CREATIVE ENGINEERING
Promoting Innovation by Thinking Differently

John E. Arnold

EDITED
WITH AN INTRODUCTION AND
BIOGRAPHICAL ESSAY
BY

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Table of Contents

BACKGROUND

Preface

This book collects and makes readily available a classic in the philosophy of engineering design, heretofore only available in university archives. The original paper manuscripts have been digitized and reformatted with a detailed subject index. An introduction and biographical essay provide a historical context, including a detailed explanation of how the readings establish a scientific foundation for creative engineering.

For Arnold, a "creative engineer" combines the technical skills of engineering with a more comprehensive human-centered approach than industrial design. He gives this vision substance by reframing the design process as problem solving, which requires creativity and hence tools for thinking differently. This broad framework for "design thinking" flourishes more than fifty years after his passing.

Arnold speaks to us as individuals, inspiring with stories of genius and teaching us to be insightful about "blocks" that may be limiting personal growth and achievements. Becoming more creative is thus a process of self-actualization. Arnold challenges students, industry engineers, and citizens alike to be "positive non-conformists," examining how we think and what problems we choose to solve—seeking to uncover the unspoken ambitions and fears, biases, and stereotypes, which inhibit not only our behaviors but our thoughts as adults. At the same time, he asks us to raise our sights to the long-term, comprehensive issues confronting society and realize our creative potential. He promotes innovation by teaching us how to ask questions, so we might go beyond what is given or apparent and think differently about dilemmas and needs: "Knowing what questions to ask and how to ask them is sometimes more important than the eventual answers. Each of man's advances was started by a question."[1]

These themes of personal growth, relating to transcendent values and purposes, have a long history in American philosophy. Taking new form in post-WWII's concern for technological advances during a cold war, and flowering in the youth movement of the 1960s, the ideas continue to motivate schools of design and innovation, marked by books inciting achievement, self-confidence, and "unleashing the power within." Arnold was a pioneer in synthesizing this grand vision, relating the psychology of the self, business and social needs, design, and education. His initiatives at MIT and Stanford University from 1950–1963 were adopted and refined by his associates and students in internationally renowned product design courses and design firms. The Hasso Plattner Institute of Design at Stanford (the d.school) today realizes Arnold's "comprehensive design" approach, relating engineering, medicine, business, law, the humanities, sciences, and education to address messy, "creative problems" for the benefit of society.

Most broadly viewed, *Creative Engineering* promotes the idea of democracy we find prominent in John Dewey's work, unifying personal growth and citizenship.[2] Intelligent participation in society entails breaking out of clichés, taboos, and groupthink. This requires personal integrity and daring, which develops by expressing ideas and values in practical projects. Arnold's program for creative engineering thus explains and promotes design thinking from a humanist perspective: "The increased understanding of the creative process, the enlargement of the number of areas where it is practiced, and the encouragement of all to exercise their creative abilities to the limits of that inherent potential are the only ways in which progress can be assured."

Introduction

John Edward Arnold (March 14, 1913–September 28, 1963) was an American psychologist, engineer, and educator. As a professor of Mechanical Engineering at Massachusetts Institute of Technology (1950–57) and Stanford University (1957–63), he was a pioneer in scientifically defining and advancing inventiveness, based on the psychology of creative thinking and imagination.

This book is a posthumous publication of Arnold's course materials from the summer seminar he called "Creative Engineering." Arnold developed this course over seven years and presented it at MIT, Stanford, and in corporations. The version included here is from the Stanford summer seminar in 1959, the most complete and latest available, including readings by guest lecturers, J. P. Guilford, Robert S. Hartman, Abraham H. Maslow, and Robert H. McKim.

What is Creative Engineering?

The Creative Engineering seminar was intended to provide a broad and thorough introduction to Arnold's philosophy of engineering design. Arnold's lectures are based on social concerns that he believed engineers were called to understand and resolve through new kinds of inventions and system designs. He observed that ordinary people are "becoming concerned over the ever enlarging demand for new and better solutions to both new and old problems" (Chapter "Forward–Why Creativity," p. 60). With the growth of population and technology (including military threats), the number of problems and their complexity were increasing exponentially. Continued improvement to the American way of life required better analyses of problems and new kinds of solutions. In short, engineers needed to be more creative—to broaden the kinds of problems they tackled, to understand the modes of thinking involved in the design process, and to evaluate designs from new perspectives. This social need for creativity was part of the 1950s milieu, summarized by Carl Rogers (1953) in his reflections on the discussions at the 1952 Conference on Creativity:

> If, as a people, we enjoy conformity rather than creativity, should we not be permitted this choice? In my estimation, such a choice would be entirely reasonable were it not for one great shadow which hangs over all of us. In a time when knowledge, constructive and destructive, is advancing by the most incredible leaps and bounds into a fantastic atomic age, genuinely creative adaptation seems to represent the only possibility that man can keep abreast of the kaleidoscopic change in his world.… A generally passive and culture-bound people cannot cope with the multiplying issues and problems.

Arnold described his motivation for creating the Creative Engineering seminar in his February 1955 lecture about creative engineering to the M.I.T. Mid-west Conference:

> I suppose my interest in this field dates back to my early interest and training in the field of psychology. Later, engineering and design became of prime importance to me, and now I feel that I have been able to combine these two interests in the field of Creative Engineering. I have been spurred on in the development of this program by the understanding support received at M.I.T; by the fascinating new experiments carried on at other institutions; and by the ever-increasing interest of American Industrialists in the question: "how do we get new ideas?"

Arnold lays out logically the nature of this inquiry. He begins by asking, *"What is engineering?"* Engineering is oriented towards solving difficult societal problems. *"What is required of engineers?"* Engineers must find new ways to deal with new kinds of problems, and furthermore must look forward, providing future value by anticipating "interrelationships and interdependencies" fostered by the burgeoning population—"two thirds of the world's population goes hungry" ("Creative Product Design," p. 127). *"How can engineers attain this capability?"* They must relate different disciplinary perspectives, including business, the sciences, and art—and this requires unifying within the self different aspects of intellect and emotion. Thus, the advance of creative engineering depends on the personal growth of individuals, developing an understanding of their own thinking processes, especially to reveal biases and to promote openness, integrity, and confidence.

Critically, complicated social situations, which Arnold terms "creative problems," do not have one right answer; they cannot be solved analytically by choosing and manipulating the right equations in the manner of engineering textbooks of the day. In the later parlance of problem-solving research, creative problems deal with "ill-structured" contexts and constraints, such as designing a home (Simon, 1973). Indeed, Arnold was emphasizing that "the problem" is itself not given, but must be understood and framed to deal with fundamental values and constraints. Schön (1979) characterized this as "problem framing"—are the people living on city streets "homeless," mentally ill, or exiled by gentrification of cities (Marin, 1987)? Considering the design of advanced automation today, such as self-driving cars, is the problem to deal with a "human in the loop" or is the problem to "put a machine in the loop," to fit how people think and interact with each other and their environment? The art of asking good questions to appropriately frame the situation and define a problem to be solved is therefore fundamental to creative engineering.

Arnold argued that for engineers to be creative problem solvers they must master more than draftsmanship, physics, and manufacturing. Thus he asked the final question, *"How do engineers develop the required capabilities?"* He concludes that for engineers to innovate, we must educate them to think differently—about the nature of problems, about problem solving, and especially about their own mental processes.

Arnold's five lectures in *Creative Engineering* motivate being more imaginative and inventive ("Why Creativity?"); explain how creativity is manifested in problems, methods, and results ("What is Creativity?"); describe thinking styles and approaches that facilitate and inhibit creativity ("Factors Influencing Creativity"); suggest how to awaken and strengthen creative potential ("Useful Creative Techniques"); and illustrate how creativity is applied in practice ("Creative Product Design").

Arnold's theory of design as problem solving focuses on identifying and satisfying human needs by relating personal, scientific, and practical concerns (p. 61, emphasis added):

> …somehow a few [prehistoric humans], even without language, asked themselves questions. Perhaps not the kind we are used to with question marks at the end; but *emotionally they became aware of problem areas*, they were sensitive to themselves and the limited world around them, and these in effect were *questions* for them to solve. They made keen *observations* in search of the answers to these questions. They *related these answers together and combined them with past observations* so that finally they could make a *prediction*, a prediction that was valid, that answered the question first asked.

> These answers were probably resisted then as our new answers are resisted today. Many died in their attempts to *verify and sell their answers*. They were ridiculed and tormented, but the truth prevailed and progress was achieved.

Thus, problem solving consists of four key steps—Question, Observe, Associate, and Predict—preceded by an emotional experience and followed by dealing with reality of the market and potential resistance from other people. Here Arnold presents design as a *process* that operationally relates different modes of thinking—analysis, evaluation, and synthesis ("What is Creativity," p. 65)—a psychological foundation for a science of design that would become central in Simon's (1969) *Sciences of the Artificial*.

Arnold mentions that General Electric had at the time an eight-step process for product development that relates mental processes to organizational processes. Arnold emphasizes that such lists are qualities or characteristics of problem solving, not a fixed method ("Creative Product Design," p. 117):

> I don't actually like to think of them as steps of a process that are followed in a certain definite sequence. To me these four words represent attitudes of the mind or the personality of the learner, the seeker, or the creative problem solver. They represent the cognitive process as well as the process of science. The first three should be going on all the time, simultaneously or in almost any kind of combination or sequence. They represent the questioning mind, the prepared mind that finds the unexpected through keen observation as well as the mind that is generic in the relationships, the associations that it makes. Prediction typifies the daring spirit that is not afraid to fight for what he believes to be right, to stick his neck out and take a chance, to be different when it makes a difference.

Emphasizing that it is the person's intellectual and emotional attitude that matters, Arnold uses the words "daring" or "daringness" fourteen times in the text. This perspective—open questioning, observing, associating, and predicting—is a scientific stance, finding the unexpected and then with determination proclaiming an idea, which is effectively a prediction: "This will work. This addresses the problem."

From the perspective of engineering, a solution to a societal problem is expressed as a design. Mechanical engineers design tangible things, such as a household appliance, farming tool, or transportation vehicle. In this realm of engineering design, Arnold addresses fundamental issues about the quality of designs and how to improve them. His creative solution is to develop a new kind of engineering pedagogy, namely teaching engineers the psychology of problem solving. Following Rogers and Maslow, his approach adopts a positive, humanist view: Imagination and learning are inherent human traits, everyone has the potential to be creative. Personal growth stems from reflecting on your habits, mental biases, and skills so you might correct and improve them. Engineers therefore "must have a complete understanding of and mastery in the use of the creative process" (Arnold, 1955b, p. 3).

In everyday life people are not always as creative as they might be because of certain "blocks" in how they think about problems, how they engage in the problem-solving process, and how they conceive their personal roles and capabilities. Arnold calls these *Perceptual Blocks*, *Cultural Blocks*, and the *Emotional Blocks* ("Factors Influencing Creativity," p. 88). "The blocks refer to all the ways in which we fail to get true, adequate and relevant information about the outside world." Blocks affect our sensitivity to what is happening in the world and how objects and processes are related: We fail to perceive a problem or cannot grasp its essence. Our cultural milieu, our peers, and norms instilled in how we act, look, talk, and relate to our environment contribute to our blindness and limit how we generate new ideas. Perceptual and cultural blocks are rooted in emotional blocks, which dominate—"they include all our fears, and most of the defense mechanisms that we build up in order to make our lives seemingly more tolerable" (p. 89).

The fundamental question, "Why are some designers better than others?" is thus largely addressed from the perspective of psychology: Creative potential is inherent in everyone, but better designers are less hindered by perceptual, cultural, and emotional blocks, which instruction can help. We can unseat blocks by an innovative pedagogy, which Arnold realizes in the seminar with lectures about the qualities of the *intellect* (Guilford), *values* (Hartman), *emotion* (Maslow), and *objects* (McKim). As explained in the next section, these readings constitute the scientific foundations for Arnold's creative engineering vision and program.

Arnold's presentation impressively synthesizes and explains ideas from many contemporary scientists and engineers whom he quotes and credits in his lectures. He distills their detailed analyses into a few essential ideas and unites them into a compelling vision and pedagogy. Besides the ideas from Guilford and Maslow on the nature of cognition, blocks, and growth potential, the techniques for creativity derive partly from Osborn's (1942) brainstorming, Rogers's (1953) theory of creativity, and Guilford's (1950, 1967) analysis of thinking.

Arnold was also influenced by Henry Dreyfuss's human-centered approach to industrial design described in the autobiographical *Designing for People* (1955), which appears in the *Creative Engineering* bibliography. However, Dreyfuss's mantra was an inspiration that Arnold sought to realize, rather than an existing, mature method to assimilate. Notably, Arnold never mentions Dreyfuss or his work in the seminar.

Dreyfuss viewed the designer and engineer as two individuals and ascribed the imaginative creativity to the designer: "The designer does the dreaming…and the engineer makes the dreams come true" (p. 48). Arnold conceived of this relation very differently. Where Dreyfuss promoted a collaboration between the dreamer and the engineer, Arnold's vision was to develop engineers capable of both modes of thinking, melding industrial design with engineering in "comprehensive designers"—creative engineers who could both dream and realize breakthrough innovations. To this end, Arnold hired two lecturers in 1959–1960 who had an association with Dreyfuss: James Adams had Dreyfuss as one of his mentors at UCLA (Adams, 2011, p. 128), and Robert McKim, with degrees in both engineering and industrial design, had worked in the Dreyfuss Associates studio in New York.

As both an industrial designer and engineer, McKim straddled the perspectives Arnold sought in a comprehensive designer, making him a "creative engineer." Although respecting Dreyfuss's approach and success, McKim left to form his own consultancy in California when he determined that the firm's consideration of "human factors" was good public relations but the "fit" of a design from the human perspective was too often interpreted superficially, symbolized and embodied by the studio's "Joe" and "Josephine" anthropometric charts. The designers were using the "designing for people" perspective and physical mockups more as a styling rationale, instead of starting with a holistic understanding of human needs (a point elaborated by McKim's seminar lecture, "Designing for the Whole Man"). Industrial designers were often just putting "a beautiful-looking box on something that someone else designed"; McKim believed like Arnold that it would be better if engineers designed everything. McKim had planned to attend the 1958 seminar as a student, but in their first meeting Arnold converted him to being a leader in the cause.[3]

Arguably the most radical idea and intent behind the Creative Engineering seminar was that designer–engineers with multiple perspectives and skills—applying the analytical methods of engineering with the incipient human orientation of industrial designers—were necessary to create innovations that identified and satisfied both emotional and practical, circumstantial needs ("What is Creativity?" p. 66, emphasis added):

> The needs that we are trying to satisfy may be implied as well as expressed. The need for beauty, truth, peace, love, belonging, transcendency, and so forth are some of the implied needs that lead to great creative acts in the fields of the fine arts, literature, and philosophy. The expressed needs are those associated with man's physical environment, food, clothing, shelter, communication, and transportation. Attempts to satisfy most of these needs are being made by engineers or men with special technical training. A still better solution can be arrived at, however, if somehow some of the implied needs of man can be given consideration at the same time the more direct expressed need is being investigated. The rapid rise of the industrial stylist verifies this thesis as does the growing importance of the "Human Engineer." *The ideal situation would be to have in addition to a few specialists in the various fields, a greater number of men who have fundamental training in and knowledge of a number of related fields. This person is the "Comprehensive Designer"* and as Bucky Fuller [1949, p. 176] first described him, he is "the emerging synthesis of artist, inventor, mechanic, objective economist and evolutionary strategist." One of the aims of Creative Engineering is to bring about a union between the physical sciences, social sciences, and the arts. In this way and perhaps only in this way can we be assured that our innovations better satisfy some need of man.

Arnold's reference here to the "industrial stylist" could be interpreted as a critical response to Dreyfuss's repeated mention that engineers were not designers: "… the designer supplements but in no way supplants the engineer" (1955, p. 48). Coupled with Dreyfuss's observation that early on "many engineers regarded the designer as an intruder who was after their jobs," we might view *Creative Engineering* as an effort to bring "designing for people" into the engineering domain, to give the rubric scientific substance, and to establish in a new way the identity of engineers as designers. This transformation involved changing what questions a design answered, how a design was evaluated, and re-formulating the design process in psychological terms.

In relating design to problem-solving—Question, Observe, Associate, and Predict—Arnold focused attention on both the nature of problems engineers might address and their cognitive process. Thus, he gave a scientific foundation to the aesthetic, functional, and practical concerns of 1950s industrial design, prompting engineers to consider more general objectives than how to make something or how to make an existing thing more comfortable or accommodating. For example, where industrial designers might begin with a given aircraft interior to design seats, lavatory, etc., and engineers might begin by developing a more fuel-efficient and safer aircraft, Arnold's methods were suitable for inventing new ways for people to travel (e.g., the Harvard Bridge case, p. 100), or even how to avoid traveling altogether. Such open-ended challenges went beyond described issues and circumstances to consider more deeply what people wanted to accomplish or experience; these challenges had no right answer and required different modes of thinking, which is why Arnold called them *creative problems*. Rather than starting with a defined problem to be solved—in Dreyfuss's terms matters of utility, safety, maintenance, cost, sales appeal, and appearance (1955, p. 178) —comprehensive designers first had to understand what implied and expressed needs made a situation problematic.[4]

As Adams (2011) describes it, "Arnold's sound-byte was 'Comprehensive Design.' His philosophy was that the design of industrial products should be an extremely interdisciplinary activity and much more creative" (p. 137). The term "comprehensive design" came from Buckminster Fuller (1949), who spoke during the first Product Design course at MIT in fall 1950, the 1956 Creative Engineering summer program (Pulos, 1990, p. 185), and possibly on other occasions. Arnold followed Dreyfuss (1955) in considering characteristics of people ("the potential users' habits, physical dimensions, and psychological impulses," p. 219), but emphasized Fuller's systemic, future orientation, which Fuller called "total thinking" and Arnold reframed in terms of creativity.[5]

Arnold (pp. 118, 126; also 1955b) described how a comprehensive designer's inquiry must be socially motivated, thorough, balanced, and articulate:

- *"He must be motivated by very broad concepts of human thought and behavior";* be concerned about "the world's geographical and cultural groups"; "anticipate and predict very closely the impact his designs will have."
- *"He must adapt his creations to fit man, rather than the other way around";* become "thoroughly familiar with the organism for which he is designing, and the total environment in which his product will be conceived, manufactured, sold and operated."
- *"He must be articulate in all types and all levels of communication";* "understand how one man communicates with another, or how a man communicates with a machine, or how one machine communicates with another machine."
- *"He must maintain very delicate balance necessary in his ability to analyze, synthesize and to evaluate.* Great analytical ability without imagination or judgment leads to prosaic, common solutions, while great imagination without the other two results in a fool."

In summary, the Creative Engineering seminar is motivated by Arnold's serious concern about the nature of the world of the 1950s, but he was an optimist, convinced that people are capable of meeting the challenge. We use much less brain capacity than we were born with. We can unleash our creative potential, generating new and better ideas, if we are taught how to see, how to express our emotions, how to relate different modes of thinking, and how to combine technical engineering and people-oriented design methods. By transcending our psychological and cultural limitations we can be more ambitious, more imaginative, and more productive in ways that make other people happier and might change the world.

