DESIGN

creation of artifacts in society

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Contents

Chapter draft of October 2007.

SEVEN

Problem Solving and Design

Benjamin Franklin was an irrepressible problem solver, tackling challenges as diverse as fire prevention, higher education, and home heating. Yet, I don't think of him as first and foremost a designer, perhaps because of some real differences between problem solving and design. This chapter attempts to disentangle the real and perceived differences between design and problem solving and to elucidate both barriers and opportunities for the application of "design thinking" to problem solving more generally.

Exhibit SPECS is a photograph of a pair of bifocals from Benjamin Franklin's time. Franklin is widely credited with the invention of bifocals, although there is some controversy about this attribution. In a letter to George Whatley in 1785 (Exhibit FRANKLIN), he explains the difficulty of seeing both the food on his plate in front of him and the faces of his guests at the end of the table. He describes a way to address this difficulty by combining lenses in the now familiar bifocal configuration.

Franklin's narrative (provided in the Appendix) follows the design process I described in the introduction to this book and that is articulated in Exhibit MODEL. Franklin sensed a gap (vision out of focus), defined a problem (objects at different distances require different optical correction), searched for a solution, and then selected a plan (a lens formed from two halves, each with a different diopter).

This process is almost exactly the way I describe *problem solving* in a course I teach on the subject. Exhibit PSMODEL is the way I articulate the problem solving process to my students. An agent operating in the world senses a gap between the current state and some desired state. The agent then defines a problem or problems, generates alternative solutions, selects an approach, and then takes action by implementing the solution. In most cases the problem solver then assesses whether the gap has indeed been closed and, if not, the problem solving process may be repeated iteratively[1]. This problem solving process is almost exactly the design process in Exhibit MODEL. There is one conceptual difference and several practical distinctions. The conceptual difference between design and problem solving is the difference between *plans* and *outcomes*. The design process results in a plan for action, but not necessarily in a realization of that plan. One nice aspect of the way problem solving is typically taught and practiced is the relative emphasis on action, learning from that action, and improving on the initial solution as a result of that learning. Of course, many good designers are also complete problem solvers, remaining engaged in their challenges through the implementation, testing, and refinement of the artifacts they design. Because problem solving essentially includes the steps in the design process, problem solving is the more general human activity of which design is a critical element.

There are other practical distinctions, though, beyond the issue of implementation and action. They derive from the relative emphasis of design on the creation of new artifacts and from the relative importance of time in some problem solving challenges. These and other distinctions are clarified by a taxonomy of problem types, which includes design problems.

