2 Thinking, Acting, Creating

Introduction

While creativity might strike the reader as an archetypal form of "abstract" cognitive activity to be performed "in the head," it has been poorly served by the information-processing literature. Indeed, for many writers the study of creativity is currently in some sort of crisis.[1] In part, this might be because the concept of "creativity" is not always clearly defined and so cannot be reduced to something that can be amenable to laboratory experiments. Research on how we might understand "creativity" has reached an impasse, stuck in divergent thinking tasks,[2] such as "multiple uses of a brick."

In chapter 1, I proposed that the word "information" has (at least) two meanings: one related to the information's content and one related to the context in which the information is presented. In terms of design, theories that inform "creativity" (and, to a lesser extent, "design thinking") tend to focus on information-as-content and ignore information-as-context. Let's say that "content" relates to the form of the artifact and that "context" refers to the environment in which the artifact is being used. Many theories of design thinking focus on content and draw heavily from information-processing theories of cognition. Many design textbooks propose that design is a form of problem-solving. Indeed, the very suggestion that design is about problem-solving contains within it the implication that the artifact represents a "solution" to a specific problem and that this can be defined in terms of content (which can be conceptualized, manipulated, and communicated). For example, if the problem is how to contain hot liquid for drinking, one solution might be a tea cup. The notion of information-as-context implies the need to focus on the environment in which artifacts are used—that is, the ways in which the ambiguity of an artifact's "meaning" needs to be resolved in order to let people use it. This is a perspective that is inherent in design *practice* and can be seen in some versions of design thinking (although much of this discourse still draws heavily on information processing and problem-solving). Furthermore, focusing on information-as-context is what designers do as a matter of course, but theories based on information processing ignore or trivialize this.

In this chapter, and throughout this book, my arguments overlap with those of Kees Overbeeke,[3] who led the Designing Quality Interaction research group in Eindhoven. He long argued that designers give too much weight to "cognitive" (i.e., information-processing) skills at the expense of technical or craft skills. Drawing on the work of Gibson and Merleau-Ponty (as radical embodied cognitive science does), he emphasized how meaning emerges in interaction. In this chapter, my argument is simply that embodied cognition helps theorize context, as it is experienced by designers, as the ongoing, reciprocal engagement in a human-artifact-environment system engaged in high-level cognition—such as creativity.

Convergent and Divergent Thinking

The manner in which designers respond to what Charles Eames called "a willing embrace of constraints" has been explored by Peter Rowe in his influential (and very readable) book *Design Thinking*. Rowe is concerned with "the situational logic and the decision-making processes of designers' action, as well as with theoretical dimensions that both account for and inform this kind of undertaking."[4] Taking his cue from Simon's conception of design as problem-solving, Rowe proposes that design involves the ability to respond to problem-oriented constraints in ways that adapt to the "covering characteristics" (or specific circumstances) in which the designer is working. Using concepts drawn from a blend of information-processing theory and phenomenology (particularly ideas from Merleau-Ponty) he proposes that

> the design process may be seen to be marked by a sequence of episodes or situations that are, in turn, coincident with periods of heuristic reasoning through which problems are defined and solutions sought. During each episode a particular heuristic device or set of devices can be said to be in operation and in general control of the reorganization of a problem space. Further, the orientation of this

> operation is neither entirely objective nor entirely subjective. It is both. Between episodes, control is relinquished, so to speak, from one set of organizing principles to another.[5]

A "problem space" is a set of plausible solutions to a problem (given certain constraints, such as the "rules" by which a problem could be solved, the features of the problem available to the problem solver, the end-point or "goal" of the activity of problem-solving). While Rowe's arguments employ the language of information processing (e.g., "heuristic reasoning," "problem space") and speak to the idea of information-as-content presented in chapter 1, their tenor is more suited to the experience of design and the need to work with "organizing principles." For me, this feels less like an argument based on information-as-content (in which the designer perhaps builds a mental model from which to imagine design concepts) and more on the practical, physical interaction in situations in order to explore and respond to constraints (organizing principles). Rowe, following Merleau-Ponty, considers a "situation" as involving the focused attention of the problem solver (this is similar to Csikszentmihalyi's notion of "flow"[6]). Situations, from this perspective, are ambiguous not only in their open-endedness but also in the dependence on the prior experience of the person experiencing this situation, who may or may not have a sense of how to respond. The "situation" can be regarded as a "wicked" problem (which does not have an obvious solution). To complicate matters (for an information-processing approach), heuristic reasoning becomes less about the simple application of "rules of thumb" (as might be implied by a literal reading of information-processing concepts), and more a matter of relying on general principles that are "sedimented" (using Merleau-Ponty's term) such that these can be adaptively applied to different situations. The accumulation of these "sedimented principles" leads to "know-how";[7] that is, repeated exposure to different "situations" creates a repertoire of responses that allows experienced designers to respond to ambiguities across situations. Another way of explaining this involves the contrast between "divergent" and "convergent" thinking. In the latter, design concepts are narrowed (converge upon) a promising set of solutions. In the former, design concepts spread out (diverge) as far as possible to encompass many alternatives.

