Some Ways of Thinking

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Abstract When thoughts overwhelm the mind, the mind puts them into the world. Talk, gesture, diagram, and sketch help not only to augment memory and information processing but also to structure thought and promote inferences and discovery. Research from many domains will be presented that highlights the similarities, differences, and special characteristics of each of these tools of thought.

1 Some Ways of Thinking

How do we think? One of those questions that elicits shoulder-shrugs. There are the simple knee-jerk answers: with our brains, or, in words. But there's more to thinking than that. Here I'd like to show, and I'm by no means the first, that we have other ways of thinking. That we take our thoughts out of our minds and put them into the world. Of course we do that every time we talk. But when we talk, we don't just use words, we use the prosody in our words, a bit of which can negate what the words seem to say. When we talk, we use our bodies, our faces, our hands. We use things in the world, pointing to them, arranging them, manipulating them. We use proxies for things in the world, looking toward or pointing to empty places that represent them, where they might have been. Similarly for thinking, which, after all, is communicating with our selves. We think with our hands and our faces and our bodies. We think with the marks and the arrangements of marks we make on paper and the things and arrangements of

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things in the world. You might counter, but all that goes through the brain. Of course, nearly everything goes through the brain. Eating goes through the brain, from the biting and chewing onward. As does walking. Nevertheless, we don't say we eat or walk with the brain.

Perhaps some experiments, thought experiments as well as laboratory ones, will make the case. One of the many reasons for putting our thoughts into the world is the limitation of memory. We make to-do lists, set buzzers and timers, put the shoes that need new soles by the door to remember to take them to the cobbler. In this we are in good company with the rulers of empires who inscribed their accomplishments in stone, often in depictions, not for themselves, but so that others would learn and never forget. Another reason is limits of information processing. Imagine computing the square root of a 4-digit number without paper and pencil. Imagine counting without pointing, and even moving the objects to be counted when their number gets large. When prevented from counting with our fingers, we count with our heads, or with our eyes (e. g., [1]. Sometimes that knowledge is embedded in the actions that produce it. If you're a touch typist, tell me where the keys for "c" or "i" are without moving your fingers. Touch typists typically can't do that without moving their fingers. The brain needs the actions of the fingers to find where the keys are in space.

Thinking with Paper. Putting ideas on paper is common practice for artists, designers, architects, mathematicians, scientists, and ordinary people. Designers refer to having "conversations" with their sketches (e. g., [2]), going to far as to say that the sketch was trying to tell them something. Here's the gist of the conversation: designers, artists, scientists put something on paper that represents their ideas, usually tentative ones. When they contemplate their own sketches, they may discover things in their sketches that they did not intend, they see new things in their sketches, and make inferences from them. Architects, designers, artists, scientists see new relations and configurations (e. g., [3, 4–6]). The new relations and configurations encourage new interpretations. This process–sketching, inspecting, discovering, re-sketching–creates a virtual cycle, a creative one that produces new ideas. A detailed analysis of one experienced architect as he designed a museum revealed that when he reorganized the elements of his sketch, when he saw new configurations, he was more likely to get new ideas, leading to new designs, expressed in new sketches [7]. Expertise matters. In designing a museum, novice architects made many perceptual inferences from their sketches, like noticing sharp angles or finding patterns but experienced architects made more functional inferences from their sketches, for example, inferences about view lines or traffic patterns or changes in light [4]. Intriguingly, the perceptual inferences typically depended on examining the given overhead viewpoint of the museum, but the functional inferences often depending on imagining a different viewpoint, from within the depicted environment.

To further understand the conversation with sketches, we brought the task into the laboratory, borrowing a paradigm of Howard-Jones [8]. We presented ambiguous sketches, those in Fig. 1 below, to participants trial after trial, asking them to produce a new interpretation of the sketch each time they viewed it.

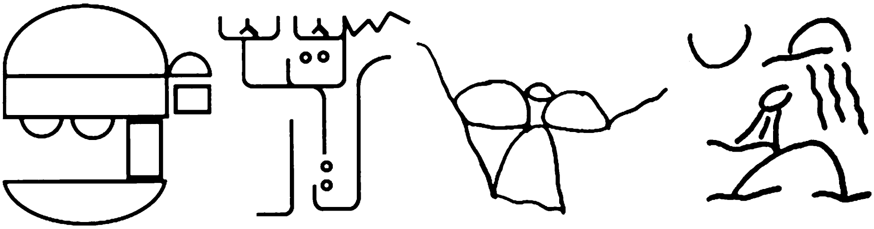

Fig. 1 Four sketches used in experiments of Suwa and Tversky

In various experiments, we presented the sketches to ordinary people, to designers, to architects [9]. In some experiments, we asked people to complete two measures of spatial ability, embedded figures and mental rotation, and a measure of associative thinking, the remote associates task. We counted the number of new interpretations each participant produced for each sketch, and then asked participants how they generated new interpretations.

What did we find? We found that professional designers and architects surpassed untrained participants in numbers of new interpretations of the sketches. We found that those who reported focusing on different parts or reorganizing the parts of the sketch produced more than twice as many new interpretations as those who didn't report that strategy [7]. We found that those who were adept at finding simple figures like triangles and rectangles embedded in complex ones generated more new interpretations than those who were not adept at finding hidden figures [9]. We had already shown that finding new interpretations benefits from perceptual reorganization of complex visual stimuli. We found that mental rotation, a spatial skill requiring imagining objects at different orientations, was unrelated to number of interpretations. We found that those good at producing remote integrative associations, an index of fluid thinking, generated more new interpretations than those who had difficulties in that task. We found that the perceptual reorganization skill was uncorrelated with the associative thinking skill; they were independent of each other Producing interpretations of ambiguous sketches, then, relies on a perceptual skill, generating new organizations and patterns, and a thinking skill, producing a rich web of meaningful associations to those patterns. We proposed that people adept at interpreting and reinterpreting ambiguous sketches rely on a strategy that combines these skills, a strategy we called Constructive Perception, the deliberate and active use of perception in the service of innovative thinking. And we wondered if analogous processes underlie innovative thinking in other domains.