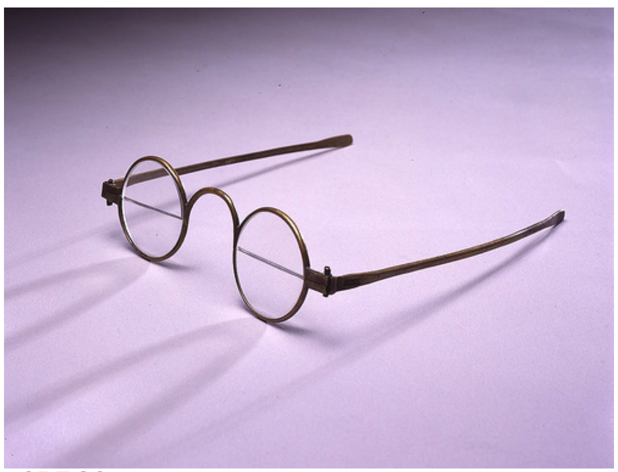
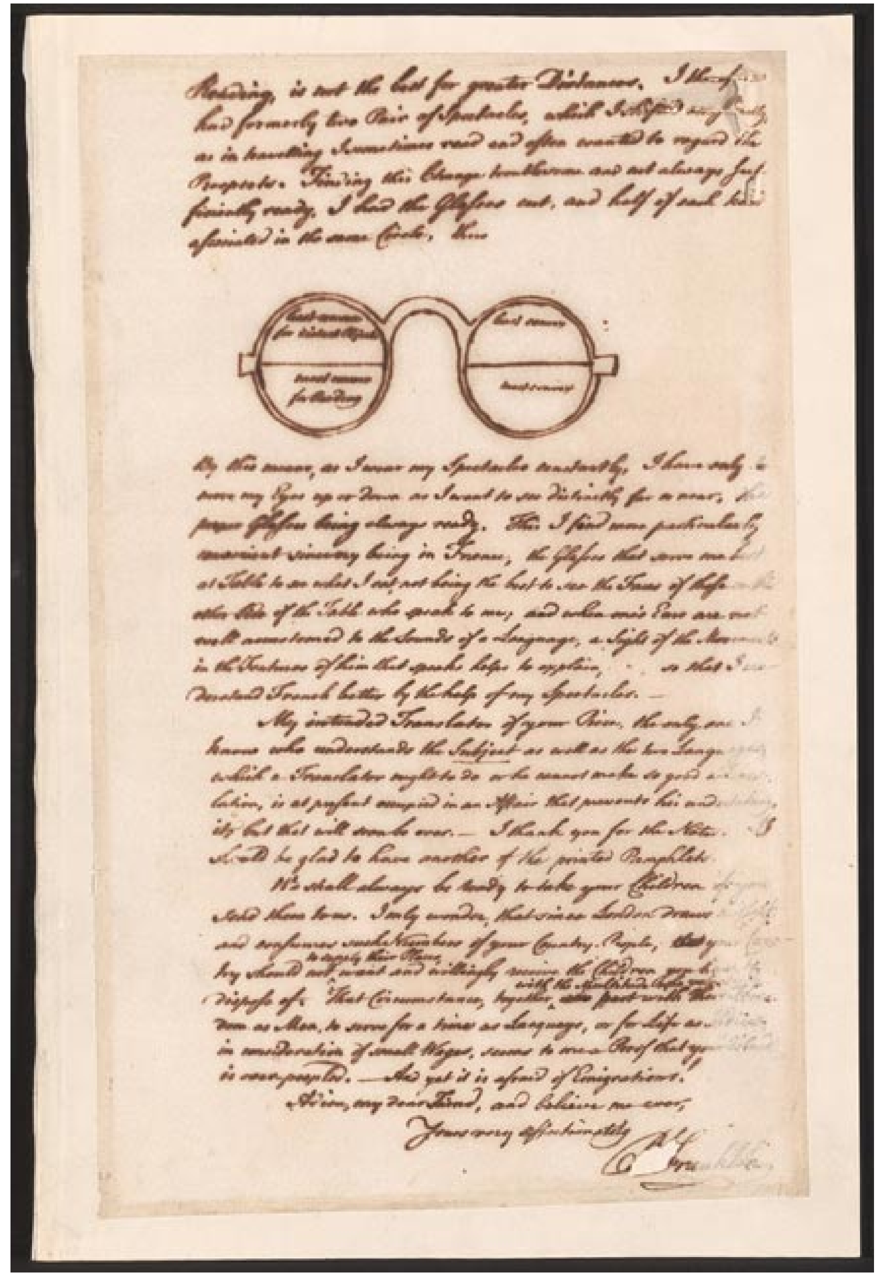


Exhibit SPECS
A pair of "Franklin-type" bifocals from the late 18th Century. Source: The College of Optometrists (British Optical Association Museum), London.

[1] Karl Popper (1999) argued that "all life is problem solving" and that the basic elements of all problem solving are (1) recognizing the problem, (2) attempting alternative solutions, and (3) eliminating approaches that do not work.



Reading, is not the best for greater Distances. I therefore had formerly two Pairs of Spectacles, which I shifted occasionally, as in travelling I sometimes read, and often wanted to regard the Prospects. Finding this Change troublesome, and not always sufficiently ready, I had the Glasses cut, and half of each kind associated in the same Circle, thus

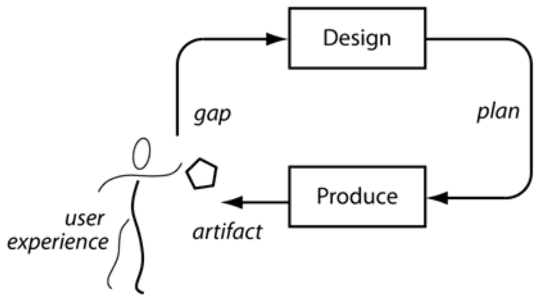
By this means, as I wear my Spectacles constantly, I have only to move my Eyes up or down, as I want to see distinctly far or near, the proper Glasses being always ready. This I find more particularly convenient since my being in France, the Glasses that serve me best at Table to see what I eat, not being the best to see the Faces of those on the other Side of the Table who speak to me; and when one's Ears are not well accustomed to the Sounds of a Language, a Sight of the Movements in the Features of him that speaks helps to explain; so that I understand French better by the help of my Spectacles. —