"Divergent thinking" studies, such as the Alternative Uses Test or the Remote Associates Test, take inspiration from "synectics"[8] in which designers are encouraged to "make the familiar strange, and the strange familiar" or Koestler's suggestion that creativity involves the "bisociation of two mutually incompatible contexts."[9] While such approaches look as if they relate to the specific abilities of individuals, in terms of their potential to be "creative," they lack validity.[10]

A second approach to studying creativity explores how body posture or movement can constrain or influence the approach taken to the tasks. Here, body posture and movement provide "minimal embodiment"[11] that can affect divergent thinking. The view is minimal because we are considering only one aspect of the human-artifact-environment system. If we are to take this system seriously, then we need to better understand how the various elements interact with each other. Without consideration of these interactions, any account of creativity will be as limited as the information-processing or the body-based accounts. This is why it is important to understand creative practice in situ.

Hence, a third approach is to study creative practitioners in their workplace. This is my preferred approach and has been employed by researchers across a variety of domains.[12] For now, I want to look more closely at the role that problem-solving plays in discussions of creativity and more broadly of theories of cognition. The reason for this is that, in an information-processing approach, problem-solving is the sine qua non of symbolic manipulation through which a set of features needs to be internalized in order for a solution to "pop out" and reported. For embodied cognition, in the absence of mental models, how are problems solved?

Problem-Solving

Problem-solving has been proposed as a basis for explanations of creativity. Much of the work on problem-solving manipulates information-as-content. That is, people are presented with situations in which either they do not have a strategy (i.e., a familiar pattern of activity) or the strategies that they apply do not lead to a successful outcome. From this, a "problem" is a situation in which you do not have a familiar strategy for producing a defined outcome. This might be due to the features in the situation being unfamiliar to you or to some set of constraints that prevent certain actions (i.e., the "rules" by which the problem is permitted to be solved). Even before considering the features in the situation, however, it is equally important to recognize the need for an "outcome" and the actions that can be made. An incomplete Sudoku puzzle is, for someone who has no interest in Sudoku, not a “problem” but merely a partially filled grid of numbers. In the domain of artificial intelligence, Boden’s[13] account of creativity has long held sway. In this, problem spaces are mapped, explored, and transformed to create new concepts, typically using strategies that have been described in problem-solving studies.

A common strategy in the problem-solving literature is “means-ends analysis.” Here, the problem is presented in an initial state and the problem solver is asked to produce a goal state (end) by discovering the steps (means) to make transitions from initial to goal state. Let’s take a simple example:

$$\frac{xii}{vi} = ?$$

The first thing to do is make sense of this as a problem, or to define the initial state. In terms of content, you need to interpret the symbols and know that the *vi* and *xii* stand for numbers (in Roman numerals). To define the context, you need to recognize this as something to do with arithmetic (there is an “=” sign, and the horizontal bar indicates a division sum). If one or more of these features does not make sense, then the “problem” itself is insoluble, and the solver is forced to take further steps until there is an understanding of the initial state. From the initial state, you define the goal state—here, solve a division sum to replace the “?” with a Roman numeral. Following this, the “means” are defined in terms of converting from the number system that is used here to another that is more familiar, performing some calculation, and producing a solution.

What might not have been immediately obvious from this example is that having the problem printed in front of you is a great help in attempting the solution. This reiterates a point made in chapter 1, in relation to solving simultaneous equations, which is that problem-solving experiments often make use of “external representations” but rarely consider how participants interact with these in solving the problem. It is as if these experiments assume that problem solvers do all the manipulation in their heads and then report the result. A challenge for theories of problem-solving is to explain how people keep track of the steps and the rules as they solve the problem. If all the information used in solving a problem is kept in the person’s head, then one can see how this can quickly become overwhelming for all but the most practiced of problem solvers. Try verbally presenting the problem to someone and have them solve it: chances are that the statement of "*x*-*i*-*i*-over-*v*-*i*-equals what?" might need to be repeated a couple of times before they can begin to attempt this. Thus, the visual presentation of problem spaces has a bearing on how strategies can be applied.

Once you have developed an approach to solving a problem, you can apply this to similar instances. This reduces the need to "solve" the problem in future (as long as you can recall the approach). Suppose the problem is now

$$\frac{xxx}{x} = ?$$

Repeating the previous approach (translate from Roman to Arabic numerals and perform the calculation) produces an answer. But it would be much simpler to recognize that there are three lots of *x* above the line and one *x* below the line—so you can "see" that the answer is 3 (or iii) without the need for intervening steps. Information-as-context frames the problem and minimizes the need for translation. Getting stuck on a single approach to solving a problem (when there are more efficient alternative approaches) is called "functional fixedness."

Design Thinking

Design thinking is concerned with breaking free of "functional fixedness" by which particular problem-solving strategies become ossified and inflexible. Consequently, approaches to design thinking emphasize the need to continually question and challenge both the presentation of the problem and the consequences that might arise from proposed solutions.

