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Multiple Models. In the Mind and in the World

Barbara Tversky [*]

Abstract: *»Multiple Modelle. Im Geist und in der Welt«*. Models, in whatever sense, have a dual status: they are what they are and they represent something else, even Borges' (1999) legendary point-to-point map. Representations select, add, and distort the information they represent. Models are meant for more than representation; they are meant as thinking tools, to promote inference, discovery, and creative thought. Research has shown that representations created on the page or in the air (gesture) have an accessible semantics and syntax and that such representations promote thought through a wordless conversation between the eye and the hand and the (sometimes virtual) page.

Keywords: Model, representation, inference, diagram, sketch, gesture.

1. Introduction

Model is one of those abundantly useful words that gets used abundantly by many communities in varying senses. Whether a model airplane or a model of good behavior or a business model or fashion model or a mathematical model or a mental model – what these seemingly disparate examples have in common is that they *represent* something else. Now, *representation* is one of those abundantly useful words that gets used abundantly in varying senses, so it's not clear we've made progress. But let's dig a little deeper, starting with the concept of *representation*. A common view of *representation* is that it extracts certain features and relations from whatever it's representing, but not all. It maps elements and relations in the represented world to elements and relations in the representing world. Whoever or whatever created the representation presumably selected those features and relations for a reason. A paradigmatic example of a representation is a map; it takes places and relations among them

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in the real world to places and relations in the representing world, the map. Someone designing a map for cyclists would select different features and relations than someone designing a map for drivers. Representations do more than select. They can also add information, say names of towns and streets, geographical borders, icons for restaurants and hotels, bands of color for depths of oceans or altitudes of mountains, and they can distort information, say straightening roads and enlarging them. Weather maps add notations for weather patterns that are invisible.

A model generally does more than represent. It is meant to go further, to encourage thought, to allow inferences, discovery and creative leaps. It's a thinking tool.

Models need not be tangible. Models can be mental, a set of beliefs of how something, a machine or a government or a person, operates. Of course physical phenomena, the firings of neurons, underlie mental models but mental models are not equivalent to the firings of neurons or even the specific firings of specific neurons. Models can be created by words, which have physicality in the form of sound waves or marks on a page, but again they are not equivalent to their physical instantiation. I can use words instead of a map or a diagram to tell you how to get from the train station to the hotel or how to operate the ticket machine for the train and you can use those words to create a mental model. If my words created from my mental model and your mental-modelling are precise enough you should be able to buy a ticket and arrive at the hotel. Even if, as is typical, much information is left out; representations and models are always used in a context of shared understanding.

Even if the words are carefully crafted, turning a mental representation in one mind into the right set of words and translating the words into a mental model in another mind can be effortful and error-prone, especially when the spatial array or the set of actions are complicated. Words are wonderful, I use them frequently and rather like them, but they bear arbitrary relations to meaning.

There are other forms of communication, both for self and for other, that have more direct correspondences to meaning. I'm thinking, of course, of gesture and graphics. By gesture I mean poses or actions of the body, especially of the hands and head, that act on thought rather than on the world. By graphics I refer to marks on a virtual page, with a broad scope for both. Marks could be the parts of a model of a building or a molecule and a page could be a screen or the face of a rock or a virtual 3-D space that stands for a building or a molecule. Graphics also include sketches, photos, maps, charts, diagrams, and such. There are two important points here. The ways that information is represented in gesture and graphics is more natural, immediate and direct than the ways information is represented in words. Next, both gesture and graphics are in the world, not in the mind. They are outside the mind and not only can be sensed but must be sensed by the body. Of course we can imagine gesturing and imagine seeing or creating graphics but imagination is between the ears, and the stuff that's beyond the ears and can be sensed has a different status and different effects. And of course words can be outside the mind and sensed by the body but they fail the tests of naturalness and directness of representation.

So far, a lot of words. Now for some action. Or truthfully, words that describe research activities that give backing to and expand the claims. Because we thought that representing and thinking with words is far from sufficient to understand how people represent and think about many of the important things in their lives, faces, bodies, objects, spaces, and events in time, we studied those one by one to uncover how they are represented and thought about (Tversky 2005a, 2005b; Tversky 2009; Tversky, Zacks and Hard 2008). The upshot: mostly not in words; each followed its own logic though descriptions of each in words turns out to be fascinating in and of itself. Then we turned to the spaces people create to expand their own thought. These have a long, long history. Cave paintings date back at least 35,000 years. Images of maps, animals, people, and mysterious symbols incised in stone are ancient and scattered across remote parts of the world. What roles these served for the people who made them or viewed them can only be a matter of speculation but the difficulty of making them and their ubiquity attest to strong human–and only human–desires to create and contemplate them.

2. Graphics

One line of research has been showing how graphics communicate (Tversky 2009): what are the semantics and pragmatics of graphic displays and how do people use them for comprehension, inference, discovery and creativity? Graphics make use of marks on a page and place on a page to convey a range of meanings quite directly. Gesture turn out to be similar, but of course also different. Let's start with graphics even though gesture comes first, phylogenetically and ontogentically. Again maps serve as a paradigmatic example: maps map; they use elements and spatial relations on a page to represent elements and spatial relations in the world. Visual-spatial representations of people, animals, objects, and mechanical systems do the same. Many other sets of concepts that are not inherently spatial can be spatialized: mandalas, the Periodic Table, organization charts, and graphs among them.