My intended Translator of your Piece, the only one I know who understands the Subject as well as the two Languages which a Translator ought to do or he cannot make so good a Translation, is at present engaged in an Affair that prevents his undertaking it; but that will soon be over. — I thank you for the Notes. I should be glad to have another of the printed Pamphlets.

We shall always be ready to take your Children if you send them here. I only wonder, that since London draws to itself and consumes such Numbers of your Country People, the Country should not want and willingly receive the Children you have to dispose of. That Circumstance, together with the Multitudes who part with their Freedom as Men, to serve for a time as Lackeys, or for Life as Soldiers, in consideration of small Wages, seems to me a Proof that your Island is over-peopled. — And yet it is afraid of Emigrations!

Adieu, my dear Friend, and believe me ever,
Yours very affectionately
B. Franklin

Exhibit FRANKLIN
Letter to George Whately from Benjamin Franklin describing the creation of bifocals to address the problem of vision correction for both near and far distances. The text of a portion of this letter is in the Appendix. Source: United States Library of Congress.



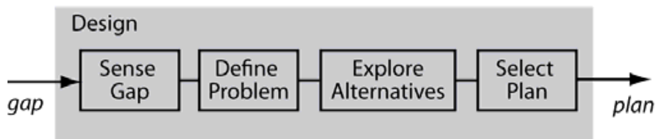


Exhibit MODEL
Design and production address gaps in the user experience. The design process can be thought of as four steps.

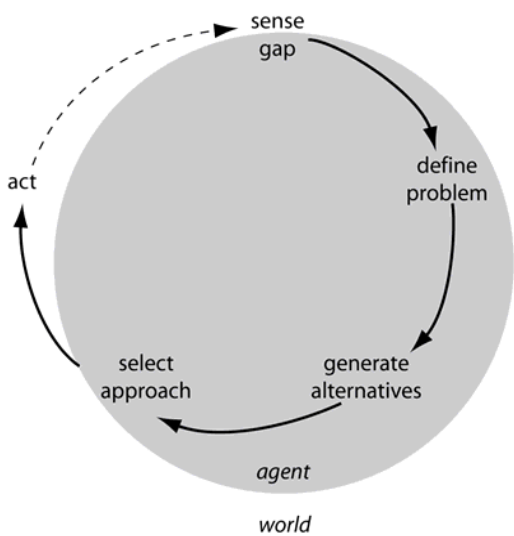


Exhibit PSMODEL.
A generic problem solving process. Problem solving addresses a gap between the state of the world and a desired state from the perspective of an agent.

Tazonomy of Problems

While pretty much all problems can be thought of in terms of a process by which a gap in an agent's experience is closed, a taxonomy of problem types allows us to tighten the distinction between design problems and other types of problems. The categories in the taxonomy and their relationships are illustrated in Exhibit PROBLEM-TYPES. The first distinction in the taxonomy is between problems for which there is an existing artifact or operating system and for which there is no such artifact. This distinction separates all problems into two broad categories: design problems and system improvement problems. The other categories map either across or within these two divisions.

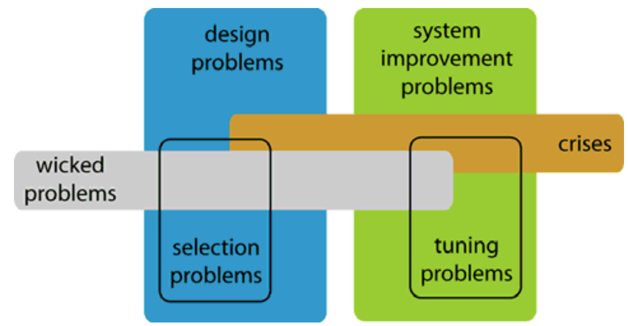


Exhibit PROBLEM-TYPES
Six types of problems, one of which is design problems.

