visual image. The Simonides' method of "loci" by which images of well-remembered places are used to frame new material was used by the Roman orators to memorize their speeches. In his dual-coding theory of memory, Paivio (1986) has documented in detail the imagability of words in relation to meaning. A depictive image is meaningful to the extent that its inspection allows us to generate new descriptions of its subject matter. Kosslyn and others have shown repeatedly that the time to locate components of memorized spatial maps by covert mental scanning is proportional to relative distances in the actual maps. Denis and Cocude (1989) obtained similar mental scanning results when their subjects were asked to generate mental images of maps from purely verbal descriptions. We use mental images to answer verbal questions such as "How many windows does your house have?" (Kosslyn 1980). Like labelled maps, mental images are descriptively interpreted (Reisberg and Chambers 1991). Thus bidirectional translation of representational mode is a fundamental component of visual thought.

Sketching as Mental Translation

Catalysis: a metaphor

A chemical catalyst such as an enzyme enormously accelerates chemical change (new configurations of atoms within molecules) by forming a temporary compound with the reacting molecules. This temporary intermediate compound has the effect of lowering the activation energy "hill" that the reacting molecules must reach and, by temporarily holding them in the right configuration for a new molecular structure to be formed, greatly speeds up the reaction. After the reaction, the catalyst is restored to its original state. The speed is such that thousands on thousands of molecules can be transformed in a fraction of a second.

According to the metaphor, early design sketches are like catalysts in that they can combine with and transform at high speed superimposed mental information in working memory. They are not complete representations but temporary representation holding structures that help the "inner designer" to manipulate and transform the invisible representations of design thought. The mental translation "reactions" that sketch attributes catalyze are of two kinds: (1) the retrieval of implicit knowledge for depictive image generation, and (2) the manipulation and inspection of depictive images to derive new descriptive concepts. Both these mental translation processes need visual support.

Figure 7.5 shows the activation level for a hypothetical chemical reaction in which compound A-B reacts with C-D, exchanging atoms to form compounds A-D and C-B. In order for the reaction to occur, the reactants must overcome an energy barrier or hill – the activation energy. By forming a temporary intermediate compound, the catalyst (such as a biological enzyme) lowers this activation energy hill (dotted line). In the metaphor I compare mental invention to a process by which mental propositions and images are recombined in the mind in novel ways. The barrier that must be overcome is the mental effort (the amount of processing in the brain) that is needed to perceive new combinations of images or propositions. The sketch is like a catalyst in that it too forms a temporary intermediate compound with some

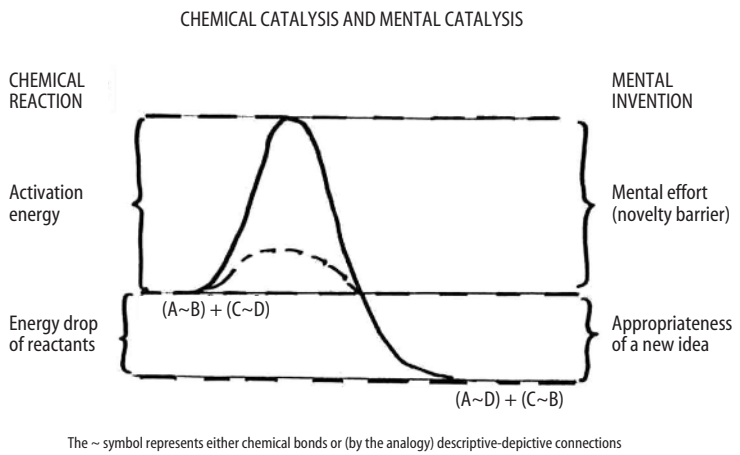

Figure 7.5 Chemical catalysis and mental catalysis.

initial propositions or mental images. This lowers mental barriers to deriving new propositions from mental images or new mental images from propositions. Just as a stile makes it easier to step over a fence by providing an intermediate platform, so, I suggest, sketches provide temporary intermediate platforms for a designer's mental representations of the task. Of course, however inventive, a design solution must fulfil its criteria. It must be appropriate. I compare the appropriateness of a new idea to that change in potential energy level of chemical reactants that drives an exothermic reaction and determines its direction.

However, perhaps this is pushing the metaphor too far. Like paintings (according to Picasso), metaphors are "lies intended to make you see the truth."

Retrieving implicit knowledge

We can create novel design concepts and objects only if we have the component parts of acquired visual expertise in memory and can retrieve these parts for fluid manipulation. "As when from the sight of a man at one time and a horse at another we conceive in our mind a Centaure" (Hobbes, 1651).

As a hunter-gathering lifestyle would demand, the innate capacity of the brain for long-term visual memory is immense. For example, Standing et al. (1970) found that after viewing 2560 colour slides for 10 seconds each, their subjects could distinguish 90% of the familiar slides from unfamiliar ones several days later. The problem for visual thought, however, is that long-term visual memory is inaccessible for manipulation. Thus retrieval capacity is a key component of visual invention that needs support in the form of verbal notes or visual stimuli.

I have proposed various mechanisms by which sketch components can provide retrieval cues for remembered objects (Fish 1996). One such mechanism is to use written notes or descriptive symbols to access, via their meaning, a complex network of associated images and descriptions. Another