2.1 Place on a Page

Even preschool preliterate children can use place on page meaningfully. They can put stickers along a line on a page to represent the temporal relations of breakfast, lunch and dinner or the quantitative relations of handfuls, bag-fulls, and shelf-fulls of candy or their preferences for foods. They are inclined to put greater quantities and values up rather than down. Older children readily use proximity on the page to represent proximity on an abstract dimension, time, quantity, preference. Why up? Most likely because going up means countering gravity, so going up takes strength and health, because people grow taller as they grow older, that taller people and buildings and trees are stronger, that more money makes a taller pile, that healthy energetic people stand tall and weak depressed ones are stooped – the vertical dimension is loaded. All (or almost all) good thing go up; it's overdetermined. The horizontal dimension is more neutral though reading order confers substantial directional preferences and handedness confers value preferences.

2.2 Marks on a Page

There are several kinds. First there are words and word-like symbols and abbreviations. Next there are depictive elements, presumably the original foundations of ideographic languages, depictions that resemble what they represent like a depiction of the sun or a crescent moon as well as depictions or icons that represent figuratively, like the scales of justice or a trash can for deleting files or a file folder for creating them. The elements we have been most interested in are a third kind, meaningful abstract forms: dots, lines, arrows, circles, boxes, and blobs. It's a long story, so just a few examples here. In a series of experiments in which people interpreted and created graphics, we found that these forms have context-sensitive meanings that have shared readily grasped meanings. Dots can represent intersections in maps, people in social networks, ideas in knowledge networks. Lines connect dots. They serve as paths in maps and relationships in social networks and connections in knowledge networks. Boxes contain one set of things and separate those things from things in other sets. The Periodic Table elegantly puts each separate element in a box and arranges them in rows and columns that represent their molecular properties.

2.3 Using Graphics

We've not only looked at how graphics are designed to represent a range of information, we've also looked at the ways different forms of graphics serve learning, comprehension, inference, discovery and creativity. These interact interestingly with expertise, ability and task. Maps allow a plentitude of inferences based on proximity and direction as well as terrain. So does the Periodic Table. The same information presented in different ways encourages different inferences, for example people interpret bar graphs as discrete comparisons and lines as trends. For learning and comprehension, clarity is critical. Creating either a visual or verbal explanation of STEM phenomena increases learning but creating a visual explanation is far more powerful (Bobek and Tversky 2016). For design, art and data discovery, ambiguity is productive because it allows for reconfiguration and reinterpretation. Architects and artists say they have conversations with their sketches, they draw for one reason but when they examine what they've drawn, they make unintended discoveries. From those they get new ideas (Tversky and Suwa 2009). The same processes of discovery hold for scientists trying to understand a large and complex data set.

3. Gesture

Like graphics, gestures also map and spatialize. They use actions in space and place in space to map meanings directly. Gesture has some advantages over graphics, and some disadvantages as well. Gesture needs nothing more than the body we were born with, no pencil, no paper. Gestures are dynamic, so perhaps better suited to represent dynamic information, change over time. But gestures are fleeting while graphics on a page stay still in front of the eyes to be contemplated and revised. We have been studying the roles of gesturing and different kinds of gestures for both those who view gestures and those who perform them. Gestures commonly accompany speech and often add important information not conveyed by the words. The same explanation in words, say of arrangements of events in time or explanations of the workings of an engine, are understood differently depending on the gestures that accompany the speech. More surprising is the finding that the gestures people make alone in a room without speaking influence their own understanding and memory. In one study, students alone in a room studied descriptions of environments such as a small town or a large gym with four or eight landmarks and paths among them (Jamalian, Giardino and Tversky 2012). They knew they would be tested and that the tests would require inferences, such as spatial relations from perspectives different from those in the descriptions. A majority of participants gestured while reading at least one of the four descriptions. They produced line-like gestures for paths and point-like gestures for landmarks. That is, as a set, their gestures formed models of the environments. Those who gestured performed better on the tests than those who didn't and those who gestured for some descriptions but not all performed better on the descriptions for which they gestured. Another group was required to sit on their hands; they performed worse. They rarely looked at their hands so the facilitation seems to be spatial-motor. Gesturing clearly helped them think. We think the spatial-motor representations created by the gestures translated the words into thought.

4. In Sum

Models are necessary for thinking; by omitting, adding, and distorting the information they represent they can recraft the information into a multitude of forms that the mind can work with to understand extant ideas and create new ones. Models take elements and relations among them in the represented world and map them onto elements and relations in the representing world. In the cases of tangible, diagrammatic, and gestural models, the elements and relations are spatial. The fundamental elements are dots and lines, nodes and links. A dot can represent any concept from a place in a route to an idea in a web of concepts. Lines represent relations, any relation, between dots. As such, spatial models rely on more direct and accessible mappings than language, which bears only arbitrary relations to meaning. These mappings can be put into the world and made visible or visceral in graphics and gesture. Putting thought into the world promotes thought in self and other.

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