> Design thinking relies on our ability to be intuitive, to recognize patterns, to construct ideas that have emotional meaning as well as functionality, to express ourselves in media other than words or symbols.[14]

In his "Science of Design," Simon[15] set out ideas that informed the concept of "design thinking" (although it is fair to say that design thinking is not a single school of thought so much as a loose collection of methods and manifestos that take the term in different directions). Simon's perspective echoed that of other early champions of design thinking in viewing design as an activity that could employ principles and concepts from information-processing. I am not going to review the various methods that have been advocated for these activities. Many of the methods emphasize "spiral design" processes indebted to Asimow's "iconic model,"[16] in which a vertical axis moves design from concept to prototype to product and a horizontal axis defines stages (analysis / synthesis / evaluation / communication). I am, however, interested in the ways in which design thinking has become untethered from its original information-processing moorings to become something that has more affinity with phenomenology (in terms of "user experience"). We noted earlier that Rowe's account was based on a blend of information-processing and phenomenology. However, I felt that Rowe's account has a disconnect between the practice of doing design and the "theory" illustrated by the language of problem-solving, problem statements, and "thinking outside the box." Indeed, there have been calls for design thinking to define itself in terms of "situated, embodied material practices."[17]

Design and Cognition as Multi-Objective Satisfaction

Some notions of design thinking can be traced to Campbell's[18] "Darwinian" theory of creativity. For Campbell, creativity is a form of trial and error in concept generation (or "blind variation and selection retention"). There is the implication that generating ideas "unrelated to the solution" (as Campbell advocated) would be a random process, or at least unstructured and opportunistic. Relating blind selection to problem spaces, might, if it were unchecked, lead to a combinatorial explosion which creates the sort of "wicked" problem mentioned previously.[19] Consequently, the challenge is to generate many ideas while also battling with the constraints that one might apply to make the problem space manageable. In other words, the problem space could be defined in terms of its degrees of freedom, DoF (as discussed in chapter 1). Applying DoF to design, we might define the problem space in terms of many objectives that create many constraints. One way of understanding the problem space is to recognize that constraints provide a local impetus to a global strategy.

When problems are well defined (table 2.1), producing novel solutions is less important than making sense of the constraints. Indeed, a well-defined problem most probably has a strategy that can be applied to solve it. This is why Herbert Simon proposed that novel solutions can occur only in ill-structured or wicked problem spaces.[20]

Table 2.1
Defining types of problems

Well-Defined Problems	Wicked Problems
Specific goals	Vaguely stated goals
Clear and predictable solutions	No unambiguously right or wrong answers
Clearly defined means (paths to solution)	Unstated or assumed problem constraints
Most information that is required will be available from the problem space	Require a large database of relevant information that is often difficult to access

One approach, from computer science and engineering, that has been applied to design, is the use of multi-objective problem analysis. In mathematics, multi-objective problems can be described in terms of optimization. The aim is to produce a solution that can be mathematically proven to be the best. However, it can be difficult to satisfy all the objectives. So, we select one or two objectives and treat the others as constraints (i.e., by setting limits on the extent to which the other objectives can vary). We want to optimize our objectives (maximize or minimize, depending on the outcome) by performing an action on them (i.e., in mathematical terms, we are optimizing a set of functions). In this case, we are seeking a solution that maximizes both sets of values, while also treating any other factors as limits or constraints on the solution space. This can be expressed as

$$\textit{Maximize}: f_i(x) \quad \textit{subject to } f_i \leq \varepsilon_i \; (i=1,\, 2,\, q-1 \cdot q-2,\, q+1 \;.\;.\;.\;,\, n).$$

Here, we are taking a mathematical problem and dividing it into something tractable to define the set of constraints. This process, in turn, defines a set of solutions that can be represented graphically as a Pareto Front, for pairs of objectives. In figure 2.1, each dot describes a space of solutions to the problem, using different values of two objectives, *a* and *b*. The boundary (shown as the dark dots) of this space is the Pareto Front; adjusting the constraints shifts this front and changes the solution space.

I am not going to elaborate on the mathematics here and am using the concept of multi-objective satisfaction as an analogy based on the simple observation that designers select objectives to optimize. The objectives to optimize might be defined by a collection of features in the situation, where all other features are assumed to be constrained (or held constant).