Design problems

The bulk of the book focuses on design problems. The hallmark of design problems is that the designer creates a plan for a *new artifact* in response to a gap. A central feature of design problem solving is the exploration of alternatives.

Selection problems

Selection problems are a subset of design problems in which the alternatives are already well articulated or relatively easy to discover. The central challenge is to select from among those clearly articulated alternatives. For example, when a firm needs to install a new accounting system, the problem solver can typically readily identify the available alternatives. These alternatives are the systems available on the market, as the firm would rarely create its own accounting system from scratch. The challenge is evaluating the alternatives and selecting from among them. I include selection problems within the larger category of design problems because even with the most straightforward selection problems, the problem solver does have to at least articulate the alternatives, which is a form of exploration.

System improvement problems

Unlike design problems, system improvement problems concern modifications to existing artifacts or systems. The problem solving process for system improvement problems typically involves the comparison of existing performance with some notion of ideal performance. Then, the problem solver focuses on exploring alternative approaches to improving performance. For example, the admissions process for business schools is a tricky undertaking requiring high levels of efficiency, fairness, and predictive accuracy. Most schools are continually attempting to improve the performance of the system. While creating an admissions process from scratch is clearly a design problem, improving an existing admissions process is somehow qualitatively different. Some elements of difference are: improvement tends to comprise several incremental changes, often applied sequentially; the focus of problem solving is often *defect reduction*, which has a forensic quality to it; and system improvement typically benefits from a wealth of data from the existing system. None of these attributes is typical of design problems.

Tuning problems

A particular flavor of system improvement problems is *tuning problems*. Tuning problems are limited to incremental adjustments to parameters of an existing artifact. For example, consider the process for making plywood. A log is positioned on a machine (essentially a large lathe) that spins the log while a wide blade peels off a 2.5-meter-wide ribbon of wood veneer. That ribbon is subsequently cut into rectangular pieces, stacked into a sandwich with glue between the layers, and then squeezed in a heated press to cure the adhesive. Like most manufacturers, plywood makers are continually engaged in system improvement problems. One such problem is the tuning problem associated with the veneer making process. The process parameters include, among others, rotational speed, blade shape, cutting angle, cutting pressure, and log moisture content. There are of course infinite possible combinations of these variables. The tuning problem is to find the combination that both achieves the best performance (wood utilization, consistency,

surface finish, etc.) and delivers consistent results under varying conditions. A variety of methods has been developed for solving tuning problems. See particularly "optimal design" methods, which are appropriate in cases for which mathematical models of the artifact exist (Papalambros and Wilde 2000) and experimental methods, which are appropriate for cases in which analytical models are elusive (Ulrich and Eppinger 2008).

Crises

A crisis is simply a problem that must be solved quickly. In economic terms, the opportunity cost of time is very high for crises (e.g., a patient is bleeding, a company is failing, coal miners are trapped, public opinion is forming in the wake of an event). Crises can be design problems or system improvement problems. For example, when the crew of Apollo 13 said "Houston, we have a problem[2]," everyone soon knew that the problem had to be addressed quickly or the astronauts would die. The Apollo 13 crisis comprised, among others, a design problem—how to create an air filter from available materials (Exhibit FILTER)—as well as a system improvement problem—how to minimize the electrical current draw from the systems in the aircraft.

Wicked Problems

Rittel and Webber (1973) defined a class of problems as *wicked*, kind of a catch-all term for problems that are extraordinarily hard to solve, and for which even clear definition is difficult. I like the term *wicked problem*, but have never felt it was defined with adequate precision. Here I use the term to refer to problems for which stakeholder objectives are fundamentally in conflict. Examples of such problems include territorial disputes in and around Israel, global warming, public school reform, and terrorism. Like crises, wicked problems can be either design problems or system improvement problems.

[2] This quote isn't quite right. Astronaut James Lovell actually said "Houston, we've had a problem," but the present tense sounds better.

