and it is this neuronal circuitry which form the basis of the conceptual metaphor. The question why "affection is warmth" and "warmth is not affection" can be answered as follows: The primary metaphor is always the more fundamental. Thermoregulation via the hypothalamus is an ongoing process, i.e., our brain constantly computes temperature whereas the activation of affective states is something which happens only infrequently. Therefore, temperature forms the source domain and affect the target domain in the construction of the metaphor (Lakoff, 1993). The directionality of the metaphor is thus determined by its neuronal underpinnings.