Understanding the Readings

The four essays by Guilford, Hartman, Maslow, and McKim are eminently readable but reveal considerable hidden depth when studied carefully. Arnold didn't choose the speakers haphazardly; they address different aspects of his philosophy of design, and taken together they present an imposing, penetrating analysis of the nature of creativity. Indeed, the edifice of the Arnold's project will be better appreciated by realizing how the readings are logically ordered and fit together to make a larger argument.

Each of the four speakers addresses the nature of mental experience and its products. They consider the nature of the intellect, how emotion can both guide and inhibit creativity, and how a harmonious design relates to "the whole man." In effect Guilford describes a general framework for thinking abilities; Hartman elucidates how creative thinking values "intrinsic properties"; Maslow relates these values to subconscious processes; and McKim shows how aesthetic, integrative values are realized (or not) in engineering designs.

In the first lecture, "The Psychology of Thinking," Guilford describes the "structure of intellect" applied to creative thinking and training people to be creative. His theory is historically notable for shifting from a linear model for measuring intelligence (an IQ number) to a dimensional analysis (Figure 1, p. 154). Essentially, he is applying the technique of morphological analysis ("Useful Creative Techniques," p. 100) to understanding creativity itself. Guilford's focus on *intellectual operations* (e.g., comprehending, remembering, evaluating), rather than the modalities of thought by which intelligence had been conventionally measured (e.g., verbal, visual, mathematical logic), is a breakthrough that prefigures modern cognitive science, particularly studies of expertise (Ericsson et al., 2006). Indeed, Guilford observed that his analysis would be a good starting point for creating artificial intelligence (p. 163):

> … if I were at all concerned with the construction of a new kind of computer, I should use the structure of intellect as a guide concerning the kinds of information that should be coded for input and the kinds of operations that would be needed in order to produce the kinds of products desired.

For Arnold, the salient point of Guilford's analysis is that the basic mental attributes identified with creative thinking—problem sensitivity, fluency, flexibility, and originality—are *general*, *inherent*, and *can be developed* ("Useful Creative Techniques," p. 96):

> You would not, however, until Guilford isolated them in his factor studies, know that they have been recognized as basic mental attributes, and ones essential to the creative, imaginative thinker. This is true whether he be a poet, an artist, an engineer, or a physicist. They are part of the inherited potential of each individual, and combined with certain emotional attributes make up the personality of the innovator.
>
> Being basic, these factors may individually vary from person to person, both in the amount of inherited potential, and also in the degree to which this potential has been realized and developed. This latter point would seem to indicate that these mental attributes can be developed through training and exercise, and certainly my experience with students and industrial groups during the past few years tends to prove it.

Taking Guilford's analysis of mental operations (e.g., transformation) as a starting point for understanding how ideas such as solutions of problems develop, Hartman's essay, "The Value Structure of Creativity," goes a step further by characterizing what distinguishes creative ideas, or put another way, why we *value* some ideas as being more creative than others. In effect, Hartman is elaborating what Guilford calls the "evaluative" mental operation by naming and relating different perspectives for ascribing value.

Arnold described the relevance of Hartman's analysis in a letter to him earlier in 1959: "…one of the main themes that would be running through the program, at least as far as I am concerned, would be the key phrase GROWTH, and certainly values are the basis of this growth."[6] In effect, by understanding how a creative person values a construction, the basis of its goodness, we can effectively tell engineers what kinds of questions, observations, associations, and predictions are important for creative engineering. Hartman's answer is that creative evaluation is not based solely on symbolic thought ("systemic value") or on the senses alone and an object's function within the world ("extrinsic value"), but must come from within the person. This special relation that unifies the person and the construction ("intrinsic value") is a way of being, of experiencing the relation of the self to the world, called "compenetration" (p. 182).

Hartman's analysis is dense yet articulate and precise. The first pages of his presentation provide perhaps the most important orientation for the reader. Here is a selection of the key points (p. 167 ff.):

> [T]he outstanding feature of all creative thinking is Unification.
>
> The creative thinker sees the totality of a large field of phenomena as one and finds the essence in it. The unity and structure he sees in what before him seemed an unrelated heap of items is really the unity and structure of his own self…. one not only *creates* something, one *becomes* something as well.
>
> Such creators *live* their problem; and its solution is their own becoming themselves, their own self-realization.
>
> The secret of the creative person, thus, is the capacity for identification with some external material, whether canvass and paint or sound or movement or ideas. It is the limitless capacity of giving oneself and regaining oneself in a work.
>
> The creative view must be applied to creativity itself and the total pattern must be seen of which this experience is only a part. The psychology books see only glimpses of what actually is an entirely new world.
>
> The creative experience is one of an infinity of experiences of a world as varied as the ordinary world in which we live, the world of our senses ["extrinsic value"], yet as different from it as is that other world of ours, the world of symbols, or science ["systemic value"]…. But the world of intrinsic value, to which creativity belongs, has hardly been discovered…. I would like to give you an idea of this unitary view of the three worlds in which we constantly live, and locate the creative experience within it.
>
> Phenomena of creativity are what is called today "intangibles." Modern axiology, or value theory, may be defined as that discipline which makes intangibles tangible.
>
> The most important events and choices in our lives are based on intangibles…. What specifications can you write down for the president of a company like General Electric or General Motors who has to make decisions of hundreds of millions of dollars in terms of hundreds of thousands of men? How about the choice of the President of the United States?

> What then are these tremendously important choices based upon? Can these intangibles be known, let alone be measured?

The "unitary view of the three worlds in which we constantly live" is realized by Arnold's dictum to seek a balance in analysis, synthesis, and evaluation, avoiding both prosaic solutions or wholly foolish imagination. This balance, a "unity of the thing with the valuer" (p. 183), is experienced as *compenetration*, a non-verbal thought. It constitutes a blended understanding of description, abstraction, and feelings and is not reducible to words (i.e., it is a non-discursive conceptualization). Put another way, this construction is personal and hence *subjective*, in contrast with objective (extrinsic and systemic) values: "I can say that a chair is a 'good chair' without the urgent desire to use it; but on the other hand, I cannot value it intrinsically without at the same time desiring to use it" (p. 183). The general concept of a chair and ways of describing its goodness (its properties) are blended with an "urgent desire to use it," which makes the valuation personal, that is, intrinsic. Aesthetic appreciation and creation is another intrinsic value, fundamental to creative design.

You might have noticed that Hartman equates compenetration to self-actualization ("[a problem's] solution is their own becoming themselves, their own self-realization"[7]), a term more often today associated with Maslow's (1954) framework of personal development. Maslow characterized human needs as a hierarchy: Physiological, Safety, Love/belonging, Esteem, and Self-actualization, identifying full development with "exemplary" people such as Albert Einstein and Eleanor Roosevelt. We find throughout Arnold's lectures the same approach of analyzing creative people and characterizing their thinking, motivation, and personality.

Here then is the fundamental insight in Guilford, Hartman, and Maslow's theory of creativity: They ascribe the nature of creative thought to openness to experience, specifically allowing feelings and emotions to guide thinking. They posit that this openness is malleable; it is an inherent potential that can be realized through personal growth.

Thus we have the overall creative engineering program in a nutshell: 1) A creative person tunes to inner desire, to be what he or she can be, true to oneself, and becoming and accomplishing the most that one can; 2) Everyone has this potential because it entails being oneself in whatever we endeavor, a style of integrity and insistence to certain standards that come from within our personal knowledge and feelings; 3) We attain self-actualization through attention and effort, effectively by questioning, observing, associating, and predicting in a certain way; 4) This orientation, this creative way of thinking, can be guided and practiced, such that tuning our thoughts and actions to intrinsic values is the basis of personal growth.

But dark clouds loom. As Maslow cogently describes in his essay, "Emotional Blocks to Creativity," our understanding of the world and ourselves is not all articulated in our conscious thought. We experience and learn much more than we have expressed to ourselves and others. Some conceptual organizers are non-discursive relations, that is unspoken and unformulated in words, yet they order our habits and bias what we perceive and believe, and indeed even the way we talk. A simple perceptual example is how an adult learning a foreign language may find it impossible to hear let alone say sounds that are not in his or her native language. Our beliefs are biased similarly by implicit ways of interpreting and ordering what we see and hear, and especially what sources of information we seek and monitor; examples abound in any society's political and racial–ethnic turmoil, in which some people rally with fervent emotion for what others believe to be morally wrong or even logically absurd. (These neuropsychological processes underlie *groupthink*, discussed in the section "Personal Development in a Team—the Challenge of Groupthink.")

Non-verbal conceptualizations are not formed by nor organized by the logic of reasoning; they form their own system, which Maslow calls *primary processes* (p. 191):

> These primary processes, these unconscious processes of cognizing, that is, of perceiving the world and of thinking, which interests us here, are very, very different from the laws of common sense, good logic, of what the psychoanalyst calls the "secondary processes" in which we are logical, sensible, and realistic.

Maslow here elaborates Freud's psychiatry of the mind, characterizing the *primary processes* as a kind of thinking that affects creativity both positively and negatively, which he impressively summarizes here as the unconscious world of the self:

> Deep down, we look at the world through the eyes of wishes and fears and gratifications. Perhaps it will help you if you think of the way in which a really young child looks at the world, looks at itself and at other people. It is logical in the sense of having no negative, no contradictions, no separate identities, no opposites, no mutual exclusions. Aristotle doesn't exist for the primary processes. It is independent of control, taboos, discipline, inhibitions, delays, planning, calculations of possibility or impossibility. It has nothing to do with time and space or with sequence, casualty, order, or with the laws of the physical world. This is a world quite other than the physical world. When it is placed under the necessity of disguising itself from conscious awareness to make things less threatening, it can condense several objects into one as in a dream. It can displace emotions from their true objects to other harmless ones. It can obscure by symbolizing. It can be omnipotent, ubiquitous, omniscient. (Remember your dreams, now. Everything I've said holds for the dream.) It has nothing to do with action for it can make things come to pass without doing or without acting, simply by fantasy. For most people it is preverbal, very concrete, closer to raw experiencing and usually visual. It is prevaluational, premoral, pre-ethical, precultural. It is prior to good and evil.

Secondary processes are expressions of speaking, writing, gestures, painting, singing, dancing, etc. that we consciously control to describe, model, and explain our feelings, images, and ideas. These expressions are called secondary processes because they are *behaviors* that occur *in our experience over time*, often in reflective cycles of perceiving, conceiving, and acting (Clancey 1997). Expressive behaviors are grounded in (arise from) feelings and learned ways of seeing, acting, and speaking that are not known explicitly—the primary neuropsychological processes of categorizing and ordering our experience conceptually (Clancey, 2000). They are ways of *representing,* making known to ourselves and others, our feelings, images, and ideas. Saying something to ourselves is an action, a behavior occurring in our experience, too.

A very common example of primary processes at work is our experience of worrying about something. We find ourselves thinking about something that might happen in the future or perhaps dwelling over something we said or did. Did I offend that person by what I said? Is the hotel room on the street going to be noisy? How am I going to cover these bills? We do not decide when these thoughts will occur. During such experiences, tacit ways of conceiving our relation to the world, that is, non-verbal processes in the brain, arise in our conscious awareness as words and images laden with emotion. In our imagination we are expressing our desires and fears as wonderings and visualized events, both anxieties and fantasies. In daydreams such ideas may be pleasurable as we anticipate what we will see or do. In our imagination, internal conceptual-emotional organizers are realized as *emotional experiences*—private words and images that are as real and important at that moment as anything that happens in the world. Some are inventive and productive and we may pursue them, others make us feel bad and we may try to squelch them. An important aspect of emotional intelligence is learning to deal with and manage these unbidden experiences. Denying and inhibiting them is one approach, but it blocks who we are from ourselves—and this affects our creativity.

From a psychoanalytic perspective, people are more or less healthy in terms of how they relate what they see, say, and do to their desires and fears, their feelings of joy or disgust, their fantasies and anxieties. This is the topic of Maslow's lecture: "How do you get these two worlds, the psychic world and the world of reality to be comfortable with each other?" (p. 193). Much of Maslow's presentation is about what goes wrong when people have difficulty being true to themselves, when they are not self-actualizers, but rather wall-off part of themselves, developing a mental dynamic that psychiatry characterizes as neuroses. Rather than psychiatric disorders originating in the unconscious, which a superficial reading of Freud might suggest, the actual psychological disorder is an inability to *relate* the two aspects of the self, the conscious and the unconscious, to become an integrated person who is not afraid of emotion, imagination, and illogical associations and finds a way to work with them, to make the psychic life part of a productive social life. Maslow describes this unification and how the theory developed:

> Chronologically, our knowledge of primary processes was derived first from studies of dreams and fantasies and neurotic processes, and later of psychotic, insane processes. Only little by little has this knowledge been freed of its taint of pathology, of irrationality, of immaturity, and primitiveness, in the bad sense. Only recently have we become aware, fully aware, from our studies of healthy people, of the creative process, of play, of aesthetic perception, of the meaning of healthy love, of healthy growing and becoming, of healthy education, that every human being is both poet and engineer, both rational and non-rational, both child and adult, both masculine and feminine, both in the psychic world and in the world of nature. Only slowly have we learned what we lose by trying daily to be *only* and *purely* rational, *only* "scientific," *only* logical, *only* sensible, *only* practical, *only* responsible. Only now are we becoming quite sure that the integrated person, the fully evolved human, the fully matured person, must be available to himself at both these levels, simultaneously.

Maslow is explaining how a cultural bias shaped the development of psychoanalysis and the very study of human intelligence, effectively inhibiting our theories of creativity. We find the same bias in the dominant theory of intelligence that shaped artificial intelligence and cognitive psychology research in the 1950s through the 1980s—a dichotomization and valuation that walled the unconscious aspect of intelligence from the consciously known aspect. These fields began by effectively equating intelligent behavior with the application of mathematical and scientific knowledge. The theory of intelligence was restricted to the secondary processes, viewing problem solving in particular as only and purely rational, only scientific, only logical, only sensible, only practical, and only responsible to the defined professions of the academy (e.g., medicine, engineering, physical sciences).[8] The primary processes of the intellect were viewed as primitive, undeveloped, and essentially not serious, not what occupied the minds of adults. Emotion was viewed as distorting thinking and illogical, as if reasoning and emotion were entirely different systems in the brain, and the ideal human was Spock on the TV show *Star Trek*.[9]

Maslow's lecture is important because it speaks to a problem experienced by individuals and society alike, limiting our ability to be creative:

> What I'm leading up to is that out of this unconscious, out of this deeper self, out of this portion of ourselves of which we generally are afraid and therefore try to keep under control, out of this comes the ability to play—to enjoy, to fantasy, to laugh, to loaf, to be spontaneous—and, what's most important for us here, creativity, which is a kind of intellectual play, which is a kind of permission to be ourselves, to fantasy, to let loose, and to be crazy, privately.

In effect, a logical way of thinking, *dichotomization*, enables secondary processes to block feelings and thoughts arising from primary processes, constructing an inherently partial concept of the self:

> We can now see this as an illegitimate dichotomy, an illegitimate "either/or," in which by the very process of splitting and dichotomizing, we create a sick "either" and a sick "or," that is to say, a sick conscious and a sick unconscious, a sick rationality, and sick impulses.
>
> Once we transcend and resolve this dichotomy, once we can put these together into the unity in which they are originally, for instance, in the healthy child, or in the healthy adult, or in especially creative people, then we can recognize that the dichotomizing or the splitting is itself a pathological process. And then it becomes possible for your civil way to end. This is precisely what happens in people that I call self-actualizing. The simplest way to describe them is as psychologically healthy people.

In short, Maslow's psychoanalytic framework of primary and secondary (conceptual/representational) processes elaborates Hartman's notion of *unification*. Maslow is explaining the nature of the "intrinsic values" that the creative person exploits and incorporates in both problem solving and everyday affairs, in professional activity as well as making sense of oneself. He explains how the extrinsic and systemic values, the world of adult reality and logical-scientific thinking, may repress all that is not articulately defined and rationally justified, thus reducing human thinking to a verbal, symbolic calculus and limiting the range of questions, observations, associations, and predictions we can make in understanding and dealing with our personal and the world's affairs.

It should give us pause that AI and cognitive science followed this reductionist path for 50 years, creating in computer models of cognition and "intelligent systems" a Pygmalion of our own biased, preferred and idealized image of ourselves. Our creativity was restricted, significantly limiting how automation was conceived and deployed, as well as limiting the very models of cognition that justified these hyper-rationalized "expert" and "autonomous" systems. The title of Winograd and Flores's (1986) breakthrough book says it all: *Understanding Computers and Cognition: A New Foundation for Design.*

Given the limited nature of the information processing theory of cognition and of the computer tools we constructed based upon it, we can better appreciate Steve Jobs' vision for the Macintosh as "a computer for the rest of us." He meant not only a tool for everyday folks and artists, but also a tool for the rest of our *being*—"the medium the best capable of transmitting some feeling that you have that you want to share with other people"[10]—and thus a tool for thinking differently.

Maslow ends his essay on this very note, an appeal to look out for the Uncommon Man, the self-actualizer:

> Common sense means living in the world as it is today; but creative people are people who don't want the world as it is today, but want to make another world. And in order to be able to do that, they have to be able to sail right off the surface of the earth, to imagine, to fantasy, and even to be crazy, and nutty, and so on.
>
> The suggestion that I have to make, the practical suggestion for you people who manage creative personnel, is simply to watch out for such people as they already exist and then to pluck them out and hang on to them.
>
> They are precisely the ones that make trouble in an organization, usually. I wrote down a list of some of their characteristics that would be guaranteed to make trouble. They tend to be unconventional; they tend to be a little bit queer; unrealistic; they are often called undisciplined, sometimes inexact, "unscientific," that is, by a specific definition of science. They tend to be called childish by their more compulsive colleagues, irresponsible, wild, crazy, speculative, uncritical, irregular, emotional, and so on.

These people are the "crazy ones" in the Apple commercial narrated by Steve Jobs (1997):

> Here's to the crazy ones, the misfits, the rebels, the troublemakers, the round pegs in the square holes—the ones who see things differently. They're not fond of rules and they have no respect for the status quo. You can quote them, disagree with them, glorify or vilify them…about the only thing you can't do is ignore them, because they change things…they push the human race forward. While some may see them as the crazy ones, we see genius…because the ones who are crazy enough to think that they can change the world…are the ones who do.

To complete the logical sequence of the Creative Engineering seminar lectures, it remains then for McKim to ask, "Who designs for the whole man?" As we look at designs around us, our cars, marquees, homes, furniture, etc. where do we find designs that relate our physical, intellectual, and emotional needs? What are examples of unifying designs that respect human aesthetic and emotional sensibilities? Applying a holistic perspective to critique recent designs, he asks, "If modern designers were not practicing "Form satisfies human physical and emotional needs," what were they practicing?" (p. 211).