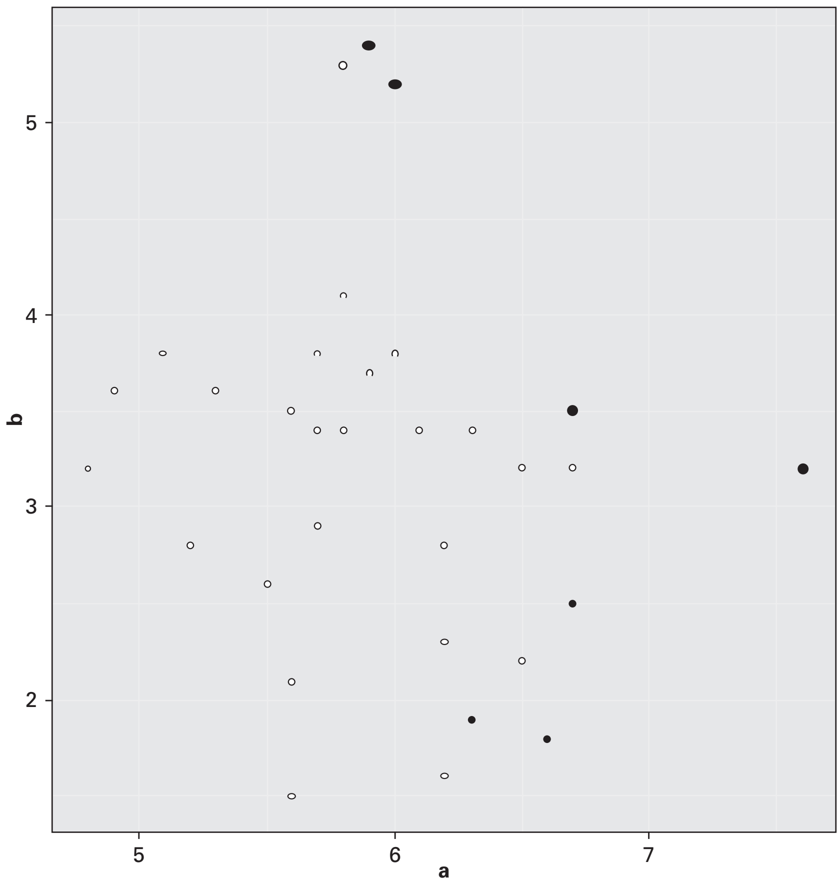

Figure 2.1
Pareto Front maximizing values for objectives *a* and *b*.

Designers are unlikely to address all the objectives in their activity, and most of the objectives will be treated as constraints on their activity (with the implication that picking the "wrong" constraints could result in poor, unoriginal, or incomplete designs). I should also note that, rather than seeking a mathematically optimal solution, designers are likely to seek satisfactory solutions—that is, solutions that involve "satisficing"[21] in terms of the objective and the constraints. In this way, we have a description of what might look like "trial-and-error" exploration during design. Design is a cyclical response to changing situational cues: "All creation . . . has the same foundation: gradual steps where a problem leads to a solution that leads to a problem."[22] In the information-processing approach, these steps involve translations into (and out of) mental models. In embodied cognition, these steps involve physical manipulations to (re)shape the problem-space.

Reitman[23] and Stokes[24] show that problem solvers can be more creative and efficient when given constraints that allow them to structure the problem space than when they have no constraint. Reitman speaks of the problem solver both identifying and breaking constraints in order to progress to a solution. However, this is not simply about violating rules. "The greater the number and complexity of the violations . . . the more the problem solver risks introducing complications."[25] The argument is that the transformation of a problem is often something that can be performed physically. Reitman characterizes this process of transformation as one of "exposition plus development plus conclusion."

For Stokes, the selection of constraints to attend to or ignore is a purposive, deliberate act. The question is how this sense of purpose or deliberation can be reflected by embodied cognition. Stokes acknowledges the possibility of spontaneous creativity, in the form of the "skilled execution" of, say, a jazz musician improvising. But even here, the introduction of constraints can lead to greater spontaneity and innovation. Designers have a repertoire of well-learned, manipulative techniques that come from their work practice. So, for example, one would expect that when confronted with materials and tools that are familiar, the creative person would respond to them in ways that exploit these well-practiced techniques.[26] Applying this to problem-solving experiments, one would expect that when confronted with physical representations of problems, people would rely heavily on their prior experience of the physical properties of objects and how they are used to find a solution. This means that the application of prior experience, in the form of repertoires of movement, becomes integral for solving problems.

The Roles of Physical Action in Problem-Solving

In the popular "Tetris" game (figure 2.2) shapes drop down a computer screen and are manipulated (rotated or moved sideways) to align with spaces in the lower layer.[27] When people play this game, they manipulate the shapes as a way of trying out different solutions. This is what Kirsh and Maglio term "epistemic action,"[28] which involves manipulating the problem space

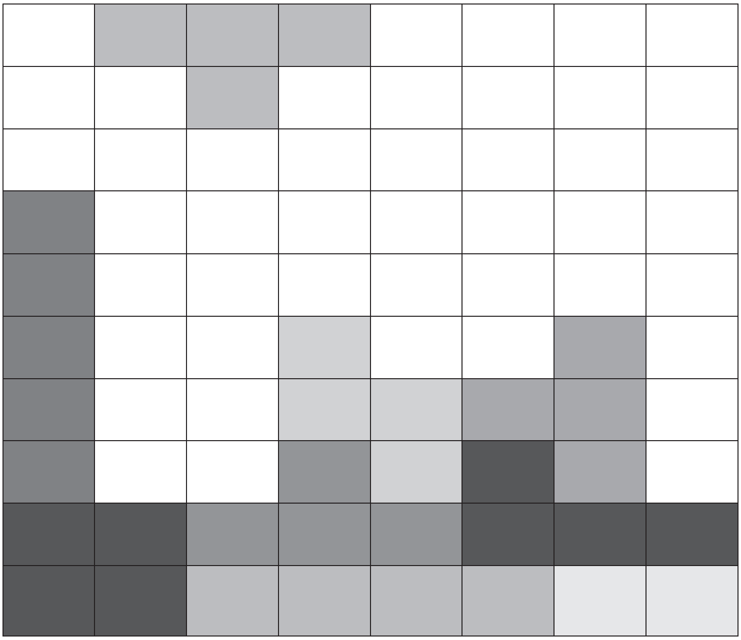

Figure 2.2
Tetris. Paul Maglio and David Kirsh show that "in Tetris—a real-time interactive video game—certain cognitive and perceptual problems are more quickly, easily, and reliably solved by performing actions in the world rather than by performing computational actions in the head alone."