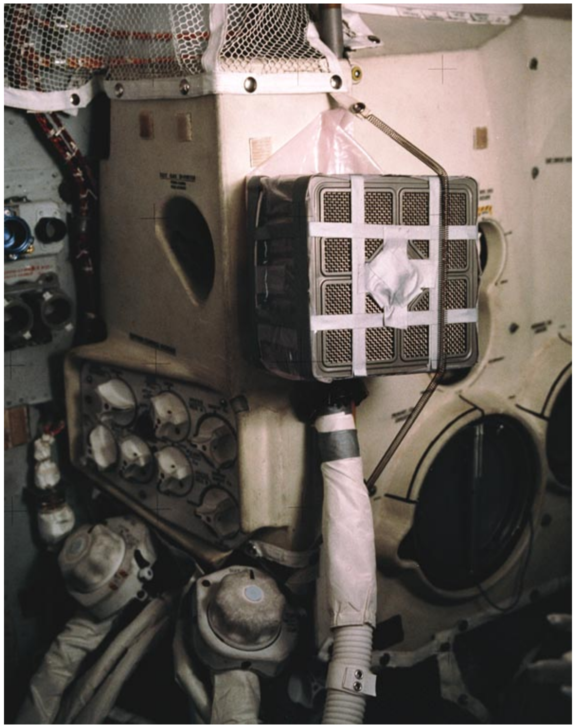


Exhibit FILTER
The air filter designed and built by the Apollo 13 crew from available materials when faced with a crisis. Source: NASA.

Deliberate Process, Importance, and Time

My view of problem solving and design is process oriented. My students often ask whether a deliberate process is always the best way to solve a problem.

I know of only two studies that have looked at the question of effectiveness of structured problem solving processes. Griffin (1997) studied the effectiveness of structured product development processes, a fairly close cousin of design processes (Terwiesch 2007?). She found that firms that adopted structured development processes completed complex projects more quickly than those that did not.

Tyre and colleagues (1993) studied the effectiveness of structured problem solving processes in addressing manufacturing problems at the Saturn division of General Motors. They found that the use of structured problem

solving processes (essentially the process articulated in Exhibit PSMODEL) was associated with both better solutions and faster completion.

This limited scientific evidence is consistent with my beliefs based on experience. At a minimum, structured processes act as checklists to ensure that no critical information processing task is omitted.

The question of whether a deliberate process is always warranted can be illuminated with some conceptual thinking. Exhibit TIME lays out two relevant dimensions. First, how important is getting the right solution? Second, how urgent is the problem? These two dimensions can be thought of in economic terms for the sake of relative quantitative comparisons. The first (horizontal) dimension can be thought of as the economic value of getting a near-optimal solution compared to the value of getting a typical solution[3]. For example, in branding a video recording and storage product, how much is the name *TiVo* worth compared to *Replay*? (My answer on that one is "millions".) Compare this to the value of figuring out exactly what to eat for breakfast one morning. (It's worth something to me, but not much.)

The second (vertical) dimension represents the opportunity cost of time. What is the cost of not having a solution? We can think about this in terms of cost per hour. For example, when formulating a solution for how to turn around a troubled company, one can think about the negative cash flow to be averted by that plan, which might be a million dollars per day (i.e., tens of thousands per hour).

The relative position of a problem on these two dimensions informs the question of whether to apply a deliberate problem solving process, and of what type. For problems for which the value of an excellent solution is worth not much more than that of an average solution, there isn't much point to investing in problem solving, and so problem solvers may resort to just picking default solutions or to automated problem solving techniques based on simple heuristics.

In the upper right portion of the exhibit, the right solution is valuable and time is extraordinarily precious. Examples of such settings would be

[3] The notion of optimality is a bit loose here because most problems can not be formalized in a way that optimality can really be defined. One way to think about the definition of the value of a near-optimal solution is to think about the probability distribution over the quality of solutions for a given problem. One might think of the horizontal axis in Exhibit TIME as the value of the standard deviation of this distribution.

action sports like soccer or hockey, or at the extreme, life-or-death military engagement, such as dogfighting between aircraft. In these settings, there is not time for even the most streamlined deliberate problem solving. Action must be reflexive and instantaneous. Humans cope with such situations only with extreme levels of skill, specialization, and practice, and they perform well only within a narrow range of problem types.