McKim lays out a method that decades later we would call "human-centered design"—not considering people after the functional design is complete, as industrial designers were so often required to do, but starting with people from the very beginning:[11]

> If our human values are such that we consider the machine to be an extension of man, with man the boss and the machine the servant, then early consideration of man's physical relationship to the machine becomes of obvious importance. By early inclusion of man into the design hypothesis as a non-variable, it is usually possible to accommodate the other design variables to man's physical nature. Once the design is partially "set," however, the designer will often begin to consider man the variable. Man, unfortunately, is not a variable—he has already been designed. Only early inclusion of man into the design process can bring man into his proper relationship with the machine.

McKim's presentation is particularly strong in articulating how we experience a design in practice and in our feelings. To this end he provides sixteen illustrations that illustrate how human values, in terms of physical, intellectual, and emotional needs, are met (or not).

In conclusion, the four readings by Guilford, Hartman, Maslow, and McKim establish a science of creativity that provides a theoretical foundation for creative engineering. Their presentations relate the nature of the mind, the nature and development of creativity, and an approach to questioning and studying engineering designs to better understand needs and values. On the one hand, their analyses relate reason and emotion; on the other hand they show this to be a false dichotomy, that realizing the potential of the mind is unifying the self by allowing feelings, fantasies, and playful ideas to guide our analysis and constructions. Reason and emotion, like mind and nature, are a necessary unity (Bateson, 1988), as stated more recently by Christopher Alexander:[12]

> This is not merely an emotional appendix to the scientific theory of the other books. It is at the core of the entire work, and is rooted in the fact that our two sides—our analytical thinking selves, and our vulnerable emotional personalities as human beings—are coterminous, and must be harnessed at one and the same time, if we are ever to really make sense of what is around us, and be able to create a living world.

Arnold's vision in bringing together these elements of design theory and practice in the Creative Engineering seminar was to promote personal growth, to enable others to be creative at whatever they do in life. He presents brainstorming methods and addresses personal difficulties people encounter, the cultural, mental, and emotional blocks. The depth of Arnold's vision is perhaps most apparent in whom he invited to speak and the guidance he provided, embracing a theory of the intellect, of values and subconscious processes, and self-actualization. The intent is comprehensive and unifying, in relating the professional fields, relating people to aesthetic and practical values, and relating the individual to society: "One of the aims of Creative Engineering is to bring about a union between the physical sciences, social sciences, and the arts. In this way and perhaps only in this way can we be assured that our innovations better satisfy some need of man."

History of the Seminar

The theme of "creative engineering" was probably known to Arnold by the time he joined the MIT Mechanical Engineering faculty in 1942. The American Society of Mechanical Engineers (ASME, 1944) published symposium proceedings from 1942 and

1943 with that title. The phrase can be found even fifty years earlier in transactions of society meetings (ASME, 1893). In 1956 the symposium was characterized as "a series of discussions at ASME meetings emphasizing the importance of ingenuity, intuition, and creative ability in the engineering profession: suggesting how these qualities might be encouraged and developed." Arnold (1956a) directly responded to this challenge in his presentation at that meeting and throughout subsequent lectures and courses (1956b; 1957, 1959c, 1962a, b).

Many of the ideas presenting in the Creative Engineering seminar were developed and put into practice by Arnold in his courses at MIT. His first machine design course is described in the 1949 MIT President's Bulletin in a section written by the Dean of Engineering (Söderberg, 1949, p. 131):

> A new elective subject, a seminar in machine design, was offered by Professor John E. Arnold. The number of students in this subject is limited to approximately 12 and to those who have shown exceptional design ability. Its purpose is to develop creative thinking as well as to advance design technique.

In 1950 Arnold was promoted to Associate Professor of Mechanical Engineering; the seminar is then re-characterized as a "senior elective subject, Product Design," a name for courses and ME majors that persists today. The course was conceived as "education in Industrial Design" and intended to be "an extremely comprehensive program" (Söderberg, 1950, p. 148). The MIT Bulletin a year later confirms Arnold's early association with Dreyfuss and Fuller (Söderberg, 1950, p. 158):

> *Machine Design Division*. During the [1950] fall term a course, Product Design (2.734), was offered for the first time under the direction of Professor John E. Arnold. This course has materialized as a result of demand from industry and students for training in the field of industrial design. The course was a co-operative enterprise with representatives from the Departments of Architecture, Business and Engineering Administration, Building Engineering and Construction, and Metallurgy taking part under Professor Arnold's direction. A practicing industrial designer, Mr. Gordon Florian was engaged to work with the students one day per week. In addition, the following outside speakers participated: Henry Dreyfuss, Buckminster Fuller, Walter Baermann. This course was limited to approximately 20 students and was notably successful. This represents one more step forward in our program to encourage creative design work. Plans are under way to expand the program to a two-term sequence in the near future.

In the fall of 1951 Arnold added the Arcturus IV case study (Arnold 2016/1953; Howe, 1952; Woodbury, 1953) to Product Design—here he sought to unblock students' creativity by having them design products for aliens on Arcturus IV, an imaginary fourth planet of the star Arcturus.[13] The beings were called Methanians because they breathed methane.

Students had to approach the Arcturus IV project scientifically by learning about the physiology, psychology, and in part the culture of Methanians, as well as the planetary environment in which they lived (gravity, atmosphere, etc.). Thus, engineers were prompted to understand the Methanians and their world, inventing new kinds of products (e.g., a device for harvesting underground fruit)—fitting "the organism and the environment." Needing to understand the situation more comprehensively prompted the students to ask Arnold for more information, which showed that asking questions to frame underlying causes and concerns was required to define suitable problems. Rather than incrementally refining something already on the (Earth) market, or answering a question posed by the instructor with a single correct solution, students were obliged to discover and articulate a problem that needed to solved, an essential aspect of what we call "design thinking" today (Roth, 2015, p. 11).

Arnold described the Arcturus IV pedagogy and design philosophy in some depth in an invited article in *Astounding Science Fiction* (Arnold, 1953). About this time, Arnold's perspective was broadening (Pulos, 1990, p. 185), as he lectured and published articles that form the genesis of this book:

> The popularity of the [Product Design] course convinced Arnold that it would also be of value to practicing engineers. Accordingly he organized a series of short courses in creative engineering for engineers and product designers, which were offered for several summers in the 1950s. The cases consisted of engineers from manufacturing industries, military personnel involved in research projects, and a few industrial designers. In the beginning, the goal was to explore and demonstrate factors contributing to the human creative potential; however, by the summer of 1955 increasing emphasis was being placed on the management of creative personnel, the testing and measuring of creative ability, and the psychology of creative thinking and imagination [Arnold, 1955a]. The 1956 program addressed techniques for organizing "inspired" creative activity and the selection and training of creative individuals. With some perspective, it seems that Arnold was trying to help engineers and engineering managers break out of petrified modes of education and experience.

In summary, Arnold's extraordinary corralling of half-a-dozen departments and disciplines for the first Product Design (2.734) course suggests that by 1950–1951 his vision of a creative engineer was embracive and penetrating. It is apparent that the Arcturus IV class didn't develop into the Creative Engineering seminar, but rather the class was a way of realizing the vision for students. In that respect, Arcturus IV is a window into his ideas and methods at the time. Arnold presented the Creative Engineering seminar for the first time in the summer of 1953; it is the work of a mature scientist–engineer, presenting a comprehensive *philosophy of design*.

The summer seminar continued through 1959. Pittman, Arnold's student, quotes the 1954 MIT summer session notes in his 1955 dissertation.[14] Kizilos-Clift (2009) quotes[15] from a 1956 summer workshop for Honeywell (Arnold, 1956c, d). Pulos (1990, pp. 185–186) describes the 1956 MIT summer program as being notable for bringing together lecturers championing different methods for stimulating creativity, including R. Buckminster Fuller on the "comprehensive designer," Charles H. Clark of the Ethyl Corporation presenting Alex Faickney Osborn's notion of "brainstorming," and William J. J. Gordon of Arthur D. Little presenting "Operational Creativity." About 150 people attended this session.

Arnold's joint appointment as Professor of Business Administration at Stanford in 1957 reveals how strongly his philosophy of design and pedagogy had become oriented towards practicing engineers and their managers.[16] According to Wessinger (1964), the lectures at General Motors were particularly influential in business by virtue of what we could call today Arnold's "train the trainers" approach:

> What has grown into probably the largest creativity program in industry started in September 1953, when a group of distinguished men of science, education, and industry met at the AC Spark Plug Division of General Motors for the purpose of discussing creativity…. The first formal training was conducted by the late Professor John Arnold, then of M.I.T., who presented his course in Creative Engineering to the Management staff of AC Spark Plug. The course was so enthusiastically received that the decision was made to introduce the course in the Management Development Program. Professor Arnold, accordingly, trained twelve "in-house" instructors who each trained fifteen persons in the spring of 1954; several thousand employees have now completed the course.[17]

The version of the summer seminar presented in this book is dated 1958–1959 in the Stanford University Archives (Arnold, 1959a). The material was updated and prepared in advance (notably, 1959 publications appear in the Bibliography), then presented over two weeks. Written in a conversational voice, it was apparently read at the meeting, though in places it appears to be more like a transcript: "Bucky Fuller's Dymaxion car was a radical, although unsuccessful functional change and I am sure that he will tell you about it tomorrow" ("Creative Product Design," p. 120).

Regarding the style and completeness of *Creative Engineering,* we must remember that it was prepared and distributed as summer seminar course notes, not an academic book for publication. Some citations are incomplete (e.g., referring to Rogers on p. 88) and many times he refers to "psychologists" where a source would be expected (e.g., p. 108). It seems likely that Arnold planned to complete and elaborate the notes as a book on "the philosophy of engineering" during his sabbatical (*The Stanford Daily,*1963). The course description of Philosophy of Design 214a, introduced in autumn 1958, is indeed an excellent two-sentence summary of the Creative Engineering seminar (p. 218). In short, the notes had a limited purpose that did not require an academic style of citation.[18]

In summary, Arnold's seminar embodies the scientific principles and creativity that he espoused. He associated his observations in factories, universities, and corporations with published analyses and theories. He formed basic questions about society, problems, engineering, and thinking. He predicted that a new pedagogy could develop a new capacity to innovate, such that thinking differently about the world, materials, and methods could lead to breakthrough solutions to large-scale practical problems. And true to his claim that a creative solution must take tangible form, he developed and delivered a solution, recorded as the *Creative Engineering* lectures.

Reception and Influences

Arnold's remarks about how prehistoric creative people were treated by society relate to what we know about his own situation at MIT: His "new answers" were resisted and perhaps also he was "ridiculed and tormented, but the truth prevailed and progress was achieved" ("Forward–Why Creativity," p. 61). Conflicts in the mechanical engineering department, likely inherent and long-standing (Hapgood, 1993; Kizilos-Clift, 2009), concerning the nature of engineering and what should be taught likely crystalized around the *Arcturus IV Case Study*. After all, this exercise was deliberately designed to provoke students and professional engineers alike to question how they defined problems and rotely applied tools of the design trade.

The 1955 *Life* magazine article on Arcturus IV reveals the discord he experienced (Hunt, 1955, p. 196):

> Arnold's seemingly farfetched methods have made him suspect in the eyes of some academic colleagues and some of his engineering profession. Like other naturally flamboyant members of his naturally sober calling, Arnold is regularly accused of theatricalism and publicity-seeking.

Nevertheless, MIT's Dean of Engineering, C. Richard Söderberg, praised his pedagogical approach:

> I personally feel the Arcturus case study and similar case studies are an excellent teaching device, but ours is a conservative profession and there are many who think of Arnold's course as a publicity stunt. But I feel he successfully gives the student a chance to express his entire personality in his designs. This makes him genuinely creative, not just a prettifier of details.

Speaking at a conference on creativity in 1955 which Arnold didn't attend, Maury H. Chorness from the Air Force Personnel and Training Research Center spoke highly of their experience with Arnold (pp. 147–148):

> We were fortunate to make contact with Professor John E. Arnold, who is in charge of the Creative Engineering Laboratory at M.I.T. I felt so enthusiastic about his program that I should like to take a moment to explain what he does. Arnold is a graduate engineer who has had some early training in psychology, which he has never forgotten. I should say he has as complete a library on creativity as I have seen. He has always maintained an active contact with industry and has been aware of the demand for creative thinking in the engineering field. A few years ago, he instituted a course in creative engineering at M.I.T. which was a success from the start. Students come to him with three years of training in "thou-shalt-nots," and he has taken on the mission of getting them to elasticize those imaginative processes of mind which seem to have lain dormant.

Austin R. Baer, a student in the first Arcturus IV course who painted the *Astounding Science Fiction* cover and assisted Arnold in formulating and teaching the initial Product Design courses as well as the subsequent seminars, reflected more recently on those years at MIT:

> [John Arnold's] activities were, sadly, never regarded by the ME faculty as anything worthy of attention... he was already getting too much attention as far as they were concerned. They'd always been more concerned with calculating the proper face width and hardness for an automobile transmission spur gear than creating anything new. Its focus has since changed a lot, but back then it was run by people who were buried in vibrations analysis and four-bar linkage design. I recall a fellow student in John's class who went on to write his thesis on the proper damping factor for the rotation of the knobs on a kitchen gas range.[19]

Strikingly, the Arcturus IV case study was not incorporated in Stanford courses and is not mentioned in the Creative Engineering seminar. It might have already been replaced at MIT by the more practical, albeit still futuristic *Ceres Mining* case study (Babcock and Davis, 1954). At Stanford another science fiction case was developed, *Zylerium Blindness* (n.d.), the tale of an exchange of nuclear missiles that results in the blindness of all newborn children, with a call to re-engineer all the socio-technical systems of the world to deal with their plight. One can sense in this story the urgency of Arnold's appeal for engineers to look up from their drafting boards and vibration calculations to see the troubles of the world at large and their role in it.

On moving to Stanford in 1957, Arnold became a full Professor of Mechanical Engineering (a promotion he had been denied at MIT). Unlike MIT, Stanford also gave Arnold the opportunity to create an institutional structure to support and promote his courses, which he named the ME "Design Division." His faculty hires and students carried the ideas forward in many ways. Their publications citing Arnold include McKim (1972), Adams (1976), and Roth (2015).

Arnold's joint position in the Graduate School of Business reflects his concern and involvement with corporate engineers and managers. Funding from business for student projects and faculty research supported and shaped the Design Division in a manner that continues today. The 1959 study in partnership with the McKinsey Company, reported by Arnold, Stewart P. Blake, and Sidney Jones (1960) in "The Generalist-Specialist Dichotomy in the Management of Creative Personnel," represents an early attempt to relate people, design thinking, and organizations. Arnold's presentation at the original March 11, 1959 workshop, "The Specialist vs. The Generalist," is largely drawn from his Creative Engineering lectures. Of historical note, the report co-author, Sidney Jones, was a Stanford graduate student, receiving an M.B.A. (1958) and Ph.D. in economics (1960). He later served a number of senior economic policy roles in the US government in the Departments of Commerce and Treasury in the Nixon, Reagan, and George H. W. Bush administrations.

Stephen Jay Kline was a professor on the search committee (with Robert Eustis and George Leppert) that brought Arnold to Stanford. In 1970 Kline was the driving force in forming the program in Values, Technology, and Society (Salisbury, 1997): "He realized that studies of the ways that science and technology affect and are affected by social institutions and human values were virtually nonexistent, despite the importance of the subject." The program was first offered in 1972–73; Adams was the chair 1983–1990, during which time the program was renamed "Values, Technology, Science, and Society" (Adams, 2011, p. 378) and he introduced the courses "Creative Problem Solving," "Technology and Aesthetics," and "War and Technology." Similarly following Arnold's comprehensive approach to creative engineering, Kline's book, *Conceptual Foundations for Multidisciplinary Thinking* (1995), promoted an educational program that "explored the relationships and conflicts among different disciplines and called for the development of an integrated conceptual framework that can link the specialist's expertise to the overall intellectual enterprise" (Salisbury, 1997).

Arnold's legacy at Stanford is particularly salient in the engineering design course (ME310) that began in 1967 and is credited in part to Arnold's initiative in what was later called "problem-based learning" (Carleton & Leifer, 2009; discussed further in the next section). Arnold's influence on the culture continued through his students and their students: "[Larry] Leifer also remembers the 'Philosophy of Design' course he took with John Arnold in the early 60s, which ingrained in him the importance of asking questions, a lesson that Leifer repeats to his students today."

Organizational developments include Leifer's ME Center for Design Research, Stanford's Joint Program in Design, the design firm IDEO co-founded by David Kelley (who took McKim's course), and subsequently the Stanford d.school formed by Kelley and Bernard (Bernie) Roth. Design thinking and its relation to IDEO and the d.school are presented well by Katz (2015), Roth (2015), and Kelley and Kelley (2013).

It is noteworthy that Baer, Arnold's first protégé as student and faculty member went on to become a prominent teacher of product design at North Carolina State University and entrepreneurial engineer; creative thinking pervaded his life passions (NC State Design, 2015). References to Arnold recur when people relate design, creativity, and education and rediscover Arnold's seminal synthesis, as in Felder's (1987) "On Creating Creative Engineers."

Reflections on the Case Method

Since Arnold planted the seeds of an engineering design discipline, Stanford's Design Division and associated courses and projects have developed through continuous learning and experimentation over the past half century (Carleton & Leifer, 2009). One aspect within the scope of this book is the fate of Arnold's case studies pedagogy. Arnold (1955b, p. 8) described his original intent:

> The case studies are carefully prepared collections of data and facts describing some broad general need area of man. The students, after reading over the case, must pick out and define for themselves some problem associated with that need area. They must then arrive at some solution of that problem, and must then present that solution in a self explanatory package consisting of reports and drawings. This package is reviewed by a jury of three men brought in from the outside, capable engineers themselves, and qualified to judge design. The student is then given the chance to describe verbally and present his solution, and to answer any questions that the jury may have. The student is graded by the jury on three main items: first of all, the *idea* that formed the basis of his solution, secondly, the *engineering* that went into the development of the idea, and third, the *presentation* of the idea.

Henry Fuchs' greatly expanded the collection; there are now over 290 cases in the ASEE Engineering Case Library (n.d.): "The cases are accounts of real engineering work written for use in engineering education."[20] Thus the nature of the case studies has changed from providing background for new projects to being exemplary histories to study. This distinction was already implicit in Arnold's initial set. The fictional accounts of *Arcturus IV Case Study*, *Ceres Mining*, and *Zylerium Blindness* set up a problematic situation; cases describing settings and activities with a long history on Earth (e.g., *Rice in Burma*) were accompanied by stories of historical solutions and how other engineers had approached the situation.

Typical of the non-fiction, historical genre, Arnold's *Chinese Typewriter* case study details the nature of the Chinese language and past attempts to categorize the symbolic characters, followed by descriptions of three patented typewriters, including diagrams and detailed explanations of their designs and rationale. Thus, rather than having to probe for tractable needs and opportunities ("what do Methanians need that provides a product market for the Massachusetts Intergalactic Traders?"), students are presented with a well-defined design problem—develop a typewriter for Chinese "limited to only a few thousand of the commonly used words"—and exemplary solutions.

Over time, Arnold's (2016/1953) packaging of the Arcturus IV background with student designs from three seminars led to something resembling a historical account too, as the original memos presented to the first term in 1951 were accompanied by additional background memos and designs for home appliances, transportation, and farm equipment. With more and more background reading provided, instead of an uncertain world to explore for the first time requiring a detective's investigation, "a case to crack" became "a case to study."