in order to make available information that might otherwise be hidden. So, rotating a Tetris block helps to determine whether or not it *might* fit into an available space. Similarly, people might write (in pencil) numbers that could possibly fit a cell in a Sudoku grid before committing to a specific number. In this case, the Sudoku puzzle is (at least in its initial stages) a multi-objective problem, and the puzzler is seeking to define constraints by focusing on a single objective (or seeking to eliminate alternative objectives). Epistemic actions differ from pragmatic actions, which are the means taken to move toward a goal, by allowing people to explore the constraints in the problem space. Much of the literature on problem-solving concentrates on pragmatic actions and often disregards or trivializes epistemic actions because these are not seen as goal-directed. In the means-ends notion of problem-solving, an action that is clearly not a means to the end can be dismissed as an error (moving to a different end state) or "toying" (not moving toward any end state).

A traditional explanation of problem-solving as occurring "in the head" involves "insight." A problem solver reaches an impasse and is unable to proceed to a solution but, after a period of time, is struck by an "a-ha" moment in which the solution "presents itself." Often a period of time is spent away from the problem itself, perhaps day-dreaming or thinking about something else. Central to this notion is the idea that the solution appears ready formed and shifts the problem solver from the impasse to the solution. A classic experiment on "insight" is shown in figure 2.3. This involves two pieces of string suspended from the ceiling,[29] with the goal being to tie them together. If you stand between the two pieces of string, they are placed just far enough part for you to reach one but not the other (even if, with one piece held in your left hand, you step toward and reach out to the other piece). Notice that in figure 2.3, in addition to the suspended strings, there is also a collection of objects on the floor near a chair; some of these are important for solving the problem.

Typically, during the experiment the participant attempts a variety of ways of reaching the two pieces of string. About one-third of the people in the original study were able to find a solution on their first attempt. If they remained unsuccessful, the experimenter provided a "hint" by walking into the room and brushing past one of the pieces of string, setting it gently swaying. Often this was sufficient for the participant to "see" the string as a pendulum and, using one of the objects artfully placed around the room,

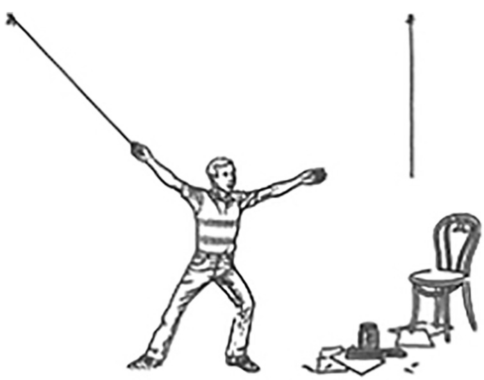

Figure 2.3
Maier's two-string problem.

could swing the string so that it could be caught when standing closer to the other piece; a further third of participants solved the problem following the hint. Interestingly, fourteen people did not solve the problem at all. Furthermore, many of the people who received the hint claimed not to have noticed it. This led Maier to conclude that "the perception of the solution of a problem is like the perceiving of a hidden figure in a puzzle-picture. In both cases, (a) the perception is sudden; (b) there is no conscious intermediate stage; and (c) the relationships of the elements in the final perceptions are different from those which preceded, i.e., changes in meaning are involved."[30] The question is what does "changes in meaning" mean, and why was there no "conscious intermediate stage"?

Maier suggested that the solution required the meaning of the problem to be changed. Implicit in this suggestion is that "meaning" must involve deliberative sense-making, which is why the idea that there is "no conscious intermediate stage" was so provocative. Indeed, Maier's idea of making the string swing to provide a hint to the participant was intended to enable such a restructuring. Key to this explanation is the idea that the problem becomes restructured.[31]

One explanation for this restructuring involves "spontaneous transfer," in which prior experience is recalled and used to help solve a problem (often without conscious awareness). In this case, the problem could be solved by analogy with related solutions and actions. If this was the case, then thinking about the objects (string, pendulum, weight of objects) could be beneficial. When explicitly instructed to think about associations between objects, people tend to be better at solving the problem;[32] but asking people to define alternative uses of objects (which could include using pliers as a weight), has no more advantage to simply being presented with the two-string problem.[33] As noted at the start of this chapter, the "alternative uses" task is a common way in which "creativity" is defined, so it is interesting to note that for Maier's two-string problem it offers little benefit. For me, this points to a possible explanation of what is happening in this situation. Alternative uses require people to focus on *general* object features, which would be instances of information-as-content (in terms of the object's forms). Such a focus might not be relevant to the task at hand. In contrast, focusing on associations between objects causes them to focus on *specific* features and draws attention to information-as-context (in terms of relations between object), which could help constrain the problem space.