In the middle right portion of the exhibit, outcomes are still quite valuable, but time is a little less costly. Even in a life-or-death setting like a rescue in a collapsed coal mine, the problem solver has hours to deal with the crisis, not seconds. Some use of problem solving process is warranted (e.g., the exploration of alternatives), but typically the problem solver will deploy a great deal of resources, perhaps pursuing several potentially redundant solutions at once. Typically, problem solvers responsible for addressing crises are deeply experienced, and so do not need to learn and adapt their problem solving methods as they go.

Most of us spend most of our professional lives in the lower right portion of the exhibit. Problems are important, with the best solutions typically worth thousands or millions of dollars more than average solutions. And problems are not typically so urgent that we can not devote days, weeks, or months to their solution. We plan events. We brand products. We form new ventures. We design buildings. We staff organizations. For these problems, deliberate process is warranted. There is no reason not to carefully define the problem, explore alternatives, evaluate and select from the alternatives, and iteratively refine a solution.

Why the resistance to structured processes?

If a deliberate problem solving process is warranted for a large fraction of the problems we face as professionals, why do humans so resist such processes? This resistance ranges from passive neglect to active loathing. I believe there are at least three reasons for the resistance. First, the application of structured processes is hard work, and most of us resist hard work when possible. Second, problem solvers rarely observe how well they might have done with the application of a structured process. That is, the opportunity cost of not applying a structured process is rarely obvious, and so the impetus for the application of process may not be well understood. The third reason is largely a conjecture on my part, but is interesting to think about.

I believe that for most of our evolutionary past, humans benefited from a bias for action. When faced with a decision of whether to flee or fight in the face of an enemy, those who reflected carefully on the problem and explored alternatives did not survive long enough to reproduce. This is an oversimplification of course. One of the hallmarks of human behavior, going back tens of thousands of years is that we use our brains to plan for the future. However, until the most recent few thousand years, this planning applied to small groups of people, perhaps over time scales of one season. We were not prepared biologically for managerial life in a mass society. Today, we often make decisions as professionals that matter to thousands of people over time scales of many years. When faced with such decisions, deliberate processes are fully warranted, and yet our biological impulse may be to just act.

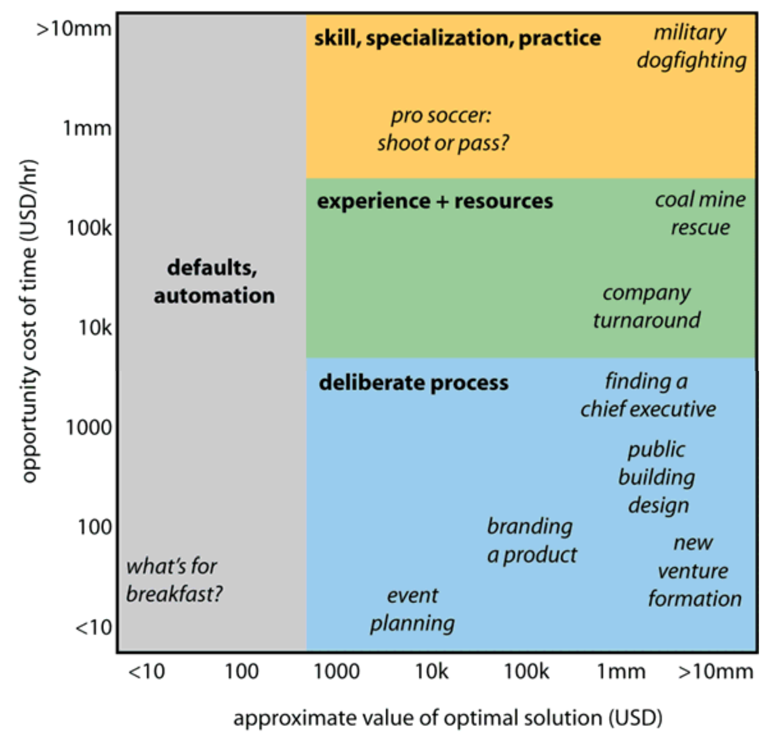


Exhibit TIME
The use of deliberate process depends on the opportunity cost of time and the relative value of achieving the optimal outcome.