A related issue is that active areas of engineering may be presented in case studies in terms of specific design challenges, rather than encouraging the student to reframe the overall problem. For example, Arnold presents in the *Box Car Design* case study (p. 82) specific design issues, such as "box cars are difficult to load and unload." He nicely illustrates how the checklist approach is applied: "I might ask myself the question, 'How do I fill or empty things?'" The case study itself provides well-defined engineering challenges, "a really good, cheap and tough exterior liner that can take a beating, have quickly attachable fittings and be easily installed and replaced is still lacking" (Arnold, 1952, p. 9)[21].

However, the notion of a comprehensive designer suggests that a student might consider instead transportation methods that avoid using box cars entirely, reframing the problem. For example, today urban planners ask how more farm products might be locally grown and consumed, reducing the need for refrigerated cars. Indeed, Arnold advocates such broad reformulations:

> I see no reason why researchers or designers can't be as creative and imaginative as management and why they can't start out with a very broad viewpoint and eventually narrow the problem down. The creative designer should be expected to look into all possible approaches, to formulate and reformulate problems and sub-problems until he finds a solution that satisfies as many of the prime goals of the initial problem as time and expenses allow.

In summary, the different case examples imply different interpretations of what a case can be and how a student might learn. A single background story can set up a term project as in redesigning boxcars, or the story can be useful for learning what today we would call "systems thinking," as for Arcturus IV. Furthermore, a case library of "real engineering work," as Fuchs intended, provides access to far-ranging real-world experience in the form of accessible stories. But the result can be more reading or brainstorming than doing, particularly when large-scale problems such as inventing a better box car—or how to design an economic system such as food production—are not amenable to design, construction, and testing in student term projects.

Reviewing the progression of Stanford's ME themes and projects, Carleton & Leifer (2009) state that by 1966 "actual development of student designs in any course was optional, subject to the instructor's approval." Very likely, Arnold would have objected as well—"the creative process is not complete until one has some tangible evidence to prove it" ("Useful Creative Techniques," p. 104). In reaction, the ME faculty introduced a graduate level sequence in 1967 oriented around *problem-based learning*; design projects in ME310 were sponsored by industry partners and covered the gamut from "defining design requirements to constructing functional prototypes that are ready for consumer testing and technical evaluation."

Arnold's pedagogy of learning by finding and resolving problems in cases is now articulated as *learning-by-doing*, and it is more appropriate to say that the method is *project-based* rather than case-based. Students are brought into corporate product development organizations and guided by their engineers and marketing culture. They learn *practices* such as rapid-prototyping, interacting with other engineers while playing different roles, and entrepreneurship. The ME310 course has continued as a reflective practice studying and experimenting with design methods and education for nearly 50 years. More recently a related course called "Foresight and Innovation" (ME410) adopted Fuller's (1949) notion of comprehensive design as being an *anticipatory science*; "future thinking" challenges address emerging, long-range problems such as care for the elderly. These "future engineering problems" (Shedletsky et al., 2009), unconstrained by current technology and markets, are the epitome of what Arnold called "creative problems." To learn more about the history of the design program at Stanford and how it still seeks to realize Arnold's initiatives, see Carleton and Leifer (2009), Lande (2012), and Katz (2015).

Imaginary Oppositions in the Relation of Art, Science, and Design

The acceptance and development of comprehensive design has been challenged from the beginning by what Maslow in his lecture called "an illegitimate either/or." In saying that "every human being is both poet and engineer" he sought to make the unconscious processes of emotion and feeling part of creative activity. In this section, we consider a number of related either–or ways of thinking that block creativity and explain why 60 years later we are still learning how to "design for the whole man." By learning to recognize imaginary oppositions in common speech such as "man vs. machine" and "science vs. engineering"—analytic perspectives that are often institutionalized in groups struggling for power—we can understand better Arnold's vision of a comprehensive designer. Most importantly, we can improve how we think about persistent conflicts in our life and society that affect creating integrative solutions.

One of Arnold's important insights that was clearly ahead of his time was intuitively and effortlessly combining art and science in his theory and practice of design, and grounded these in a humanist psychology. The art–science relation is particularly apparent in the requirements for communication that Arnold (1955b) defined as essential for the comprehensive designer ("Creative Product Design," p. 128):

> The types of communication that the comprehensive designer must use include the language of the written and spoken word, the language of symbolic logic or mathematics, and lastly, the language of vision. In order to originate ideas, to preserve them for his own later use, or present them to others, he must use one or more of these languages. The more articulate he is, the greater will be his own efficiency and easier will be his task of convincing others of the merit of his ideas. Courses then, in literature, composition, mathematics, and the fine arts must be included in his curriculum. Not only must he be proficient in the use of these three languages, but he must also understand the various levels of communication…. [He] must understand the means and method of communication within himself as a living organism…. He must understand the communication between man and man…. He must understand and be able to overcome the communication difficulties that exist between man and machine. And lastly, he must be able to understand how one machine communicates with another.

Human-machine communication is especially emphasized today in software engineering and automated systems. Arnold placed human-machine interaction within a larger framework of "communication" and implied that engineers must understand *how they* *perceive and construct information and its implications for how people communicate with each other*—they require a basic understanding of human psychology that we understand today includes social practices. For example, in developing an automated system that operates in safety-critical situations such as hospitals and aircraft, we need to consider how people express urgency as well as how emotions need to be tempered.

Arnold explicitly calls for engineers to be trained in the literature and the fine arts so they might communicate in different ways, particularly to present their ideas. Historical academic divisions among science, art, and engineering continue to fracture what Arnold understood to be a coherent whole into specialized languages and tools, yielding a self-created recurring mystery, *how are these fields related?* Oxman (2016) asks this question in "The Art of Entanglement," proposing what he takes to be a new synthesis, which suggests that the work of Arnold, Fuller, and Maslow has been forgotten:

> This essay proposes a map for four domains of creative exploration—Science, Engineering, Design and Art—in an attempt to represent the antidisciplinary hypothesis: that knowledge can no longer be ascribed to, or produced within, disciplinary boundaries, but is entirely entangled.

To understand Oxman's quandary, recall Maslow's remarks about how dichotomization divides human experience and thus the self:

> …every human being is both poet and engineer, both rational and non-rational, both child and adult, both masculine and feminine, both in the psychic world and in the world of nature. Only slowly have we learned what we lose by trying daily to be *only* and *purely* rational, *only* "scientific," *only* logical, *only* sensible, *only* practical, *only* responsible.

These dichotomizations are the basis of university departments and definitions of the "disciplines"—so-called because they impose an order to what is observed and questioned, the language and vocabulary by which associations are made, and the techniques and values that guide predictions and actions. Reified in formal systems, which Hartman called "systemic values," such oppositions allow describing and relating complicated natural and artificial processes in causal stories and scientific theories. But formally separating "the psychic world and the world of nature"— as universities have traditionally separated the humanities from the sciences and engineering—obscures how human experience and nature exist and develop in systems that depend on each other, just as reason relates to emotion in the origin and expression of ideas.

Building on the same insights from psychoanalysis that influenced Maslow, Anthony Wilden (1987) presented a philosophical analysis of how "imaginary opposition" separates a system (e.g., a domain of activity, an intellectual field, a university department) from the environment that makes it possible. This dichotomization originates in the logic by which we name and relate our experience in the world, by which mental constructions become concrete and seemingly objective. We then identify these descriptions, stories, laws, and models (such as taxonomies), with reality. In particular, we are naturally mentally disposed to look for and name contrasts, forming dualistic theories (e.g., Descartes' distinction between the mind and body). We puzzle over how these distinctions that we have constructed in our imagination are related in the real world: reason vs. emotion, nurture vs. nature, science vs. art, design vs. science, science vs. engineering, theory vs. practice, and individual vs. society. Having fragmented our experience and being into these units, we may even argue strenuously in favor of one perspective over the other. In this discourse we flock to form sides and develop an identity by contributing to groups who represent and promote one facet of reality over another.

Crucially, something else happens in these oppositional ways of describing the world—by the very act of naming complicated systems as if they are *things*, we start thinking that they exist separately as two physical objects might. For example, we obscure how theoretical ideas develop in practice and are not merely applied or "reduced" to practice. People become sorted by their identity too, thus we have "tree-huggers" arguing with "environmental rapists." Journalists create and promote imaginary oppositions (e.g., contrasting "baby boomers" with "millennials") that are accepted because they are facile and imply that the world is well-ordered and predictable; interpreted as "opposing forces" they make stories intriguing and emotionally arousing.

Fortunately, Wilden's analysis has an important, structural aspect that enables reconciling the conceptual confusion: Rather than being separately existing parts, the oppositions we have named can often be ordered and understood as being different, useful levels for analyzing a larger "complex, open system" (Figure 1 below).

Levels in a complex open system form a dependent hierarchy, such that systems of increasing complexity (e.g., organic/living systems, science, theory) would not exist or reproduce without the more general environment (e.g., inorganic, engineering, practice). In Wilden's terms, they depend on it "for subsistence and for survival." Rather than either–or (Maslow's "dichotomization") or part–subpart (viewing system processes as objects), the relation of the environment/context and organized system within it is "both–and."

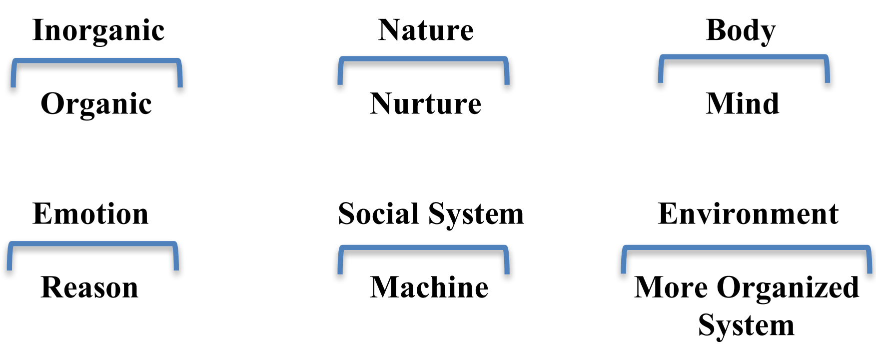

Figure 1. Common imaginary theoretical oppositions shown as dependent levels. An embracing, less-constrained system provides an environment that a more organized system depends on for its existence and development. (Inspired by Wilden, 1987, p. 82).

The mental bias to conceive oppositions is similar to (and possibly neurologically related to) the nature of figure–ground illusions: "Many of the perceptual blocks arise out of the problems associated with what the psychologists call the *figure-ground* relationships" ("Factors Influencing Creativity," p. 89). Here the figure (an organized system) exists because of the ground (the environment). In a proper analysis, one must conceive a larger system, a dependent hierarchy in which the taken-for-granted environment (e.g., a social system) becomes a thing that is creating and sustaining the more organized system (e.g., automation). In a work system design this larger complex is called a "socio-technical system": *the work system is both social and automated.*

With respect to the individual's experience in achieving such an understanding, recall that Hartman called the both–and relation between the self and the created object or idea "compenetration"—"The unity and structure he sees in what before him seemed an unrelated heap of items is really the unity and structure of his own self…. one not only *creates* something, one *becomes* something as well" (p. 167). The creation only exists because of the creator, but he or she "becomes themselves" by the process of creating it. The result is both personal and apart from the self.

We can apply this analytic perspective to answer questions like "what is the relation of science and design?" (Figure 2). Designing inherently requires scientific reasoning/methods which inherently involve forms of art (craft, skill, technique). The folk tendency is to oppose these relations or not realize they exist in one person within a single activity. The comprehensive designer is called upon to know the world holistically, as feeling and fact together, in a relationship that is both rational and intuitive-emotional, critically probing, while at the same time sensitively aesthetic.

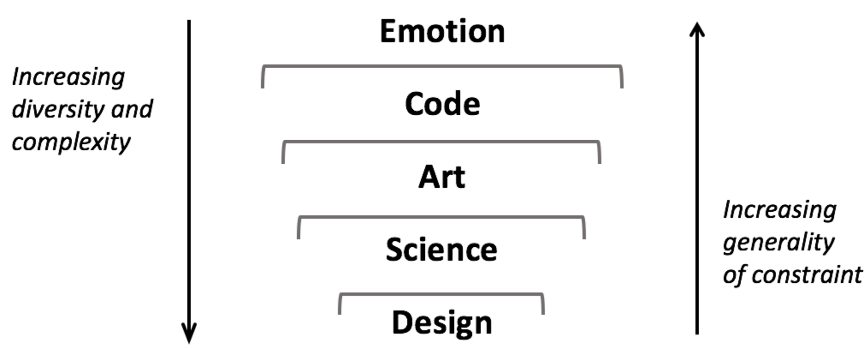

Figure 2. The dependent hierarchy relating design, science, and art. Systems of design depend on systems of science and art, which depend on mental systems of codes and emotional expression.

To elaborate the diagram levels in a bit more detail, from the most complex to the more general and less articulated:

- *Design:* Requires science to understand needs, values, materials, and the environment, as well as to experiment for durability, fit, sustainability, etc.
- *Science:* Develops within our expressions of interest, concern, curiosity; it requires artistic sensibility and activities.
- *Art:* Skills, techniques, media by which we express aesthetic sensibility; it requires "codes" for expressing feelings, perceptual relations, and meanings.
- *Code:* Analog, Digital, and Iconic schemes/systems—constituting *information* (coded sensing), *meaning* (coded information), and *signification* (coded meaning) (Wilden, 1987, p. 225)—are the context for expressing emotions (art).
- *Emotion:* The context, an evaluative basis, for categorizing and formalizing differences and distinctions (coding).

We can better understand these entangled systems by the dependent hierarchy diagram. During the overall human activity we call "designing," *each level is always operating* to constrain how attention and intentions, how we express ourselves, techniques, etc. An environment (less diverse, less organized system) serves as a constraint in the sense that it is a resource, a source of guidance and orientation. Proceeding from more general to more organized, designing is affected and organized by feelings, values, beliefs, conceptual systems, methods, notations, calculi, etc. Each level serves as the basis of more organized systems that further constrain motives and functional relations. [22] Consider for example the relation of the emotional expression in a symphony, the musical notion, the orchestral score, the layout of the instruments on the stage, and the scientific principles used to design the concert hall. These are all part of the activity of an evening's musical program.

In summary, the folk opposition of art and science is imaginary, the relation is both–and. Science depends on systems of art, and both involve coded communications and emotional experience. "Art" as the context for science includes for example graphic representations that are an integral part of scientific modeling (e.g., drawings of plants, ethnographic photographs, the double helix). From another perspective, art depends on ways of seeing—both observing nature and visualizing relationships—that are required for science. More generally, scientific investigation requires skills for perceiving, conceiving, expressing, and representing the world that are not reducible to codes (e.g., rules, procedures, facts). Rather tacit knowledge, "know how," is part of the art or craft of the scientific discipline. In engineering, such craft includes using instruments or prototyping tools; in software engineering it is called "the art of computer programming." The art of scientific exploration includes organizing and creating data visualizations and compelling scientific articles and talks.

Imaginary Oppositions Manifested as Cultural Blocks in Organizations

In the common parlance and thinking of laypeople and professionals alike, the more developed, organized system (e.g., mind, nurture, reason, science) in a dependent hierarchy is viewed as superior and dominating or controlling the system that makes it possible, such that mind controls body, nurture controls nature, reason controls emotion, science controls engineering, and so on. This section explains and gives examples of how such dualistic thinking, a product of descriptive dichotomization, has shaped the epistemology of universities, instructional practice, and scientific theory itself.

When institutionalized as named disciplines and methodologies, systemic value, by virtue of being equated with rigor, may be claimed to dominate intrinsic value and become the basis of social status. For example, the American Association for Artificial Intelligence in 1986 institutionalized an imaginary opposition by separating the conference proceedings into two volumes labeled "Science" and "Engineering," the former being more mathematical, formal, and theoretical, while the later was viewed as "soft" and "applied." Conventionally, the term "hard science" is interpreted to mean both more *rigorous* and more *difficult* to do, hence it is assumed to be a greater accomplishment and superior. By this way of thinking, real scientists create and use mathematical models; soft scientists create only taxonomic classifications and causal histories. Such sorting of the AAAI's research with its implied value distinction was destructive to the intellectual program and would have impaired the creativity of the community if it had not been discontinued the following year.

Still the battle between rigor and the imagination persists (Wilder-Mott & Weakland, 1981). In a related organizational maneuver, NASA, one of the most respected R&D organizations, separated its space enterprise during the first decade of the 21st century into three regimes of activity and financial control called "Directorates": *Exploration Technology* (e.g., spacecraft and rockets), *Science* (i.e., planetary missions), and *Human Spaceflight* (e.g., the Space Shuttle and International Space Station). Any smart high school student might be appropriately puzzled over how these enterprises could be pursued independently: Wouldn't sending people to Mars require planning and inventing new tools for scientific work? Are spacecraft designed without concern for people onboard? Aren't rovers on Mars using exploration technology? Having created these silos of activity and funding, how would projects bring together the appropriate multi-disciplinary expertise? Managers, scientists, engineers, and astronauts recognized the problem and held a workshop in 2008 called "Humans and Robots in Exploration" to attempt to define a more coherent program.[23]

NASA's difficulty in naming its activities in space reflects the difficulty in our culture of giving equal standing to the intellect and emotion. For fifty years NASA has had four enterprises: astronauts working and living in space (human spaceflight), robotic spacecraft used to study the Earth and other planets (planetary science), advanced aviation research (aeronautics), and technology development. Human spaceflight and rockets are undeniably exciting, and many people feel that going into space is fun, adventurous, and inspiring. But feelings, even when articulated as "realizing our potential" and "society at its best," are not sufficient to justify a government program that annually costs billions of dollars.

Accordingly, as of this writing an alternative intellectual framing has been adopted to rationalize our emotions, to make our wishes and desires seem reasonable: Living and working in space is characterized as being "Exploration," meaning in the words of *Star Trek*, "going where no man had gone before." The *Human Spaceflight* organization has been renamed *Human Exploration and Operations Mission Directorate*. Science missions undertaken with spacecraft didn't require any further justification, but for parallel form *Science* has become *Science Missions Directorate*. Meanwhile, with "exploration" now identified with people and "technology" pertaining obviously to both rockets and spacecraft, *Exploration Technology* has been renamed *Space Technology Directorate.*

The "exploration vs. science" dichotomy puts human spaceflight and planetary science missions on an equal footing, serving an organizational purpose. But it is an imaginary opposition, which is certainly not clarified when we say that rovers are exploring Mars. Understanding the role of exploration in scientific inquiry, how scientific theories direct exploration—and that scientists are exploring Mars using the collaborative tool of a robotic laboratory—is the realm of cognitive science and sociotechnical analysis (Clancey, 2012), which lies largely outside the expertise of rocket scientists and space scientists. Until NASA and politicians properly accept that the poetic, romantic aspect of space flight *is justification in itself because it is an intrinsic value*, until they can speak with daring and integrity for the whole man "in the psychic world and in the world of nature," they will continue to rename and reorganize people and activities in a vain attempt to intellectualize everything.