Clearly, solving this "problem" of attaching two pieces of string involves several physical acts and the appreciation of the behavior of objects in the world. Embodied cognition emphasizes how understanding the physical activity of objects in the world in response to our actions contributes to how we make sense of problems. Making sense of the two-string problem requires appreciation of how the physical objects interact with each other. Presenting this problem in terms of *real* objects that can be physically interacted with (rather than as a picture, such as figure 2.3) creates a different sense of the problem and the potential actions that can be performed. This means that the idea of there being "unconscious" actions makes sense only if one excludes the idea that physical action can be form of "thinking."

The two-string problem can be defined in terms of three aspects:[34] specific features of the objects, particularly in terms of what they can be used for; combinations of these features that can be related to problem spaces; and combinations of features that permit action in these problem spaces (either cognitive or physical). For the two-string problem, the action that is required involves tying two pieces of string together, and the problem space involves bringing the two pieces close enough to allow tying. In order to produce the correct solution, people need to appreciate how moving the end of one piece of string (treating the string as a pendulum) can bring the two strings closer. Each of these aspects of representation could conceivably be performed by creating a mental model, but each is much easier to work with in terms of the objects in the environment around you. The challenge then is less about how to "think" of the objects and their relations and more about how to "see" the relations offered by these objects and how they behave.

An elegant illustration of this distinction between 'thinking' and 'seeing' was shown in variations of the Tower of Hanoi problem.[35] The basic premise of this problem is shown in figure 2.4: there are three vertical poles on which discs of different diameter can fit, and the goal is to move three discs from one pole to another, while obeying two rules: (1) only one disc can be moved at a time, and (2) a small disc cannot sit on top of a large disc.

Solving the Tower of Hanoi puzzle involves the manipulation of objects (discs on pegs) in accordance with rules. Zhang and Norman showed how changes to the problem representation can help people apply the rules.

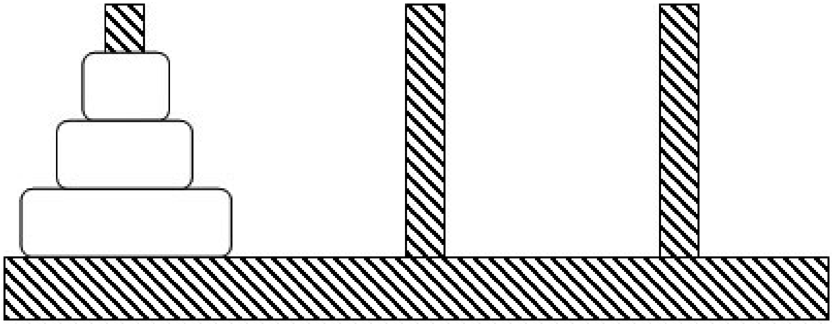

Figure 2.4
Tower of Hanoi problem.

In one version of the problem, discs and pegs were replaced with plastic oranges (small, medium, large) on plates. In other words, while the objects differed from those shown in figure 2.4, the rules were isomorphic. In another version, the problem was to move full coffee cups. The conclusion is that the more the rules are directly represented in the appearance and relation of the objects, the easier people found the problem to solve.[36] One reason why this conclusion is interesting (rather than obvious) is that the information-processing perspective would assume that objects in the world are converted into some "internal" representation in the brain. The implication from this would be that the most efficient process would be to translate the problem into a code that would apply irrespective of the presentation of the problem. After all, if the brain was going to construct mental models of a problem, why would it seek to create different models for the same problem when the only differences lie in the manner of presentation?

One way of reconciling the "internal" versus "external" debate is to suggest that the "external" representations provide memory aids, meaning that the person does not need to keep track of all of the elements of the problem in their head but rather can refer to the state of the elements in the environment. In this sense, the "external" presentation of the problem allows the problem solver to off-load some of the processing demands. So, rather than imagining what the problem space would look like if a specific disc was moved, one could make the movement and see the result. This changes the nature of the problem-solving task from one that is performed "in the head" to one that is performed "in the world." Given these findings, it is not surprising that so much of our everyday problem-solving involves some form of external representation, such as jotting down notes, sketching solutions, building simple models, or using physical objects to stand for elements of the problem. For this book, the question is whether the externalization of problem-solving is solely about supporting memory and off-loading some aspects of cognition or whether working with external representation *is* cognition.