Design and Innovation

I wrote the bulk of this book at the same time I was co-authoring a book on innovation (Terwiesch and Ulrich, 2008). Because of this unusual confluence of activities, I was forced to reflect on the similarities and differences between *design* and *innovation*. Design and innovation are quite similar endeavors, but there are at least three distinctions:

First, innovation is typically broader in scope than design, and includes the entire set of activities that create a new match between a solution and a need. Design is often one of these activities, but so are market launch, the ramp-up of operations, and the management of regulatory issues.

Second, and related closely to the first distinction, innovation is often thought of as an economic activity whose basic unit of analysis is the innovation system, whereas design is an activity typically thought of at the level of a particular artifact or project. This is a tendency in practice more than a theoretical distinction. General managers in firms and other institutions worry about their innovation "pipelines" or "systems." When viewed as a system, innovation includes the more focused activity of design.

Third, design usually proceeds from the identification of a gap to the creation of a solution. Innovation can proceed in the other direction, an approach sometimes called *technology push*. With technology push, an innovator begins with a new or existing solution and then searches for possible applications of that solution. This approach is typical of the pharmaceutical innovation process, in which a newly discovered chemical compound is screened for possible medically useful properties. Technology push also occurs frequently in innovation involving basic materials.

The Culture of Designers

Designers share some elements of common culture, even though diverse design domains typically possess idiosyncratic subcultures. Design culture sometimes clashes with, for example, those of politicians, lawyers, and some managers. As I reflect on the unique aspects of design culture, I identify three key elements.

Optimism versus criticism

Designers are optimistic. They are accustomed to facing problems and solving them. This optimism contrasts with the culture of criticism one often

finds in some other professions. For example, lawyers are trained to imagine the worst possible outcomes and protect against them. Designers are trained to imagine the best possible outcome that one might be able to create with a novel artifact. It is no surprise that these two groups of professionals often find themselves in a clash of cultures.

Prototyping and iteration

Good designers tend to have a bias for building, trying, and refining artifacts, rather than perfectly refining a theoretical plan. The design culture is one of prototyping and testing as much as it is one of conceptual exploration. This bias makes sense when faced with a high level of uncertainty and a lack of theory, as is often the case for design problems. The bias for action can be detrimental for problems in which data and analysis are powerful tools for finding solutions, as is the case for some problems in engineering and management.

Elegance

Designers tend to strive for elegance. It bothers most designers to create something sloppy even if it works. While elegance is an ill-defined concept, I think it tends to comprise originality, beauty, surprise, and an efficient use of resources. Many have tried to articulate what makes for good design. One effort I like is by Paul Graham (2004), a software entrepreneur, who argues that good design is, among other things, daring, timeless, slightly funny, and hard (but looks easy).

Non-Traditional Design

This book has mostly focused on designed physical objects, although in the introduction I offered a more general view of design and a more general notion of artifacts. I believe that most of the ideas in this book apply to the design of organizations, social systems, business models, and services as well as they do to the design of physical goods.

For example, consider the design of a business model. Exhibit BIZDESIGN includes a template for essentially any business (Panel A). The template includes a customer acquisition process and a solution delivery process. An infinite number of possible business models can be created through exploration of the various alternatives for the elements of this generic model. For example, NetJets is a company that pioneered the commercialization of fractional jet ownership. Panel B in the exhibit shows the instantiation of the template with the key elements of the NetJets model. Panel C is a potential new business model that is an incremental perturbation of the existing NetJets model.

I believe that a structured process of exploration can be applied both to the creation of new business models like that of NetJets as well as to the exploration of alternative models. This process is essentially similar to the way many effective designers explore alternatives for the design of physical objects and systems. While most good designers of physical goods exhibit great discipline in exploring many alternatives, this discipline seems less well developed in the creation of businesses. In a course I teach in the MBA program at Wharton, I have tried to develop *design thinking* among business students faced with non-traditional design problems, and I believe this effort has been largely successful. An extension of design thinking even further to the creation of social systems and government policies seems quite promising.

Concluding Remarks

There is a lot of human problem solving that is not really design. However, I believe that much of human problem solving would benefit from *more* design process not less. The hallmark of design is an exploration of alternatives and careful selection from among those alternatives, an approach that tends to make for good problem solving. I would also like to see greater diffusion of the culture of design, one of optimism, elegance, and a bias for action.