These distinctions among perspectives and interests are of course more than conceptual, they are politicized in institutional status that affects awards, promotions, and allocation of resources. Certainly, an organizational structure is necessary for managing a university or government agency. But rather than conceiving "people, science, and technology" as analytic perspectives involving mutually dependent enterprises (e.g., rovers enable people to do field science on Mars), leaders allow a value system to develop in which momentarily useful ways of analyzing the world and organizing projects are allowed to become enduring centers of power and funding.

Particularly striking is the fate of Human-Centered Computing (HCC) at NASA during this period of reorganization. Following the principles of comprehensive design, HCC scientists and engineers study and develop the total system, including the environment of organizations, roles, procedures, tools, and facilities by which automated systems such as robots operate (e.g., see Clancey et al., 2005). Proponents of "machine autonomy" talk about putting a "human in the loop." But this is the classic imaginary inversion that views the more organized, created system (the automation) as an independent agent, having an existence apart from the environment that makes its operation possible and meaningful. HCC frames the problem the other way—the actual news is that we have a "machine in the loop."[24]

Circa 2000–2015 NASA Headquarters' evaluation of budgeted activities replicated this machine vs. social system opposition. In the Intelligent Systems Division of NASA Ames Research Center "Autonomy and Robotics" research was taken to be the forefront of innovation, better fitting NASA's identity than Human-Centered Computing. By assumption HCC was not about technology but merely about "operations"—matters that supposedly could be addressed once the new inventions are ready for developing interfaces, training, and testing—following the technology-centric method McKim criticized in 1959, "Once the design is partially 'set'…the designer will often begin to consider man the variable." Consequently, Autonomy and Robotics projects dominated management attention, funding, and coverage in the media. The mistake was not in identifying these different professional perspectives, but viewing the organizations as being in opposition, competing for attention and resources, rather than as groups of specialists who needed to work on projects together to develop comprehensive, socio-technical designs of human–robotic systems.

While the funding programs that managers devised were inhibiting how scientists and engineers collaborated within the division (so aptly named), Autonomy and Robotics researchers were amazingly enough promoting having robots collaborate with people. A highly funded "peer-to-peer human-robot interaction" project focused on "developing techniques to improve task coordination and collaboration between human and robot partners" (Fong et al., 2005). Partnership with HCC researchers down the hall was not included. This is not the fault of the individual researchers so much as the culture of the engineering organization that made technology the "figure," blazoned with the agency logo, and people the "ground," behind the scenes like the Wizard of Oz—and AI researchers now puzzled over how to put these parts back together, for people and robots to be "partners." This anthropomorphic theme persisted for over a decade—in 2015 another workshop was held to resolve the self-imposed imaginary opposition, "Astronauts and Robots: Partners in Space Science and Exploration."[25]

Hartman characterizes such conceptualizations as inversions of Intrinsic and Extrinsic values (see the table "Value Compositions and Transpositions," p. 185). Otherwise high-valued poetic craftsmanship that expresses intrinsic values in extrinsic terms ($\mathbf{I^E}$) is inverted in the *language dimension* by "metaphors taken literally" (I_E) (e.g., believing that a robot that reacts to commands is a "partner") and in the *subject dimension* by viewing "individuals as functions" (e.g., reducing people to operations that complement and are defined in terms of robotic actions, such as monitoring automation). In defining "creativity as the capacity of translating the extrinsic into the intrinsic" (p. 182), Hartman is appealing to the engineer to relate language back to personal reality, to realize who is a *partner* in his experience (e.g., a spouse, a golf buddy, a close colleague) and how that *mutual* feeling, relation, and way of being (compenetration), differs from a person's relation to a plane's autopilot system, the Google search engine, or a self-driving car. Engineering human-automation systems that have holistic integrity must begin with self-knowledge and broad recognition of human values; as Hartman states, "The true seeing of everyday things is a model of creative activity." Or as McKim summarized, "One of John Arnold's requisites for the comprehensive designer is that 'He must understand man.'"

Arnold almost certainly experienced similar conceptual confusions and power struggles in MIT's Department of Mechanical Engineering in the 1950s when he promoted a holistic, human-centered design approach—"a more comprehensive picture that, in turn, relates back to some basic need of man" ("Factors Influencing Creativity, p. 87). Realizing the institutional headwinds to resolving departmentalized, oppositional, reductionist, and linear thinking that persists today, we can appreciate all the more the significance of Arnold's initiatives and the courage of his persistence in leaving MIT to develop a new program at Stanford, where he was emboldened perhaps by the nascent spirit of Silicon Valley and proclaimed a Design Division by fiat.

In summary, the most serious blocks to creativity are both cultural and emotional: Society provides rational frameworks that individuals adapt for "disguising [wishes and fears] from conscious awareness to make things less threatening," and these interpretations may contribute new language and models for society to adopt. The problem is not that we order our work into research programs, but that separating people into organizations and budgets defined by specialization and analytic method reinforces individual suppression of the unconscious and thus distorts how creative problems are framed. Perhaps most seriously, these blocks affect who is allowed to participate and what knowledge is called into play. Furthermore, authority structures in large organizations are inherently conservative; managers have responsibility to provide resources for their group, and protecting what a group already controls limits change.

Focusing on people and their individual growth to benefit society, Arnold sought to transcend cultural blocks, which he characterized as resisting the conformity of "the herd" ("Factors Influencing Creativity," p. 78). If we wish to solve challenging problems, Arnold suggested that we must begin with how we treat each other, respecting personal growth (which requires respecting intrinsic values), a point he explains in discussing rules for brainstorming ("Useful Creative Techniques," p. 108):

> If all members of an organization were encouraged to think as daringly as possible, without fear of immediate evaluation or possible ridicule, and without fear of making a mistake, I can't see but how the company would benefit…. If all members of an organization could be treated as individuals with dignity and integrity, but with varying potentials, and their evaluation were based on to what degree they had realized their own potentials and their actual tangible accomplishment, rather than on what they said,

> psychological freedom and safety would in part be insured and the number of new and better solutions to old problems would rapidly increase.

Dealing with institutionalized ignorance as a member of an organization requires courage, hence Arnold's pedagogy of creativity includes increasing the student's confidence and self-respect (Arnold, 1953). By emphasizing the challenges of "creative problems," admitting multiple solutions and not solvable by optimization equations, Arnold brought science and art into engineering, so it wasn't just about the "graphical, mechanical, analytic methods of kinematics" and a rational approach to designing machine elements. These methods are necessary and were taught in Stanford's Design Division, but technical ways of thinking (systemic and extrinsic values) are not sufficient.

More generally, as Arnold advocated, we need to teach scientists and engineers how the mind works: Theoreticians and designers alike need to be aware of how oppositional thinking arises naturally in how verbal conceptualization works—categorizing by an either-or logic of taxonomic distinctions, objectifying systems as part-whole hierarchies, and describing processes in linear causal stories. The art of asking good questions in problem solving involves recognizing dichotomies in our thinking and analyzing systems holistically. Indeed, pioneering scientific advances in the past century, particularly in biology, ethology, environmental science, psychoanalysis, and the social sciences, are based on a systems thinking framework that emphasizes processes, feedback, and complexity (Clancey, 2008).

Comprehensive Design Theories, Tools, and Collaborations

Design methodologies have developed considerably over the past 60 years as psychologists, social scientists, and computer scientists now routinely collaborate in engineering design projects, enabling disciplinary theories and methods to blend, like stars revolving around each other to create a single system. We can characterize the extent to which Arnold's initiatives have been realized and refined in terms of what seems insightful and fresh today, what was incomplete and often required many decades for engineers to understand and incorporate, and what has been de-emphasized over the years and might merit reconsideration.

Arnold certainly did not view his presentation on creative engineering as being the final word. For example, in his graduate-level courses he tried to keep lectures to a minimum, devoting time to discussion and "group ideation" (1955b, p. 8):

> … to dispel any idea that there are experts in the subject of Creative Engineering, and that there are firm and fixed roles that cannot be challenged. I want them to learn to question, to observe closely, to associate their ideas and then to predict, stick out their necks, to come up with a solution to a problem that they think is better than any previous solution to the same problem.

Arnold repeatedly states that the methods he presents for improving creativity "should be frequently reviewed to see if there aren't ways and means in which it can be improved and made more effective and productive" ("Useful Creative Techniques," p. 112). Consequently, many of the reflections we may make about how design methods have changed are not limitations in Arnold's work—rather than espousing a fixed design method, his message was how to be creative engineer, emphasizing how to be a continuous learner. Given this, what is remarkable is how long it takes for new insights and techniques to be reformulated, articulated, documented, assimilated, and put into practice.

Methods we view as essential today developed 30 or more years after the initial focus on design engineering in the 1950s. For example, Arnold clearly emphasizes the importance of problem description: "The words that you use in defining the general problem have to be chosen very carefully so that the referents of these words or their connotations do not limit the thinking of the designer to whom you assign the task" ("Factors Influencing Creativity," p. 81). When Donald Schön articulated this caution in 1979 as "problem framing," it seemed to AI researchers to be a radical new idea. It sharply conflicted with how problem-solving processes were modeled in computer programs, in which experimenters pre-described the problem to be solved by human subjects whose behavior the programs were designed to replicate (e.g., see Kintsch et al., 1984). In this information-processing paradigm, pre-digested "givens" are the "input" provided to people and to the program. Computational models framed in this way focus on transformations between inputs and outputs and thus obviate the creative work of formulating a problem to be solved. The effects of perceptual, cultural, and emotional blocks in problem framing are never encountered.

The radical change in academic and corporate R&D during the past half century involved major changes on many levels of the design ecosystem. Scientific fields intermingled as relations were sought among theories of the brain, reasoning, and social behavior (e.g., the Cognitive Science Society was founded in 1979; the Association for Psychological Science in 1988):

- A socio-cognitive theory of thinking and work emerged that revealed dynamic relations among use of tools, problem solving, and learning.
- Different scientific and engineering disciplines began to relate their interests and capabilities in multidisciplinary team projects.
- A revolution in miniaturized, networked, and affordable computer technology enabled new forms of modeling, documentation, and sharing.
- Businesses forged "contextual design" project partnerships with research institutions, building on integrative theories and technologies for defining problems and experimenting with prototype solutions.

A broad socio-cognitive theory of creativity was known in the 1950s but it took several decades for the ideas to mature and spread, reshaping institutions. Notably, Stein (1955, p. 172) expressed the dynamic as well as anyone might today: "Creativity is the resultant process of social transaction. Individuals effect and are affected by the environments in which they live. They do not interact with their environments without changes occurring in both directions." The notion that "experience is a transactional situation involving an organism and its environment" (Westbrook, 1991, p. 497) had been promoted by John Dewey since the 19th century.[26] Yet according to Stein, rather than conceiving a bidirectional process, sociologists in the 1950s viewed social matters as "factors in the environment which facilitate or obstruct creative developments" (p. 171), such as Arnold's cultural blocks. Relating the mind and society required more nuanced theories of cognition, learning, and identity, and this required advances in both psychology and social science, facilitated by adding anthropologists to the research team.

In view of this general and dominating disconnect between psychological and social theory which persisted into the 1980s, it is fruitful to reflect on the radical changes that have occurred in R&D and what cultural blocks had to be overcome to reach today's understanding and methods. In this section I survey how design theories, tools, and collaborations have changed. In the following section I describe the social context that made it difficult for the "social transaction" perspective on learning and innovation to be assimilated in psychological theory and the workplace, and how the conceptual blocks were overcome.

From a practical engineering standpoint, one of Arnold's important contributions was conveying that *designing is a process*, a perspective very much front and center in the workplace today. He would likely recognize and be pleased by engineers' concern with "look and feel," "human-centered design," "sustainability," "total system design," "adaptability," and so on. Yet the pace of cognitive science and computer technology (and the combination of these in automated "intelligent systems") has fundamentally changed how designing occurs, which someone from the 1950s might view as amazing. Computer technology has radically changed how designs are created, developed and tested, and documented. Consider especially the basic orientation around paper: Arnold could only draw diagrams on paper, he required film and printing to create and share photographs, and typed (or typeset) all documents on paper. Research occurred in libraries, computer simulation involved only numeric equations, animation was the stuff of Disney celluloid painters.

How we design and who is a designer have been transformed. Every aspect of design from sketching, computing forces and quantities, and even manufacturing has been completely transformed. Modeling and visualization tools now enable anyone to create three-dimensional drawings and even "print" 3-D parts from them. Today people in different organizations and countries collaborate by simultaneously or asynchronously reading and writing electronic documents; they may develop and design systems without ever meeting. Rapid-prototyping technology has added "Experiment, Evaluate, and Iterate" to Arnold's problem-solving steps (related to "Verification," Osborn's last step [1953, p. 125]).

Cognitive science studies of the human brain, thinking, problem solving, and the design process have advanced a great deal since the psychology of the 1950s (e.g., see Lave, 1988; Clancey, 1997; Greenbaum & Kyng, 1991). Today we view problem solving as being dynamic, interactive, iterative, in short, a *behavior*, not something going on exclusively inside individual brains. Many educators follow Dewey's transactional perspective—being creative is an aspect of *inquiry*, which is inherently a give and take, "thinking-in-doing" process (Schön, 1987). Rather than ideas forming in the mind and coming out fully formed, ideas develop in our "conversation with materials" (Bamberger & Schön, 1983). All our speech, drawings, and conceptions are constructed in our activity ("bricolage"; Turkle & Papert, 1991)—we change the world, re-perceive it, reframe our conceptions, and manipulate our materials, drawings, and speech again. Ideas form dynamically within activity as we speak or write, draw, gesture, perceive; creative conceptions and designs emerge in our interactions (Clancey, 1997). Paralleling this improved understanding about the relation between what Maslow called the "primary processes" and actions in the world, neuroscience is catching up with the psychiatry of the 1950s. For example, Damasio (1994, 2010) has developed a neuropsychological theory that seeks to unify reasoning and feelings.

Anthropologists today are no longer exclusively studying Third World cultures; "Business Anthropology" (Deutsch, 1991; Garza 1991) has brought ethnography to the modern workplace and made social scientists part of the design team (Salvador et al., 1999). Organizational fluidity and more frequent travel makes the worker/user part of the design team in "participatory design" (Ehn, 1988) and brought scientists, programmers, and engineers to the workplace to learn about that world through "participant observation" (Spradley, 1980).

We build systems of systems with multiple teams (e.g. Clancey et al., 2005), and so the idea of individual creativity has become less central. We have multidisciplinary teams with "interstitial" people such as computer scientists who practice ethnography working with linguists and anthropologists in designing mission systems (Clancey, 2012; Linde, 2006; Wales, 2007). In such joint projects, we learn each other's language, points of view, and methods, all of which is brought to bear in comprehensive design.

Arnold's program for creativity straddles two approaches for achieving this integration of perspectives. On the one hand, he states that it is preferable for a single person to have knowledge of many disciplines, a "renaissance man" ("Creative Product Design," p. 128):

> To be fully versed then, in the various levels of communication he must know a great deal about psychology, sociology, group dynamics, experimental psychology, cybernetics, servomechanisms, and feed-back control problems. You see, there is almost no end to the variety and to the quantity of information that this rare individual must possess.

On the other hand, Arnold appeared to recognize that this unbounded requirement of rolling everything into one person was unlikely and perhaps so rare as not to constitute a practical approach for integrating knowledge and skills. Besides a polymath "comprehensive designer," he also proposes that specialists learn to cooperate on a "comprehensive goal" (p. 118):

> There always has been a need for experts in limited fields and that need is growing; but the expert in greatest demand is that one who can see his specialty as part of a much greater, broader picture and who is capable of cooperating with other specialists in the attainment of a comprehensive goal. This latter is one of the prime purposes of this two-week course and is certainly basic in my instruction of young engineers.

Thus, the issue was not creating people who knew everything, but rather *integrating very different perspectives during the design process*, relating explicit and implicit needs of people ("What is Creativity," p. 66, emphasis added):

> The expressed needs are those associated with man's physical environment, food, clothing, shelter, communication, and transportation. Attempts to satisfy most of these needs are being made by engineers or men with special technical training. *A still better solution can be arrived at, however, if somehow some of the implied needs of man can be given consideration at the same time the more direct expressed need is being investigated.* The rapid rise of the industrial stylist verifies this thesis as does the growing importance of the "Human Engineer." The ideal situation would be to have in addition to a few specialists in the various fields, a greater number of men who have fundamental training in and knowledge of a number of related fields. This person is the "Comprehensive

> Designer" and as Bucky Fuller first described him, he is "the emerging synthesis of artist, inventor, mechanic, objective economist and evolutionary strategist."

Possibly with his strong focus on the individual growth, Arnold wants to ensure that every engineer is encouraged and enabled to become a comprehensive designer ("We probably don't need a great many of these men, but let's hope we get some"; 1956b, p. 23), although more realistically he encourages everyone to learn other analytic and design perspectives.

Indeed, superhuman capability is not necessary today because Arnold's vision of disciplinary blending has succeeded within R&D projects themselves—one's identity as a team member transcends the label conferred by formal education. New design tools developed by and for interdisciplinary teams, such as Brahms (Clancey et al., 1998; 2002; Sierhuis & Clancey, 2002), enable formal and informal aspects of work practice to be described and modeled so interpersonal and human–automation interactions can be better understood and reconfigured. Working together in teams has replaced the need for "fundamental training" in multiple fields; mutual learning occurs in practice as individuals contribute their own expertise in one or more aspects of observation, modeling, analysis, design, prototyping, and empirical experimentation. We retain our identities as specialists, but over time learn and contribute to the methods and theories of other disciplines.

Yet, more than half a century after Fuller and Arnold promoted a comprehensive approach, a study of engineering students has shown that creative engineering is impaired by university curricula that promote intellectual silos (Downey & Lucena, 2003, p. 168, emphasis added):

> This ethnographic study explores how engineering students in a traditional senior design course interpreted design assignments in terms of the engineering sciences. *These students, who had been taught to value the distinction between `science' and `design,' tended to resist design education. They had learned to think about design as a trivial extension of mathematical problem solving.* This predisposition made it difficult for activist faculty to convince students that design introduces entirely new learning issues. Although limited in scope, this study suggests that for reform in engineering education to be successful, it may need to go beyond engineering design to rework teaching in the engineering sciences as well.

The problem is uncanny—not only is the resistance Arnold faced among the MIT faculty recurring, these students have assimilated the "science vs. design" imaginary opposition and resist attempts to convert them from analytic problem solvers to inquiring designers. Further echoing Arnold's emphasis, the students don't know how to communicate and hence are hindered in working collaboratively (p. 175):

> Students' understanding of people skills or communication skills are rarely about listening, about encountering perspectives other than their own and figuring out how to work with them. They do have some sense that more is involved in working with other people…. Engineering students develop no resources for conceptualizing or implementing an approach built on listening rather than on presenting.

The students have not yet learned to be someone "who can see his specialty as part of a much greater, broader picture and who is capable of cooperating with other specialists in the attainment of a comprehensive goal." Downey and Lucena are implicitly promoting a design methodology that incorporates participatory design (the customer joins the design team) and participant observation (the designers join the customer's team). Arnold's notion of communication emphasized presenting personal ideas; today the emphasis is on listening and learning other perspectives.