Vallee-Tourangeau and colleagues have performed experiments in which participants solve problems either by using physical objects or with pen and paper (or tablet). In a "wolves and chicken" problem (moving pairs on animals from one side of the river to the other using a boat and ensuring that the chickens always outnumber the wolves), participants were more efficient (made fewer "illegal" moves and had lower decision latency) when they could manipulate physical objects.[37] In the "seventeen-animal problem"[38] (place seventeen animals into four enclosures such that there is an odd number in each enclosure), none of the twenty-four people who used pen and tablet was able to produce a solution, while ten of the twenty-three using physical objects produced reasonable solutions. Hint, the solution is to overlap the enclosures (so that some animals are placed in the intersection between enclosures). People in the pen and tablet condition interpreted this as an arithmetical challenge of dividing 17 by 4, and then applied the constraint that each resulting number had to be odd. In contrast, people using the models first built four enclosures (by bending pipe-cleaners into loops) and then placed model animals in the enclosures. The opportunity to work with physical objects changed the way in which the problem was conceptualized from being one about putting objects into containers rather than one about dividing numbers. From subsequent, fine-grained analysis of video recording of participants, it was apparent that rearranging physical objects often led to the opportunistic discovery of a path to the solution.[39] In this case, the physical action was not simply an aid to cognition but became a way of framing the problem, and from the framing of the problem, the solution was much easier to see. But for this to occur, there is a need to appreciate what actions are possible with the objects that are available.

Physical manipulation is important to problem-solving: as one manipulates objects (or makes sketches of ideas), so the problem space breaks down. This would mean that these physical manipulations could be an intuitive response to the problem space, thereby making it *less* structured. However, problem-solving is about finding structure, which means that, having broken down the "given" structure, the problem solver will look for ways to restructure the problem space. What does this tell us about design practice?

The Craft of Design

In a classic text on design from the 1960s, Archer[40] was concerned that "design" tended to be dismissed as a "mere craft-based skill." Like other design theorists of the time, he felt that there was a need to demonstrate that design could be described in rigorous scientific terms. The use of the word "mere" in his description is telling, in that it is symptomatic of a viewpoint that places "thought" above "action," assuming that these are separable modes of working. As should be clear from chapter 1, the position taken in this book is that acting *is* a form of thinking. In order to appreciate the antangonism against craft-based skill, we could do no better than to look at Christopher Jones's' reading of George Sturt's lovely 1923 book, *The Wheelwright's Shop*. From Sturt's accounts, Jones concludes that "craftsmen do not, and often cannot, draw their works and neither can they give adequate reasons for the decisions they take. The form of a craft product is modified by countless failures and successes in a process of trial-and-error over many centuries."[41] The implication from this is that craft moves along on an unthinking, slow, stumbling path and that it takes ages to produce a design, with this design often arising as much by accident as intention. This is an odd conclusion to draw, particularly as Sturt was at pains to point out how the design of something as humble as a wagon wheel was contingent on the wheelwright's knowledge of the type of wood that was locally available, the type of terrain that the wheels needed to cope with, the loads that the wagons would carry, and the knowledge of tradition and practice that was held in the wheelwright's shop. They might not have been able to fully explain the "tacit knowledge"[42] that saturated their craft (such is the nature of implicit knowledge and "automaticity" of skill), but this need not mean that "mere craft-based skill" is unthinking. An alternative perspective is to see the "trial and error" as the response to different sets of constraints which shifts the Pareto Front (figure 2.2) to optimize different designs.

What Archer and subsequent design theorists sought was a scientific basis for design. For Archer, this meant incorporating "knowledge of ergonomics, cybernetics, marketing and management science into design thinking," and for subsequent theorists it has meant a focus on cognitive sciences. A consequence of this, as Penny points out, is that "artisanal . . . practices have occupied a marginal place in cognitive science, because the tight and ongoing intercourse with materiality confounds notions of cognition understood as abstract reasoning."[43] The point that I would make is that artisanal (craft) practices also seem to have a marginal place in theories of design. In support of this claim, I very much like Glenn Adamson's lovely phrase "Craft only exists in motion."[44] This captures the "doingness" of craft and, for me, this translates fully into the realm of design (in all its definitions and permutations). So, the focus of this chapter is simply to ask how can we coherently capture the doingness of design? This is a simple question that is often swept aside—unthinkingly dismissed as "tacit knowledge" or, worse, seen as some form of mystical communion between designer and artifact. For me, answering this question involves elucidating a theory of "technical reasoning" that can stand against the "abstract reasoning" that worries Penny.

In work on jewelry making, my colleagues and I explored the role of symmetry in positioning stones on a broach.[45] Symmetry does not mean strict adherence. Indeed, a slight imbalance might be more aesthetically pleasing or more "honest" or more indicative of the brooch being handmade. There is, though, an interaction between the person laying out "by eye" the elements of the design and the physical interactions involved in moving the pieces until the layout is reasonable. Similar exploratory activities have been observed in the practice of architects. Here is an account of one of the architects that Reitveld and Brouwers studied:

> When RR moves the cardboard model around on the table, he lets go of the model when he seems satisfied with its position and immediately starts looking for the best position in relation to the model by moving his chair around and bending forward.[46]

From an information-processing perspective, these physical activities are of little consequence and difficult to account for. From an embodied perspective, such activities could readily be considered in terms of Kirsh's notion of epistemic action; the movement of the architect and the model provides ways to manipulate the problem space (and offers opportunities to shift emphasis between different objectives).