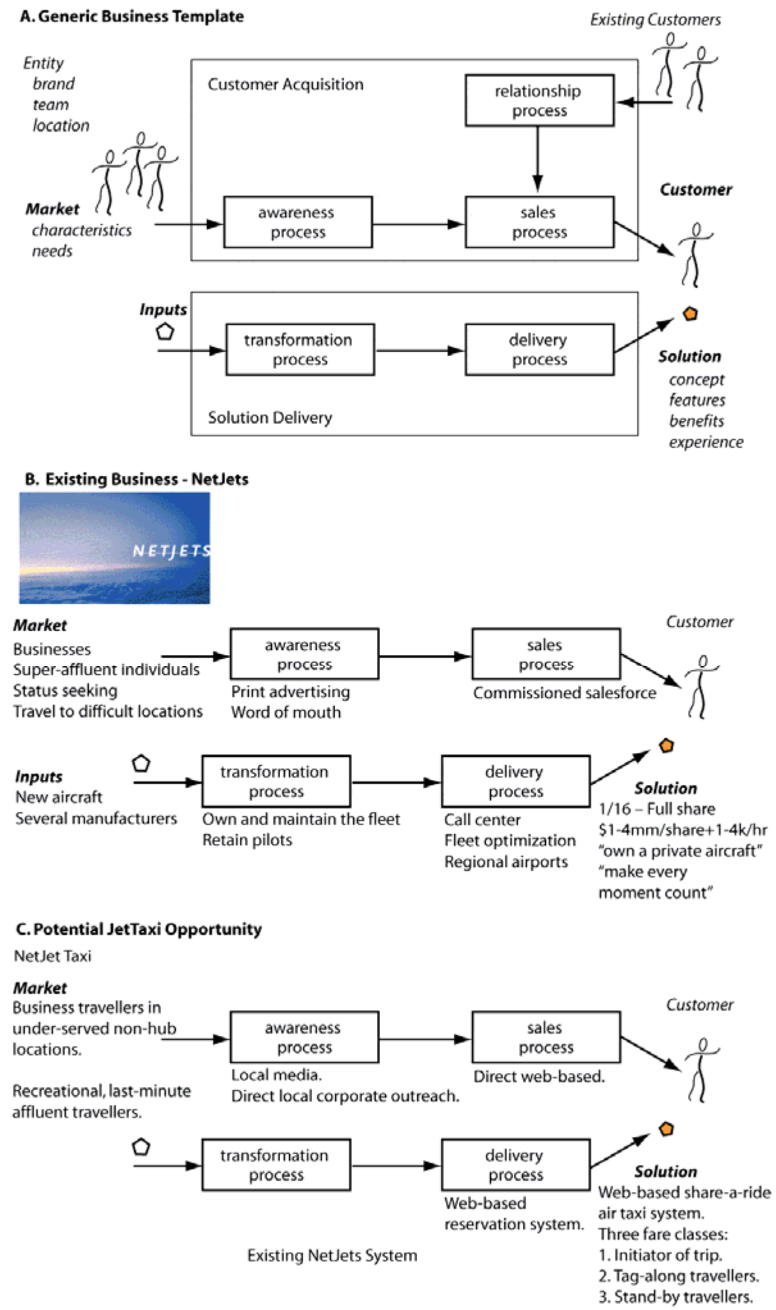


Exhibit BIZDESIGN. Design applied to business models.

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Appendix

Following is an excerpt from Benjamin Franklin's letter to George Whatley dated May 23, 1785. Whatley was a philanthropist and close friend of Franklin's.

By Mr. Dollond's saying, that my double Spectacles can only serve particular Eyes, I doubt he has not been rightly informed of their Construction. I imagine it will be found pretty generally true, that the same Convexity of Glass, through which a Man sees clearest and best at the Distance proper for Reading, is not the best for greater Distances. I therefore had formerly two Pair of Spectacles, which I shifted occasionally, as in travelling I sometimes read, and often wanted to regard the Prospects. Finding this Change troublesome, and not always sufficiently ready, I had the Glasses cut, and half of each kind associated in the same Circle, thus, <Franklin's sketch follows>.

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