Communication is inherent throughout the design process in working with other people, a key point not mentioned in the Creative Engineering lectures. We observe and question the people and the world where our inventions must fit; we engage directly with them. The Arcturus IV intergalactic traders were at a distinct disadvantage in not being able to meet with the Methanians; learning about the planet and beings by written memo alone (somehow violating the limitations of light-speed travel) reflects how scientists and engineers were in different teams, and literally light years distant from the beings they sought to benefit.

Personal Development in a Team—The Challenge of Groupthink

A strength of Arnold's presentation and the invited lectures is how they lead us to reconsider the role of personal growth in improving creativity in engineering design. As Carleton and Leifer (2009) explain, the focus today in teaching product design is on teamwork and the characteristics of successful teams. Thus, a central challenge in our learning from the Creative Engineering seminar is to determine what the presenters understood about people as individuals that we may have neglected or de-emphasized, and secondarily, what we have learned that could improve the 1950s analysis.

In this section, we will see that in Arnold's analysis of creativity the relation of the individual to the group was incomplete and somewhat contradictory. The opposition of the "individual vs. society" was driven at the time by the Red Scare, which equated group activities with conformity, particularly groupthink, and loss of personal integrity. However, by reinterpreting the insights of *Creative Engineering* in terms of what we have learned since then about the social and cognitive nature of activities, we can apply a both–and analysis to construct an integrated model of *personal development in a team*, exemplified by recent analyses of culture in successful corporations.

To recap the point made above, Arnold advocates teamwork when he explains how product design projects require and promote multi-disciplinary collaboration ("Creative Product Design," p. 115):

> Creativity provides a common meeting ground for diverse specialties, it supplies a common experience on which to base a language for communicating our ideas to one another…. Product Design provides an almost perfect vehicle for experimenting in the effectiveness of bringing people of diverse backgrounds together in a creative effort. The scientist, engineer, artist, philosopher, psychologist, sociologist, anthropologist, salesman, and advertising man must contribute their know-how to insure a successful product development.

Arnold acknowledges that "most often this will be done as a team," and to facilitate cooperation, he advocates that specialists become competent in multiple aspects of engineering at least (p. 118). But his ideal is for some rare individuals to be competent in multiple disciplines: "it is hoped that occasionally we can develop a person who is familiar with all these fields, the comprehensive designer." Why did he stress individual knowledge and creativity, and why today do we stress instead the team's configuration and practices (Carleton & Leifer 2009)?

Arnold's remark that the "creativity [referring to the creative process] is the common meeting ground" for multidisciplinary collaboration relates directly to our perspective today that collaborative activity promotes learning. However, for Arnold creativity is a *property* of a person; it is a trait, something we inherit, realize in our work, and can also strengthen. His emphasis is on the development of individual potential. Today we would adopt a social-psychological, interactive perspective on *learning to be creative*, and thus view the activity of "being creative" as a dynamic *relationship* of the person and the social environment. Consequently, we focus on the collaborative process and how it promotes learning:[27]

1. *Our capabilities develop within activities*, including everyday behaviors (cooking, doing chores), recreation and social events (reading, attending a lecture), and of course employed work. All human activities are inherently social in character; that is, our actions develop and are conceptually ordered with respect to roles, purposes, and norms of groups in which we are participants (even when alone).
2. Specifically, individual creativity develops within activities, including designing and making products and services. As skills are expressed in action, proclivities and talents can be recognized and guided. Hence *creativity develops by participating in social organizations*, including design teams.
3. In particular, by working repeatedly with specialists in other fields we will learn how they see and model the world and their methods for working. Therefore, *becoming a comprehensive designer requires being able to work with specialists in other disciplines*.
4. Thus, we must formulate design teams such that (to paraphrase Arnold) "the scientist, engineer, artist, philosopher, psychologist, sociologist, anthropologist, salesman, and advertising man *can* contribute their know-how." Everyone must be a full member, which means *having the opportunity to develop a niche, a role and style of participation in which the individual's capability can be realized, that is, creative potential becomes a tangible contribution.*
5. Hence teams can accomplish the objective of comprehensive design by providing a place for individual action and growth. In part the team provides an identity for the individual, and in part the team is created by individuals realizing their identity. *Just as the "self" is constructed within (social) activity, the team develops its creative potential through the joint action of individuals, becoming a "collective brain."*

In this both–and synthesis the individual is not placed in opposition to the group, rather the individual worker only exists (in such an activity) because of the team, and the team only exists because of the individual contributions. They are dependent on each for learning, creativity, and effective action.

As mentioned previously, these ideas were articulated in a strikingly similar manner by John Dewey more than 125 years ago. A pragmatist, he applied a biologically inspired, dynamic notion of the "organism" in living systems for understanding development of people and communities (Menand, 1992):

> Philosophy since the Greeks, Dewey thought, amounted to a history of efforts to establish, in the interests of similar class preferences, the superiority of one element over the other

> in a series of false dichotomies: stability over change, certainty over contingency, the fine arts over the useful arts, what minds do over what hands do.

He railed against the notion of society being merely a collection of atomic "individuals" who somehow existed apart from it. Rather the relation is a both–and dependency in which the society provides the environment for the existence and survival of the individual:

> "The non-social individual is an abstraction arrived at by imagining what man would be if all his human qualities were taken away," he wrote in "The Ethics of Democracy" in 1888. "Society, as a real whole, is the normal order, and the mass as an aggregate of isolated units is the fiction. If this be the case, and if democracy be a form of society, it not only does have, but must have, a common will; for it is this unity of will which makes it an organism."

He advocates a both–and perspective by which the individual in a democracy has responsibility for finding a fit within social purposes and activities, called "the collective will" (emphasis added):

> Dewey did believe in individuality; he just thought that *genuine individuality is achieved through the collective will rather than in opposition to it.* He regarded it as the purpose of societies, in fact, to provide the means by which people can achieve "the fullest and freest realization of [their] powers" [Ethics, 273]: When an individual has found that place in society for which he is best fitted and is exercising the function proper to that place, he has obtained his completest development, but it is also true (and this is the truth omitted by aristocracy, emphasized by democracy) that *he must find this place and assume this work in the main for himself.*

The role of the individual's thinking and participation is particularly emphasized in Dewey's (1899) theory of learning:

> All that society has accomplished for itself is put, through the agency of the school, at the disposal of its future members. All its better thoughts of itself it hopes to realize through the new possibilities thus opened to its future self. Here individualism and socialism are at one. Only by being true to the full growth of all the individuals who make it up, can society by any chance be true to itself.

Westbrook (1991, p. 58) tells us that "To moral reformists in the 1880s and early 1890s, 'socialism' was a fuzzy term referring to 'the principle of association or cooperation in economic and political life' and by no means implying state ownership of the means of production, to which most were opposed." But Dewey's dynamic, systems-thinking philosophy relating growth of individuals and society as a unity was not always grasped, and could be interpreted as advocating an alternative political system, "He told his students that the class divisions of industrial capitalism were incompatible with the ethics of democracy" (p. 49).

In the 1950s, ideas relating the individual to the group were shaped by the Cold War, which was experienced by many in the West as threatening individual liberty and thought. For example, Whyte's (1952) Fortune article, "Groupthink" (a name he coined) begins by stating the concern:[28]

> A very curious thing has been taking place in this country—and almost without our knowing it. In a country where "individualism"—independence and self-reliance—was the watchword for three centuries, the view is now coming to be accepted that the individual himself has no meaning—except, that is, as a member of a group. "Group integration," "group equilibrium," "interpersonal relations," "training for group living," "group dynamics," "social interaction," "social physics"; more and more the notes are sounded—each innocuous or legitimate in itself, but together a theme that has become unmistakable.

Whyte refers to "social engineering" as emphasizing "manipulation of the individual into the group role." Groupthink is "rationalized conformity—an open, articulate philosophy which holds that group values are not only expedient but right and good as well." Under this influence a person is "incapable of any real self-determination of his destiny." Very similar, yet stronger remarks are made in Mowrer's (1955) "Return to Integrity" about conformity, communism, and collective thinking—"the trend of the age": "I refer of course to the trend towards a *herd state* of which the essence is the denial of supreme value of the individual" (p. 7).

Quoting Mowrer, Arnold (1955b) brings this back to creative problem solving: "Never urge people to do together what the self-reliant among them can do better alone." He elaborates:

> The most frightening example is the ever-increasing number of people who fail or refuse to recognize that the problem they are dealing with has more than one right answer, or what is equally alarming, to meekly accept the answer of the majority as the only acceptable answer.

He repeats his concern in every speech and publication, reformulating the threat as the foundational "cultural block": "Certainly the cultural trend at the present time that demands integration and adjustment to the group may do much to inhibit productive, creative thinking" (Arnold 1956a). In the Creative Engineering seminar, he says that "some people are becoming aware of the tremendous pressure that is being exerted on them to conform" ("Factors Influencing Creativity," p. 78). He quotes Steinbeck's somber appraisal:

> In our time, mass or collective production has entered our economics, our politics and even our religion, so that some nations have substituted the idea collective for the idea God…. Nothing was ever created by two men. There are no good collaborations, whether in music, art, in poetry, in mathematics, in philosophy. Once the miracle of creation has taken place, the group can build and extend it, but the group never invents anything. That preciousness lies in the lonely mind of a man.

Here "collective production" and "some nations have substituted the idea collective for the idea God" refers particularly to the communism of the Soviet Union and People's Republic of China; the generalized claim is that nothing creative has ever been accomplished by a team. Obviously, "the group never invents anything" contradicts Arnold's statement that teams are commonly how knowledge is brought together for product design. Yet, his orientation throughout is clear: "Creative Engineering, then, emphasizes the individual, the 'Uncommon Man.'" At best, we can say that practical, developmental relation of creativity in individuals and groups is incorrect in the *East of Eden* character's philosophy and incomplete in Arnold's exposition.

Concern about social pressures to conform and groupthink is certainly merited. For example, both of NASA's Space Shuttle losses were largely attributable to organizational managers suppressing crucial engineering insights by participants who were viewed as having minimal or no authority to make decisions (Vaughn, 1996; Columbia Accident Investigation Board, 2003). Analyzing examples such as the Bay of Pigs invasion, Janis (1972, 1982) suggested that alternatives are not fully voiced or analyzed in the presence of "a strong, persuasive group leader, a high level of group cohesion, and intense pressure from the outside to make a good decision" (MindTools, 2016). Besides affecting national and global decisions, groupthink may also affect creativity in student project design teams.

The five points of the social, developmental perspective outlined above refer to two related aspects of the individual, namely being *a creative contributor to teamwork* in particular projects and *a person whose potential is being realized by being a member of the team* over time. Arnold mentioned both, but it is the latter notion of personal growth that perhaps has been diminished over time by the emphasis on team dynamics, customer satisfaction, market competition, etc. In the opposition of "personal growth" and "teamwork" we find another fascinating opposition—the relation of life and work. In some respects, this dichotomy is the cause of continuing confusion about teams and individuals.

For Arnold following Fuller, personal growth meant especially becoming a comprehensive designer, merging knowledge of art, science, and engineering, such that "the expert in style will be inspired or encouraged to attain competence in the fields of function, performance, and cost, and that the engineer concerned primarily with strength and long life will attempt to broaden himself by gaining some proficiency in the other areas of design" ("Creative Product Design," p. 119). In business, personal growth is typically called "personal development," which in practice means training in courses that relate to company goals and functions, including "being a team player." In business, personal development means becoming more capable of meeting the company's requirements. That is, what is to be learned is defined by the company's mission, products and services, methods, etc.

Following Maslow, personal growth emphasizes developing one's *personal* potential, including talents and interests; these are innate but develop contextually in the service of the society. In 1957 Arnold proposed a program for personal development (1962a, p. 138) that he characterized as furthering "the education for innovation," that is, to develop an inventive problem-solving ability:

1. Know yourself as well as possible.
2. Carry a notebook and use it.
3. Ask yourself a new question every day.
4. Develop craftsmanship in your own field.
5. Develop creative avocations.
6. Provide permissive atmospheres for family and colleagues.
7. Develop a sense of humor.
8. Speculate and daydream.
9. Question, observe, associate and predict.

10. Read and broaden your own interests.

This practical, engaged-in-the-world notion of "personal" is often lost in a business world that distinguishes "work vs. life" and "work time vs. personal time." "Personal" in business means not pertaining to work, and "your life" means what's important to you as an individual versus the company. "Personal" implies something exclusively individual perhaps, having nothing to do with other people. "Personal life" occurs outside work; it's about your family, hobbies, recreation, and entertainment. "Work life" is a job; it's your duty and it is serious—any frivolity is incidental to getting the job done.

It should be clear in making these statements that the opposition of "work" and "personal" with respect to learning and development of talents is false: Working is a large part of a person's life, and a great deal of personal growth occurs through accomplishments and learning in doing one's job. The failure to see working as learning (learning-in-doing) follows in part from seeing work as mainly procedural, following rules and policy. As mentioned in the outline of social-psychological development, *acting (participating) is when growth occurs*. Working is inherently a learning experience, though it varies of course with the kind of work. When we are reflective in doing our job, we learn problem solving, self-efficacy, self-concept, trust, teamwork, and communication (Schön, 1987). Although team building is often "taught" at retreats where people run obstacle courses and the like, the metaphorical equivalent of climbing trees occurs in the workplace as people handle breakdowns, delays, absent workers, high volume, short-term deadlines, new regulations, special customer requests, and so on. A significant contribution of social science since the 1970s is revealing just how often creativity is required to do what from afar is viewed as routine work (e.g., see Wynn, 1991).

But just as the human-centered perspective has entered the engineering design process, in recent decades a more human-centered perspective has entered the business world. A good example is provided by the culture of Zappos, which began as an online shoe company (Leslie & Aaker, 2010). Hsieh, the co-founder, aimed to create an entirely new kind of company focusing on "culture and employee happiness…lives at work and outside of work merged…[they felt they were] part of a tribe." Crucially, the employees built the culture. To Hseih a successful business required happy customers and that required happy employees. For that to happen each employee needed to be active in advancing the culture. "Personal well-being and happiness were emphasized" by an in-house "life coach." Core values included "create fun and a little weirdness…be adventurous, creative, and open-minded…pursue growth and learning." Zappo's personal development courses included how to be a happier person. Arnold's definition of happiness similarly relates creativity and contributing to something larger than oneself:

> …it seems to me that the only conclusion that can be drawn is that to be happy one must be creative. One must make positive contributions to society, must maintain an achievement curve with an over-all positive slope if one is to be truly happy. This is one more good reason for why we should try to be creative.

For Hsieh happiness derived in part "from being part of a culture whose values match their own personal values." The "Happiness Framework" specified: "Perceived Control, Perceived Progress, Connectedness, and Vision/Meaning (being part of something bigger than yourself).” One employee wrote that she learned from working at Zappos that “any issue arising in life is a welcome challenge where I can learn and grow.”

Zappos’ business culture of personal growth is not unique. It is easy to find on the Internet similar advice and stories. Vrabie (2014) writes, “Personal development is something that permeates every aspect of our lives. It can’t be separated from our lives at work. And people want and need meaningful work that enriches their lives beyond their day-to-day tasks.” She describes personal development in terms of Maslow’s needs hierarchy: “self-actualization…*becoming the person they are capable of being.”*

Similarly, The Carnegie Plan for undergraduate education articulated by President Robert Doherty in the 1940s (Shaw, 2005, p. 7) is expressed at Carnegie Mellon University today in terms of continuous learning, including “creativity and intellectual playfulness moving beyond established knowledge and practice to create imaginative ideas and artifacts,” “self-confidence and resourcefulness necessary to take action and get things done,” “skills of independent learning, which enable them to grow in wisdom and keep abreast of changing knowledge and problems in their profession and the world,” and “the ability to communicate with other*s* on topics both within and outside their chosen field of specialization.” These educational objectives bear considerable resemblance to Arnold’s list of attributes of a comprehensive designer.

A recent study of what made teams at Google effective (Rozovsky, 2015) identified five factors:

- *Psychological safety:* Can we take risks on this team without feeling insecure or embarrassed?
- *Dependability:* Can we count on each other to do high quality work on time?
- *Structure and clarity:* Are goals, roles, and execution plans on our team clear?
- *Meaning of work:* Are we working on something that is personally important for each of us?
- *Impact of work:* Do we fundamentally believe that the work we’re doing matters?

“Psychological safety” is one of Arnold’s cultural barriers to creativity; it was highlighted by Rogers in his 1953 essay on creativity (Rogers, 1961, p. 357). “Dependability, structure, and clarity” relate to communication and coordination that make interactions predictable and efficient. The last two points are the essential aspects of intrinsic and extrinsic meaning: Does my work relate to what’s important to me? Does my team’s work relate to what’s important for society? Of course, the social impact must be personally important too, providing a motivating vision.

In summary, rather than opposing “personal” and “work,” which views the individual interests and team interests as antagonistic (requiring conformity or the “herd mentality” Steinbeck feared), we view the team’s culture from the perspective of an individual, that is, the person’s experience as a member of a team. At Zappos (circa 2009) this meant that the individual has responsibility for advancing the company’s culture. Roles and contribution within business activities create a person’s sense of identity—“Who am I?” is actually “What do I do well?” and that means “What makes me happy? What do other people value in being with me and in what I do?” By this perspective, personal growth is conceived by individuals in social terms and enabled by group needs and opportunities. Hseih understood that the quality of teamwork emerges in the quality of individual experience; increasing company capability emerges from the learning experience of individuals.

Interestingly, this perspective was known to Whyte (1952) in his analysis of groupthink, where he suggests that "participation" is promoted as "a sort of end-all quality":

> There is the frequent explanation, of course, that only by group participation is the individual's potential realized. But this is only a half-truth. Individual excellence must involve something more than a respect for the group and a skill in working with it. "The sphere of individual action," writes Bertrand Russell, "is not to be regarded as ethically inferior to that of social duty. On the contrary, some of the best of human activities are, at least in feeling, rather personal than social…. Prophets, mystics, poets, scientific discoverers, are men whose lives are dominated by a vision…. It…is such men who put into the world the things that we most value."

Russell's remark betrays a well-known confusion. In opposing "individual action" and "social activities," he implies that the vision of prophets, mystics, poets, etc. has no relation to their culture, society, or interpersonal experience in content or that these people weren't motivated by a tacit audience who later received their gifts. If this were so, if there were such a thing as "individual action" devoid of a social context, we would never know that these people had such experiences. Indeed, somehow these people communicated their experiences, and they were named and remembered with respect to cultural values as being prophecies, religious revelations, poetry, inventions, etc. Russell ignores as well the socio-historical and cultural origin of language, concepts, genres, and the media by which individuals express their ideas in tangible, perceivable, and ultimately shareable form.

That individuals have and express feelings and ideas, and may work for long intervals alone, is unmistakable and important, but none of that has been at issue. Russell's (1956) concern was the "cruel, oppressive and obscurantist" police state of Soviet Russia, which Whyte apparently interpreted as developing in America as a "constant admonition to harmonize and integrate" with the group. But they were also caught up in the groupthink of the Red Scare of the late 1940s and early 1950s. This dark vision so gripped them, they interpreted scientists' and educators' articulation of the social aspects of creativity and learning as if they were advocating communism. This identification is implicit in Whyte's writing but ultimately was brought into public discourse by Senator Joseph McCarthy's infamous hearings in 1954.