One of the more striking aspects of reading Rowe's *Design Thinking* is the collection of sketches produced by each of the designers. While he emphasizes the back and forth movement between convergent and divergent thinking, the sketches can be read both as "design" and as "thinking." They provide ways of representing combinations of features, eliciting the organizing principles for the designs, and allowing the designers to explore the ways in which these principles can be realized. Indeed, the question of *how* sketching is used in design is a topic of continued research activity.[47] For example, Goldschmidt discusses the "dialectics of sketching,"[48] which shifts between "seeing as" (using sketch to visualize metaphoric relations that relate to the situation) and "seeing that" (exploring the meaning or interpretation the metaphor to the design problem). This idea of contrasting a set of features with a set from another problem space calls to mind another theme running through Rowe's discussions, which has to do with the ways in which analogy is used by architects and urban planners. In formal terms, such analogies lend themselves to "pattern languages,"[49] which provide sets of features that support navigation of problem spaces. In this way, the pattern language represents (externalizes) possible points of similarity between one domain and another. In a looser sense, the use of a "mood board" allows the designer to bring "incompatible contexts" together, as, for example, in collecting seashells and using their shapes to suggest forms that can be modified for the shape of automobiles. From this perspective, sketching is a means of informally creating a personal pattern language, in which the designer works through forms and relations to help constrain the problem space or clarify the situation. In our studies of jewelry making,[50] we argued that sketches instantiate events (where an "event" is a change in the layout of affordances[51]) and that similar instantiations of events occur as the jeweler moves pieces to test different configurations, turns a stone to catch the light, or heats metal to change its color. In each of these activities, the jeweler is seeking opportunities for action in a space of constraints. This echoes Merleau-Ponty's notion of "absorbed skillful coping" or Dreyfus's "optimal body-environment relations." A more recent account of creative practice which aligns with the arguments in this book can be found in the skilled-intentionality framework, which views creative practice as "skilled engagement with affordances by the sociomaterial environment in the context of the human ecological niche."[52] We return to this framework in chapter 4 when we discuss "affordances" in more detail.

From the perspective of radical embodied cognitive science, cognition arises from the dynamic interplay between person and objects in an environment. Accordingly, sketching can be interpreted not simply in terms of the physical action of making marks on paper, but as thinking, in the form of creative and cognitive activity. This means that rather than being the result of thinking, or even an aid to thinking, the production of the sketch *is* thinking. In studies of jewelers, I have noted that sketches, when they are used, tend to rough approximations rather than fully dimensioned engineering drawings; the sketches provide an opportunity to "think through" technical problems or to communicate.[53] Similarly, sketches are "ideation drawings": "By drawing, the designer expands the problem space of the project task, to the extent of including and even discovering, new aspects, which he/she considers relevant, as much as through a subsequent interpretation of the graphic representations."[54] In addition to sketching, jewelers might lay pieces out on the workbench, experimenting with different arrangements, or might respond to fundamental aspects of the arrangement of pieces, such as their symmetry.[55] As with sketching, these physical actions can be considered as forms of epistemic action and as a way of exploring the problem space.

Fundamentally, and importantly, the "creative" act cannot be separated from the "physical" act.[56] Creative work proceeds through episodes, to use Rowe's term, in which action alternates with interpretation. For Schön,[57] design does not operate through problem-solving in the way that the information-processing approaches of, say, Simon do. Rather, "Once we put aside the model . . . which leads us to think of intelligent practice as an application of knowledge to instrumental decisions, there is nothing strange about the idea that a kind of knowing is inherent in intelligent action. . . . There is nothing in common sense to make us say that the know-how consists in rules or plans which we entertain in the mind prior to action."[58] More specifically, Schön contrasts a problem as "given" (which is typically what happens in experimental studies of problem-solving) with "problem setting" (which involves processes through which what the problem is seeking to address), the definition of an acceptable goal, the actions available to us, and so on, all of which are, in experimental studies, removed from the problem-solving or, at least, bundled together under the rules or constraints by which activity is performed). It is this "problem setting" that leads to the notion of reflective practice. Dewey (writing 50 years before Schön) made a similar point when noting the importance of a "reflective conversation with the situation."[59] We can see how the reflective conversations relates to Rowe's talk of situations and also understand how each design activity is primarily addressing a unique task in which the situation creates opportunities and challenges for the designer.

In his analysis, Schön makes use of protocol analysis, in which conversations between designers (or design tutor and student) are reported (although, ironically, his analysis involves less reflection on the part of participants than Schön's interpretation of their conversations and activity). In these analyses, "drawing and talking" are treated as parallel means through which the conversations unfold and through which designers frame and reframe the problem at hand. The conversations tend to focus on how the objectives are defined and applied in order to explore different dependencies between these. Thus, "designers might differ, for example with respect to the priorities they assign to design domains at various stage in the process."[60] Sketches and models facilitate the conversation between designer and project. Thus, the purpose of the sketch or the model is not to make visible an idea that the designer has formed already. Rather, it is the physical instantiation of constraints as they apply to the current version of the problem being addressed. That is, these activities are as much a matter of problem setting as solution presentation. From this we would expect that recognizing "constraint" and editing or backtracking within the problem space relate to an appreciation for the materials being worked with and the developing form of the design.[61] In the next chapter, I explore the "environment" as a problem space.