Drawing is used in other domains to sketch out ideas. One such domain is art. Although laypeople may view drawing as transferring what is seen to paper, artists who draw see that process as far more complex (e. g., [3]). They report that drawing is a safe way to explore, that they deliberately get themselves into trouble to break habit and to see if they can find a way out. Like architects and designers, they make unintended discoveries, seeing new things in their own drawings.

Drawing is commonly used in exploration in science as well, beyond constructing clear and simple diagrams for communicating. Scientists look at data every which way to explore, to discover patterns and phenomena. They sketch out explanations to "get the whole picture," to test for completeness and coherence. They sketch to work through problems as well as to communicate known phenomena (e. g., Gooding, Bechtel). Would constructing visual explanations help students as well? Bobek and I presented junior high students with lessons either in the workings of a bicycle pump or in chemical bonding [10]. In both cases, students' knowledge was assessed immediately after the lesson. Then students in each experiment were divided into two groups. One group was asked to provide the typical verbal explanation of the bicycle pump or chemical bonding. The other group was asked to provide visual explanations of the same systems. After completing the explanations, student knowledge was tested again. Importantly, students improved on the second knowledge test simple from constructing explanations, without any intervening teaching. Impressively, students who created visual explanations improved more than those who provided verbal explanations. Examination of their explanations provides clues to the superiority of the visual explanations. They contained more information than the verbal explanations about the structures of the systems. This is to be expected because visual explanations map physical structure in space to the space of a page, a natural mapping, and one of the noted advantages of diagrams. More impressively, the visual explanations contained more information about function, about the operations and causality of the systems. Behavior and causality are harder to depict, and easier to convey in language, yet they were more frequently included in the visual explanations. The visual explanations used language as well as diagrams; the verbal explanations did not add diagrams. But the visual explanations went farther. Just as for artists and scientists, visual explanations provide a check for completeness and a check for coherence: are all the necessary parts there? Do they work together to produce the expected outcomes? The diagrams in the visual explanations provide a natural platform for inferring behavior, process, and causality from structure. Purely symbolic language, with no natural mapping from actual structure to the space of a page does not provide a natural, user-friendly platform for inference and thought.

Thinking with the Body. But what if we don't have paper? Until the twentieth century, paper was rare, and even now we don't have it always with us. What we have with us is our hands, our heads, our bodies, all of which are expressive. Architects, when blindfolded while designing, gesture profusely [11]. Thought has been viewed internalized action; gestures are actions, and can reexternalize thinking [12, 13]. Gestures, like thinking, can pull things together or apart, group things into categories and hierarchies and patterns, turn things upside down or inside out, repeat and delete, arrange and rearrange, and more. Gestures can do even more than reenact thought (e.g., [14, 15]). They can "paint" a scene or an object, iconic gestures. When describing environments, participants use integrated sequences of gestures to place items in their relative locations and to depict features of the items (e. g., [16]). If gestures externalize thought, then perhaps they can facilitate thought. Gestures do appear to offload working memory [17], but they appear to contribute to thinking in more refined and specific ways. Participants alone in a room solving spatial problems gesture when the problems exceed working memory capacity [18]. Their gestures reflect the structures of the problems they are attempting to solve. For a problem about a row of two groups of three glasses each, their gestures were primarily horizontal, corresponding to the two groups of six glasses; to solve a problem about a rising tide and a ladder, they made vertical gestures, corresponding to the rungs of the ladder. Those who gestured were more likely to find a solution to the problem than those who didn't gesture.

If gestures reenact thinking and can facilitate thinking, then gestures that are compatible with the thinking should be more effective than incongruent gestures. Computers with mouse or especially multi-touch interfaces provide an excellent opportunity to test this hypothesis, as well as to teach. Early school-age children from a low SES school were given a series of math problems to solve [19]. Some were discrete problems, notably, addition. Others were continuous problems, finding a specific number on a number line from 0 to 100. The tasks were matched with congruent or incongruent gestures. The congruent discrete gesture for addition was tapping and the congruent continuous gesture for number line estimation was sliding a marker. Children performed better when the gestural actions required by the interface were congruent with the mental actions needed to solve the problems.

Spraction. Both thinking with paper and thinking with the body are thinking with space, and more specifically with actions in space, the actions that create the sketches or the actions of the gestures themselves. The actions in space create simple patterns that abstract and crystallize the thought, a process integrating space, action, and abstraction that I've called *spraction*. We organize our cabinets and closets by putting like things–cups and plates and silverware; socks and sweaters and underwear–together in rows and columns, categories and hierarchies of categories. We distribute plates and silverware and glasses on tables in one-to-one correspondences, place books on shelves and houses on streets in orders. We design the world and the designs carry abstractions. The actions that design space are incorporated into gestures and their patterns into diagrams [20].

I began with an ancient unanswerable question, how do we think? I've tried to show that we think not just in words, but in actions and in the spaces those actions create. I'll end with an example, from a fellow cognitive scientist, Mark Wexler. He used to be a physicist, and worked with Feynman diagrams, elegant simple diagrams of lines straight and squiggly representing particles. Some have double lines, pairs of lines. One day, thinking about a problem, Mark wondered what would happen—he had a hunch–if he picked up the pair like a rubber band and twisted it. It worked. The thinking? Manipulating the diagram with gesture.

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