When Whyte says, "lone imagination [can be] worth a thousand graphs" and "man can be greater than the group," he is viewing importance as a *property* of individuals rather than a relationship; his evaluative scheme only exists in the imagination, viewing people as objects. Whyte (1952) didn't understand the dynamic aspects of human experience; he uses the term "dynamic" four times, but always disparagingly, as if it is not descriptive, but a rationalization for conformity. His treatment of "social" is similar. Although we can draw lines around the people, the team, and the organization viewing them as objects, what happens in practice—the activities, the language and communications, the ideas and interactions—is emergent and interpenetrates in ways that are not causally linear but dynamic, pervaded by feedback and learning, with each level adapting to and influencing the others.

To Whyte's credit, he concludes with prescience and balance, acknowledging the contributions of a social perspective and advocating an appeal to openness and respect for individual contributions, in words somewhat similar to those expressed by Zappos and Google today:

> The answer is not a return to a "rugged individualism" that never was. Nor is it a slackened interest in social science and "human relations." We need, certainly, to find ways of making this bewildering society of ours run more smoothly and we need all the illumination science can give us to do it. But we need something more. Lest man become an ethical eunuch, his autonomy sacrificed for the harmony of the group, a new respect for the individual must be kindled. A revival of the humanities, perhaps, a conscious, deliberate effort by the corporation not only to accommodate dissent but to encourage it — possible approaches to a problem so fundamental cannot easily be spelled out.
>
> Only individuals can do it.

The intention is good, but an either–or mentality will not succeed in properly relating the individual to society. In human beings, the relationship is inherently both–and. Whyte should have concluded, "Only by respecting *both* the integrity of individuals *and* the harmony of the group…."

Whyte's criticism of groupthink might have been stated as, "Social engineers appear to me to be promoting an either–or analysis, as if simply putting people in groups is sufficient." Indeed, if he had expressed his confusion this way, rather than radicalizing the other side ("straw man" and "throwing the baby out with the bathwater" rhetorical maneuvers), a productive conversation might have been possible. Today's teams emphasize this notion of *empathy*, attempting to experience the feelings and perspective of others (Roth, 2015). Respecting another person's intrinsic values is greatly helped by understanding a bit of human psychology, as Arnold advised. In particular, thinking about complicated and controversial issues is prone to reductive bias, such that we interpret claims and behavior that don't make sense as being absurd and based on ridiculous assumptions (Feltovich et al., 1989; 1997). Arnold's cultural blocks ("Factors Influencing Creativity," p. 92), "Difficulties arising from over-generalizations" and "Tendency to follow the all-or-nothing attitude," are related; these are cultural in that particular memes develop and are reinforced in social discourse, but the conceptualization bias is neuropsychological. That is, the reductive bias is both cultural and psychological, supporting Arnold's principle that creative thinking can be taught and this partly involves understanding how your mind works.

The imaginary opposition ("my common sense" vs. "your stupidity") allows quickly dismissing what we don't understand, and is largely responsible for creating binary oppositions that inhibit creative problem solving (exemplified by the humans vs. robots story at NASA). Most insidiously, a failure to understand is projected onto others in a manner that not only dismisses new ideas but devalues the people who express them: The ideas are ridiculous and therefore these people are stupid. And once we dismiss other people, dialogue is impossible. Instead, Arnold urged empathy and respect for others focusing on actions not words, evaluating them based on "to what degree they had realized their own potentials and their actual tangible accomplishment, rather than on what they said" ("Useful Creative Techniques," p. 108).

To summarize the main theoretical point, *identity is the pivotal concept, the link between the individual and the group.* A person's identity is both psychological and social—psychological because it is a conceptualization, a neuropsychological process; social because the person's conceptual system (including beliefs) is with respect to himself or herself as a social actor. The answer to "Who am I?" is a blend of interests, habits, roles, and responsibilities, all constructed in activities that tacitly or directly involve other people (Lave, 1988; Clancey, 1997; Wenger, 1998). Social setting and influences are the source of language, vocabulary, frameworks, understanding, skills, technology, culture (Luria, 1979; Wertsch, 1985). Society provides meaningful activity in which the person develops a sense of self through participating, having a role, a niche, an attachment to others. In social action, a person realizes potential and experiences the joy of engagement, conversation, negotiating, and contributing in the give and take of personal needs, interests, and capabilities within a community's needs, interests, and activities. Social action is ethical when it is grounded in respect for individuals as individuals and respects their intrinsic values. Thus social life, creativity, and personal growth arise together and this experience is essential to our well-being and happiness.[29] With this broader understanding of the relation of personal development and the team, we can agree with Whyte and Arnold that "respect for the individual must be kindled."

Conclusions and Outlook

Perhaps now we might return to the basic questions addressed by Creative Engineering: Why are some designs better than others and some designers better than others? How do we improve designers and designs? We see that the answers lie in the multi-dimensional social system of the organization–team–individual interacting and developing in time. The unit of creativity—the source of innovation—is not one-dimensional (an isolated individual's thinking or a team per se) but rather *an individual within a team within an organization over time.* Each level of this dependent sociocultural-psychological hierarchy has a both–and relationship to its environment that makes its existence and development possible: The person is both an individual and a team member; the team is both a group of individuals and a unit in an organization.

Many threads relating theories of knowledge and learning in psychology and the social sciences had to come together for this synthesis to be understood and realized. Partly, the development of systems thinking, which has now pervaded the physical, biological, and social sciences, made a difference (Clancey, 2008). We can fairly say that the pieces were present in Arnold's vision of creative engineering: multidisciplinary perspectives; comprehensive design; intellectual, cultural, and emotional factors; and creative design methods. Ironically given the Cold War mentality, the missing pieces in the Western psychology of development in the 1950s were prominent in Soviet psychology, represented notably by the work of Luria, Vygotsky, and Leont'ev. In particular, revealing the developmental aspect of "social action" doesn't mean eliminating individualism or requiring "doing everything in a group" (a common superficial interpretation). Rather it suggests providing a *conceptually inspiring, engaging, and practical environment*—a meaningful context and setting with roles and activities for realizing individual contributions and personal values, creating an integrated persona. Breaking the Western cultural block that produced the "individual vs. team" opposition and isolated psychology from the social sciences required distinguishing Soviet psychological insights from Marxist political and economic reform. These insights were especially well explained by Wertsch (1979, 1985).

Although Arnold mentions anthropologists in the Creative Engineering seminar, it would be another twenty years before they routinely engaged with American engineers in academia. Until then social scientists were either off documenting the colorful cultures of the third-world (anthropology) or turning their sights on urban subcultures and deviants (sociology). Social scientists studied workers and workplaces since the 1930s at least, but they weren't hired by corporations in the United States in substantial numbers until the 1990s.[30]

Shifting from dispassionately observing Western workers (the new natives) to making scientific study of the workplace culture part of the design process required a substantial change in thinking and methods of social science and business alike. Whyte's (1952) remarks about cultural relativism and progressive permissiveness suggest that a kind of culture war made the anthropologists unwelcome—in his either–or conception of the individual and the team, "[we are] jogged into giving up all the more readily our outworn traditions and our illusions of individual autonomy." On the other hand, sociology and anthropology labored under the academic "theory vs. practice" opposition—real science, in all its objective, factual purity, might be tainted by being paid for and possibly subverted in business projects. Indeed, social scientists today might properly worry about being embedded in business, where what counts as data and can be revealed in reports may be biased by scientists' corporate identity and social commitments and rewards as employees (Cefkin, 2009). A both–and perspective, voicing and negotiating intrinsic and extrinsic values as Hartman and Maslow explained, can ameliorate these inherent tensions; squelching one side or the other will produce neurotic individuals and dysfunctional, unhappy teams and societies.

Overall, social scientists were more ready than psychologists to enter the workplace, because by their worldview *context drives inquiry*. Practical settings that engineers and other scientists might call "applied," are always "basic" for the anthropologist, as every organization is a new tribe to study. Correspondingly, engineers needed to understand that their enterprise was constructive, not context-free, not merely applying physical law equations. Engineering's social partner, "design ethnography" (Salvador et al., 1999), is like geology—not about placeless truths like physics and chemistry, but the study of particular settings, combining physical science with general analytic frameworks and methods such as Alexander's (2003) pattern language. Some fields like architecture and anthropology were there first in viewing work through the relation of people–activities–settings, realizing that good designs reflect culture and lifestyle that develops in place. Arnold recognized this insight when he brought architecture into the joint program in design at MIT in 1950.

The rise of socio-technical design, which developed into a blended discipline of social scientists, computer scientists, and human factors in the 1990s, was necessarily an incremental and complicated process, affecting where researchers worked, who they worked with, what agencies provided funding, and where research was published. Arnold clearly anticipated this emerging discipline of people-oriented scientists collaborating with engineers ("Creative Product Design," p. 127, emphasis added):

> Now, what do we mean by the statement that the comprehensive designer should have complete knowledge of the people who will use his product and of the environment in

> which it will operate? There is a new field, long aborning, but now rapidly passing through adolescence and heading for a certain and vital mature position. Due to its present young age, it can't quite decide what to call itself, but does answer to human engineering, engineering psychology, applied experimental psychology, biomechanics, biotechnology, psycho-technology, and so forth. No single name defines accurately all the things this field is interested in. This robust technical child has some very fine antecedents that include the time and motion study people like Frederick Taylor, Frank and Lillian Gilbreth, and those that followed them. *While they were originally concerned with training and adapting people to existing machines, they soon found out that larger gains could be realized by re-designing machines so as to capitalize on human abilities and avoid human limitations….* And, if my information is correct, many members of the industrial design profession have made major contributions to this field. Strangely enough, some engineers are becoming humanized to a point where they too are becoming concerned with this problem, as well they should be. *There is no question in my mind but that this field should hold a high place in the comprehensive designer's training and eventual practice.*

Given how Arnold related psychology and engineering, reformulating the design process as a creative endeavor, it may be tempting to say that he originated the idea of "design thinking." But efforts to ascribe an ultimate inventor or a fixed time of invention to such a polymorphous methodology are doomed to fail. Just as we need labels for groups, theories, and methods, we need corresponding origin stories with heroes (Linde, 1993). We ask, "How did design thinking start? Who did it first?" But these questions belie an imaginary opposition of sorts—they suggest that at some time nothing like design thinking existed and then it came into existence, and so someone or some group must have created it.

Like dictionary editors, we can track a term through the literature to discover when it was first written or quoted. But labels can change. David Kelley says "design thinking" is just McKim's visual thinking design methodology with a new name that caught on.[31] More fundamentally, meanings can change. For example, the meaning of "human-centered design" changed considerably in the accounts of Dreyfuss (1955), Norman (1988), and Hoffman et al. (2012). Rowe's (1986) presentation of architecture and urban planning as "design thinking" is not the same as Kelley's advocacy that "practically anyone in the business and academic worlds can and should think like a designer" (Taylor, 2005, p. 165).

We can be guided here by Wittgenstein's (1953) notion of a family resemblance. We can't track the idea of design thinking or "human-centered" back as a single historical thread. It is a woven cord with many overlapping threads, named and interpreted from different perspectives by people in different fields having different interests, roles, purposes, and methodological frameworks. What Arnold meant by creative engineering is certainly not the same as what was meant by ASME engineers writing in 1893 or even 1944—otherwise his work would not have attracted so much attention. New ideas were blended into the cord by Maslow, Guilford, Fuller, Rogers, Hartman, McKim, Roth, Kelley, Leifer, and over the past decade by countless others. Similarly, in trying to understand what Arnold meant by "creativity," "growth," and even "design" we are trying to understand and describe cords he rewove and how they relate to today's stories. In the end, what matters is that a story is comprehensible, coherent, and meaningful, that is, that it provides useful guidance. In that respect, many essential aspects of what people mean today by design thinking can be traced to Arnold's Creative Engineering seminar, and for that reason the depth of our understanding about our past and what we might do tomorrow benefits from reading and reflecting on the 1958–1959 lectures.

How might Arnold himself have developed his philosophy of design? Everything in Arnold's writing and progression of thought suggests he would have been directly involved and stayed current with the R&D world of the 1960s and beyond. He implied that techniques for generating ideas could be automated (p. 69, 163); might he have collaborated with Stanford's Heuristic Programming Project (HPP, formed 1965; Buchanan & Feigenbaum, 1980) and participated in developing "automated discovery" systems (Lenat, 1976)? How might he have adapted his manual methods to use AI for generating new designs? The Heuristic Programming Project deliberately formed collaborations with Stanford physicians and chemists, and mechanical engineers served as subject matter experts (e.g., Thompson & Clancey, 1986). Arnold would have been welcome.

In the late 1960s and 1970s ME professors focused on keeping the Design Division alive by developing a more complete, relevant, and sustainable curriculum within a rapidly changing technological and business environment (Carleton & Leifer, 2009). It wasn't until the early 1980s that the ME310 course shifted "to combine knowledge of mechanical engineering with electrical engineering and computer programming." Design for manufacturability and using computer-aided engineering tools became important, too. By the mid-1990s, under the purview of Leifer the social perspective took hold:

> Leifer increased the emphasis on teamwork, experimenting with different ways to enhance team culture and cohesion. Leifer realized that students in mechanical engineering could not become students overnight in electrical engineering or computer science, and it was more effective if different types of students collaborated and shared skill sets. Leifer built on another axiom that design was a social process. For example, multiple assignments in the first quarter allowed teams to mix up members repeatedly, so students could learn each other's working styles and skills before choosing a final project team.

In summary, design projects need crossover, "Renaissance" people who might naturally gravitate today to practical projects in business and government, rather than fitting their creativity to the requirements of departmental promotion. This is the "uncommon man," the "comprehensive designer," who Arnold realized would transform the design process. Further, developing a pedagogy for engineering students to promote this kind of thinking requires reaching them early on to be both systems thinkers and to engage their own aspirations for individual growth within multidisciplinary teams.

Although society's problems today, such as climate change, global politico-economics, and personal privacy, may seem more daunting than those faced in the 1950s, development of the theory of complex systems (Waldrop 1993), a socio-cognitive science, multidisciplinary teams, and technology's exponential growth provide new concepts, methods, and tools to deal with these challenges. With Arnold's interest in "how a man communicates with a machine, or how one machine communicates with another machine," how might he have contributed to human-computer interaction research (Winograd & Flores, 1986; Nass et al., 1994)? Would he have shifted to studying creativity of the team in Stanford ME design courses, or might he have developed a more nuanced theory of invention encompassing both personal growth and teamwork? And given Arnold's evident concern with the burgeoning population, cold war, medical care, and so on, might he have shifted his design concern like Fuller to more systemic, socio-technical designs and educational programs that embraced the environment, economy, healthcare, privacy, and so on?

In the analysis of Arnold, Maslow, Rogers, and others promoting the development of human potential in the 1950s, the resolution of our practical and intellectual dilemmas lies in relating our feelings, emotions, and experiences (internal values) with theoretical reasoning and designs (systemic and extrinsic values), thus unbridling our creativity. In doing this, relating the modes of thinking and expressions of art, science, and engineering, enables and requires fulfilling the classic dictum, "know thyself." Being creative in ideas and deeds, in our loves and aspirations, our dreams and our pursuits, we learn nothing less than what it means to be human.

Reflecting recently on Arnold's insight and contribution, Baer said:[32]

> John was…a man who realized that, perhaps because of his training in psychology, creative thinking needed reinforcement within the framework of our educational system. He was a compelling speaker and voracious reader and understood how to motivate others with anecdotal evidence of the historical impact of imaginative thinkers.

John Arnold was above all a teacher—a visionary synthesizer and charismatic lecturer with both academic and social concerns. His lifework was incomplete, though he left us with a program for relating society, engineering, and education that like Dewey's was both a vision for America (Westbrook, 1991) and a pedagogical framework for the capabilities future citizens require.

What are the perceptual, cultural, and emotional blocks in how we view the world today? To a certain degree, groupthink may be inherent in social life. What fears affect our thinking today? What imaginary X vs. Y oppositions have over-simplified and rigidified our analysis of personal, community, national, global issues? Where do we conflate political and scientific domains? The next step is ours—Arnold asks us to reflect on how we think and work and take charge to develop our potential and talents, growing creatively in activities that will benefit society.

Editing of the Manuscript

John Arnold's archived manuscript for *Creative Engineering* is remarkably clean and well formatted with no discernible printing errors. The text for this book was produced by scanning the printed copy in the Stanford Archives followed by optical character recognition. The original text is 1 ½ lines spacing, left-justified; here it is single-spaced, justified. All long quotations have been reformatted as indented blocks. Otherwise format and fonts have been replicated.

Footnotes in the original text are collected and numbered sequentially in the Notes section at the end of the book. After the notes for the editor's introduction, comments added by the editor appear in square brackets; other notes appeared in the original text.

The lectures are very well written; no attempt has been made to polish the text. Editing has been limited to correcting spelling, capitalization, and grammatical errors, following standards adopted since the 1950s (for example: spelling of salability [original was saleability] and lemmings [Lemings]; capitalizing "supreme court"; correcting effect vs. affect). Commas are added before the last item in a list and to bracket adjective phrases; commas and periods are moved inside quotation marks. To reflect the spoken character of the text, usage that might be editorially corrected today was retained (e.g., use of "which" for restrictive clauses; treating "data" as singular; referring to the human species as "man" and a group of people as "men"). Underlined words and titles of publications in the original text are now italicized.

Compound nouns written as one word today (e.g., Box Car, book ends, lamp post, sketch pad, motor car, business men) are retained if they uniformly appear as two words, assuming this to be either common usage at the time or Arnold's preference. Hyphens are added to compound adjectives and phrases (e.g., "well lighted"), but deleted where they are not used today (e.g., functional-fixedness, check-list, fiber-glass, some-what). Acronyms or other unclear references are explained by endnotes.

Diagrams and charts are placed in the text where they appear in the original and redrawn when this is practical; otherwise they are scanned from the original. For references cited by Arnold in *Creative Engineering,* the reader should refer to the original Bibliography, which appears in its original tabular format after the last chapter. The References section at the end of this book includes citations appearing in this introduction and the biographical essay, the references provided by Guilford and McKim, and publications cited by Arnold or the lecturers that were not in their original bibliographies.

Biographical Essay

John Edward Arnold[33] (née Paulsen) was born in Minneapolis, Minnesota on March 14, 1913. He was very bright and ambitious as a young man and enjoyed excelling. His senior high school classmates voted him "Most Talented" and "Most Popular."

John E. Arnold, circa 1953.

Graduating in 1934 from the University of Minnesota with a B.A. Psychology and unable to find a job as a psychologist, he worked as a night watchman in an oil plant. On reading technical reports lying about, he became interested in engineering. This motivated him to become part owner of an auto repair shop in Minneapolis, where he gained practical knowledge and confidence to get a "low-paid sweeper-mechanic job" in the Horton Company, a small plant making industrial machinery. In less than a year, at age 24, he was a machine designer. That experience convinced him that he needed "a wider perspective," the mechanical principles that made devices work.[34]

Arnold enrolled in MIT in the fall of 1937, acquiring an S.M. degree in Mechanical Engineering in 1940. He then served as a designer and research engineer for United Shoe Machinery Corporation. Invited to return to MIT, Arnold became an instructor in 1942, an Assistant Professor in 1945, and Associate Professor in 1949. There he developed the first Creative Engineering Laboratory.

On joining the MIT faculty Arnold first taught courses in Engineering Mechanics, but his interests in teaching shifted to the process of engineering design. He became known internationally as an innovator in educational philosophy. Bringing his understanding of psychology into the design process, his notion of "creative engineering" showed industry engineering designers how to approach and solve problems creatively.

Arnold sought to shift the meaning of design from being "the language used to tell fabrication and assembly where to make their cuts" to "the language of innovation," by which engineers expressed their imagination (Hapgood, 1993, p. 110). As described in the introduction of this book, he taught summer seminars in creativity for manufacturing engineers, military researchers, and industrial designers (1953-1956 at MIT and continuing at Stanford).

Arnold consulted for government agencies and large American companies, including General Electric, Ford, Alcoa Aluminum, Corning Glass, RCA, and Bell Laboratories, advising how to manage "creative personnel" for new project development and increased R&D productivity. He was a major consultant for the General Motors Corporation's AC Spark Plug Division creativity program, one of the first industrial organizations to promote creative thinking.[35]

Appointed in December 1954 as MIT's first Educational Television coordinator, he directed the program for two years, involving more than a hundred broadcasts. He was also President of the M.I.T. Faculty Club and participated in the MIT Science Fiction Society (*The Tech*, 1954).

Arnold moved to Stanford University in 1957 with a joint appointment as Professor of Mechanical Engineering and Professor of Business Administration. He was founding Director of the Design Division of the Mechanical Engineering Department, continuing to formulate and teach about creativity in engineering. He died at the age of 50 of a heart attack while traveling in Italy on sabbatical; he had planned to write a book on the philosophy of engineering (*The Stanford Daily*, 1963, p.1).

Arnold's extraordinarily broad and diverse activities demonstrated his vision of what it means to work and live as a creative person. Arnold designed and built a substantial portion of his home in Wenham, Massachusetts. Besides cultivating his fields and raising sheep, he was an amateur printer and photographer. He built miniature railroads, played tennis and the violin, and was chairman of the town school board (Hunt, 1955, p. 200).

On his passing, Arnold's Stanford colleagues described him as "an uncommon man...a visionary thinker who set trends in design education." They said he was "warmly human, an outstanding and articulate speaker...sought by many groups to contribute to their programs" (Kayes et al., 1963).

Stanford's Mechanical Engineering Design Group continues to develop Arnold's design methodology, combining creativity and technology with a "concern for human values and the needs of society."

Acknowledgements

Assembling this book and preparing the introduction and biography have been made possible by the permission and enthusiastic assistance of John E. Arnold, Jr. We have met and exchanged hundreds of emails as we have learned together the history and influence of his father's work.

We are grateful to the approval and support provided by Stanford Special Collections and University Archives, particularly Daniel Hartwig (Stanford University Archivist) and Tim Noakes (Head of Public Services). Original materials are held in copyright by Stanford University with usage controlled by his heirs. Additional materials are archived at the MIT Museum in Cambridge, MA. My visit there and subsequent orders for copies were arranged with Rachel Robinson. Access from afar as a non-alumnus can be frustrating, but Rachel made it all simple and convenient.

Securing a copy of the minutes of first meeting of the MIT Science Fiction Society from the MIT Institute Archives and Special Collections was made possible by David Mindell (Professor of the History of Engineering and Manufacturing), Michelle Baildon (Liaison to the Science, Technology, and Society Program), and Nora Murphy (Archivist for Reference, Outreach and Instruction). I gratefully thank as well Julia von Thienen (Hasso Plattner Institute, University of Potsdam) for her support and historical perspectives that I incorporated in the introduction.

I am especially grateful to John Arnold's students and colleagues for showing great interest in this project and sharing their memories and perspectives in meetings, phone conversations, and emails—Austin Baer, Peter Bulkeley, Bob Eustis, Jim Johnson, Larry Leifer, Bob Mann, Bob McKim, Bernie Roth, and Thomas Sheridan. Reaching back to events that occurred 50 to 60 years ago reveals that memories become spotty and uncertain, but everyone spoke positively, with clarity and conviction about the character of John Arnold and how working with him changed their lives.

Portola Valley, California
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About the Editor

William John Clancey is a part-time senior research scientist at the Florida Institute for Human and Machine Cognition in Pensacola. He received a PhD in computer science from Stanford University (1979) and a BA degree in mathematical sciences from Rice University, graduating Summa Cum Laude and elected to Phi Beta Kappa (1974).

From 1999–2013 Clancey was on an assignment at NASA Ames Research Center as Chief Scientist of Human-Centered Computing in the Intelligent Systems Division. Prior to joining IHMC he was Senior Research Scientist and founding member of the Institute for Research on Learning (1987–1997), where he co-developed methods for studying workplaces with social scientists. Earlier he was at the Knowledge Systems Lab in the Computer Science Department at Stanford University (1979–1987), where he developed artificial intelligence programs for diagnosing infectious diseases and teaching medicine. He holds six software patents involving expert systems, computer-aided instruction, financial analysis, and work practice simulation.

At NASA Clancey led several partnership projects with Johnson Space Center, notably automating all routine file management between Mission Control ground support and the crew onboard the International Space Station. His team received the NASA Ames and Agency Honor Awards and the JSC Exceptional Software Award (the first granted outside Houston).

Clancey also participated in seventeen field science expeditions, including Mars mission simulations during five field seasons on Devon Island in the Canadian High Arctic and as "commander" of two-week field experiments at the Mars Society's Desert Research Station in Utah from 2002–2006. These "missions" demonstrated the methodology of empirical requirements analysis, with a development cycle combining storyboarding, prototyping, experimentation, observation, and analysis. During this period his team developed a voice commanding system used by geologists at lunar analog sites in Hawaii and New Mexico for science data collection and navigation, as well as biosensor interpretation, remote monitoring, and plan management. The system was demonstrated for coral reef surveying at the Smithsonian's research atoll in Belize.

Clancey's research in "trust and autonomy" for NASA's Aeronautics Directorate from 2010–2013 applied multiagent work practice simulation as a tool for early-in-design evaluation of work systems involving human-automation interaction in safety-critical situations.

Clancey was the founding Editor-in-Chief of AAAI/MIT Press and a Senior Editor of *Cognitive Science*. He is a Fellow of the National Academy of Inventors, the Association for Psychological Science, the Association for the Advancement of Artificial Intelligence, and the American College of Medical Informatics. He has presented keynote addresses and other invited lectures in more than 20 countries. Clancey has published seven books, including *Situated Cognition: On Human Knowledge and Computer Representations* (Cambridge University Press, 1997). *Working on Mars* (MIT Press, 2012) received the American Institute of Aeronautics and Astronautics 2014 Gardner-Lasser Aerospace History Literature Award; it explains how the Mars Exploration Rovers provide virtual presence and serve as a kind of collaboration tool for the scientists who have been conducting field science on Mars.

For more information, see: http://bill.clancey.name

CREATIVE ENGINEERING

by
John E. Arnold

Forward – Why Creativity[36]

It takes but a cursory survey of the indices of book and periodical literature to note the rapid increase in the number of titles relating to creativity, imagination, ingenuity, etc. For one reason or another growing segments of our population are becoming concerned over the ever enlarging demand for new and better solutions to both new and old problems.

This growing concern is most readily observed in the fields of engineering, science, and business, but it is by no means restricted to these areas of activity. Educators, ministers, human relation councilors, politicians, labor leaders, government leaders, parents, and housewives are also seeking diligently for better answers to the problems facing them. Some are being momentarily waylaid and diverted by different answers rather than better answers, but most are sincerely searching for definite improvements.

In business and its close ally Research and Development, there is a continuous pressure for increased sales, greater profits, larger wages, and increased benefits. This is to be accomplished in part through better machines, products, and processes, having an increased function, higher performance level, lower cost, and greater salability.

Considerable study is also being carried out in an attempt to discover why people buy the things that they do so as to direct the advertising messages to appeal to these motives. Many groups throughout the country are now offering their services to the marketing and advertising people in an effort to increase sales through a greater understanding of individual and group motives. This service is called Motivation Research and is the newest adjunct of statistical market surveying and consumer analysis.

But why this restless quest? Aren't the old answers good enough? My parents, and their parents before them, got along quite happily and satisfactorily on much less than I have. Why isn't what was good enough for them also good enough for me? Isn't it true, that once you have started on this search for better solutions there can be no end; that you must go on and on at a task that becomes increasingly more difficult? Isn't it also true that innovation is born out of dissatisfaction with the old and that dissatisfaction is the antithesis of happiness? Why then are people urged to be creative?

Let's take a little different approach. Look at history for a moment. Man started out a true animal and only very gradually did he acquire the characteristics we call man-like. The greatest invention, that of language, the taming of fire, the invention of the wheel, were these deliberate, organized, logical acts of creativity? Or were they accidents or divine revelations? History draws a graph of steady, upward progress, with only an occasional and temporary regression. Hasn't all this been accomplished without a clear understanding of the creative process and the factors that influence it?

Haven't you heard people say, or perhaps you've said it yourself, when faced with the problem of giving up something old and cherished for something new and questionable, "well, progress is inevitable." If this is true, why must we stress creativity at this time? Don't we really mean that *change* is inevitable and we hope that it is a change for the better? We know this to be a wholly dynamic world and that everything is subject to constant variation. Heraclitus recognized this thousands of years ago when he said that one cannot step into the same river twice. Both you and the river undergo continuous change. But this continuous change is apt to be a cut and try affair with many many failures for every success. Nature seems to be in no hurry and is very wanton in her experiments.

We could go on and on, investigating all the areas of human thought and behavior and in each case, I'm sure, we would come up with the question, why worry about creativity? One last example from studies in human drives and motivations. It has been quite clearly shown that one of man's basic motivating instincts is that of transcendency. He strives not only to transcend his environment but also himself. Unfortunately this instinct can be satisfied by destruction almost as easily as by creation, and it can be mitigated by strong opposing instincts associated with having roots, belonging and being associated with something bigger than yourself that emphasizes stability and the maintenance of the status quo. But again, won't chance alone, if nothing else, insure that there will be some people who wish to improve mankind's lot and that they will be effective and the necessary progress achieved? Is it necessary to stress creativity in all? Do we all have to be subjected to the apparent frustration that is associated with the creative process?

Let us look at our main question again and some of the related questions that arose out of our initial search for an answer to "Why Creativity?" Weren't some of our greatest inventions achieved by ignorant, untrained savages? Doesn't chance, in a dynamic world, insure that progress as well as change is inevitable? Doesn't the dissatisfaction that triggers off creative activity lead to frustration and unhappiness? Can't we leave the creative work to just a few and the rest of us relax and do only what we are told to do? Can't we have a moratorium on invention for a while and learn to be satisfied with what we have?

The answer to all these questions is probably yes and no, yes with lots of qualifications and exceptions. So many qualifications that it might be easier to say no and let it go at that. However, the chances are very good, that the answer we are actually searching for lies in some of these exceptions so we shall look at them one by one in brief detail.

"Weren't some of our greatest inventions achieved by ignorant, untrained savages?" Yes - - but! They were certainly untrained in the scientific process, the process of creativity, and they were certainly ignorant, based on modern standards. The amount of past experience that they could draw upon was extremely limited and at first confined to that which they themselves had lived through. But somehow a few, even without language, asked themselves questions. Perhaps not the kind we are used to with question marks at the end; but emotionally they became aware of problem areas, they were sensitive to themselves and the limited world around them, and these in effect were questions for them to solve. They made keen observations in search of the answers to these questions. They related these answers together and combined them with past observations so that finally they could make a prediction, a prediction that was valid, that answered the question first asked. These answers were probably resisted then as our new answers are resisted today. Many died in their attempts to verify and sell their answers. They were ridiculed and tormented, but the truth prevailed and progress was achieved.

It is very likely true that while these few were sensitive to problems and persistent enough to solve them they were not necessarily sensitive to the process that they used to arrive at a solution. Some were able to retrace, using hindsight, the observations, the relationships, the steps that culminated in the invention, but this unfortunately was not done often enough.

Actually it is not a rare thing today to see early history repeat itself. Men, who in light of the total knowledge of the arts and facts of a field of endeavor are, in effect, "untrained and ignorant savages," are making predictions of great value. These men are the amateurs, the tyros who not knowing what can't be done, go ahead and do it. So frequently does this happen that I have heard some men say that they are convinced that it is only the amateur who can really invent. I'm afraid that I don't agree with this. I am certain that innovation is not limited to amateurs, but it may be limited to only those who think like amateurs; who are as fearless, as uninhibited, as sensitive and observant as a newcomer to a field of activity.

So it did happen and will happen many times more that formally untrained yet highly sensitive men brought about changes of vast importance to the rest of the human race. These are some of the genii, known and unknown, that we revere today. But while it was true that in certain periods of our species' history we could leave it to the chance few to lead the way, I am sure that it is no longer true. From our vantage point in America the progress seems tremendous, but it doesn't take much observation to quickly note that the progress has been severely limited to a small fraction of the world's total population and to relatively few areas of man's thought and activity. With a world population of over two and one half billion persons, we in the United States represent but a fraction over six percent. While most of us have all we care to eat each day, two thirds of the world's population goes hungry. Over one billion, six hundred million people have insufficient and inadequate food. As a species we still have a long way to go; we cannot leave it to chance. The survival of the fittest is too high a price to pay for continued trial-and-error activity.

We can easily see that the total population of the world is increasing rapidly. Each morning we have to feed, in our country alone, seven thousand more people than we did the day before. If the numbers increase and we assume (perhaps properly so) that the ratio of genius to mediocre to dullard remains the same, won't we also have an increase in those having inherent potential of great worth so that we can still sit back and let those fortunate or unfortunate few solve all our problems for us? Unfortunately while our population may increase geometrically, our problems, in number and complexity, increase at a considerably higher exponential rate. An increase in quantity, moreover, does not guarantee an increase in quality, although this sometimes seems to follow.

Man has always found it difficult to get along with other men. This is one of the areas that only recently has come under the influence of the scientific method. Tremendous creative effort must be expended if the problems associated with getting along with a relative few are to be solved so that we can be prepared, in part, for the problems that come with increased numbers and interrelationships and interdependencies.

Chance alone, a laissez-faire attitude, will not insure progress from inevitable change. Total destruction could easily be the result. The increased understanding of the creative process, the enlargement of the number of areas where it is practiced, and the encouragement of all to exercise their creative abilities to the limits of that inherent potential are the only ways in which progress can be assured.

Organized research is a relatively new tool as far as man is concerned. It is only during the last ten or fifteen years that we have observed its rapid expansion in numbers of men participating and dollars spent to support it financially. The engineer and the scientist now command a premium at the market place and there is nowhere near enough to go around if the plans for new research and development are to be carried out; that is, if we rely on quantity alone. In face of this shortage of technically trained personnel, a shortage which is growing more acute rather than lessening, private and government laboratories must find other means of supplying the additional needed manpower. One obvious way is to increase the efficiency and productivity of those engaged in research and development. If the demonstrated creative ability of individuals can be increased by understanding and exercise, this, then, is one more good reason for studying creativity.

Actually in this same area of activity there is a still better reason for investigating as thoroughly as possible the creative process. It seems, at the present time, that a great deal of so-called creative effort is being expended on gadgets or on being different for differences' sake. As Thomas Wood Krutch put it in his book, "The Measure of Man," "Psychologists have taught the merchant that he can make more money by selling fat-free milk than he can when he calls it skimmed; but what have they done to help us write a better Hamlet?" A good share of our creative effort results in making things larger, faster, more powerful, and more efficient. It is granted that these efforts can and do result in better products, machines, and processes, but it seems to me that if even a small fraction of the above time were devoted to basically rethinking the needs that various products are supposed to satisfy, that entirely new, from a functional standpoint, means could be evolved that would better solve the needs of all men.

For one reason or another (probably because of lack of confidence in ourselves as effective and novel problem solvers) most of us prefer to work in established fields of endeavor rather than strike out into the unknown. Like the drunk who searched for his lost ring under the lamp post rather than by the dark park bench where he lost it because there was more light by the lamp, many of us search vainly for important answers in the well-lighted areas, knowing full well that they aren't there; they are in the dark fringe areas. Perhaps another important reason for this hesitancy is our fear of failure or ridicule. Therefore, we must not only study the creative process, but we must also study ourselves as the only creative instrument our species has. This is "why creativity."

But one objection has not been covered as yet. Much as I hate to admit it, this objection has been made by mature men as well as students. It is, "Why should I try to be more imaginative and creative? Won't this lead to discontent, frustration and unhappiness?" Again the answer is yes and no. An attitude of healthy skepticism in place of complacent acceptance is essential to the creative personality. The highly imaginative person is one who is motivated by a deep spirit of inquiry, of questioning. He is constantly asking himself how he can improve the things he sees. He is concerned with how the basic needs of man can be better satisfied. If this is discontent, then part of the question must be answered in the affirmative. I feel, however, that the word discontent connotes a rather definite negative quality and, therefore, should not be used. The spirit of the innovator is wholly positive.

Frustration cannot be avoided in problem solving situations and if recognized and handled as a necessary and important part of the creative process, it, too, can have positive qualities rather than negative. Frustration is frequently the immediate forerunner of solution. Those practiced problem solvers who can, when they arrive at the frustration stage, turn the problem over to their sub-conscious mind, to incubate as Wallas put it, are more apt to arrive at an insightful solution than those who fret and fuss, those who, in effect, react negatively.

In order to answer the last part of the objection, it is necessary to define happiness. The definition that I like best is that happiness is the first derivative of your achievement curve. When you are progressing, making positive contributions and using your talents to the full, the slope of the achievement curve is positive and you are happy. The opposite situation results in a negative slope and unhappiness. Since the curve is most likely a continuous one, there are apt to be times when the curve flattens out and the slope is zero. The zero derivative can be indicative of one of two situations. It can represent a period of contentment, a resting period before another upward climb, or it can be a period of frustration which, as I have already mentioned, if handled properly, will lead to a further advancement and resultant happiness, or if handled improperly, will lead to a descending achievement curve, a negative slope and unhappiness. Zero slopes are periods of indifferent or unstable equilibrium and should not be continued for too long a period. They require too delicate a balance to be maintained and should be avoided as much as possible. One way to avoid the zero slope resulting from frustration is to have so many things to do, so many interests, so many problems to solve that while you are incubating one or more you are going ahead positively with others.

Now if you accept this definition of happiness, it seems to me that the only conclusion that can be drawn is that to be happy one must be creative. One must make positive contributions to society, must maintain an achievement curve with an over-all positive slope if one is to be truly happy. This is one more good reason for why we should try to be creative.

There are, of course, many more reasons why we all should try to understand the creative process and make ourselves more expert in its use. It is hoped that as you read further in these notes you can provide these answers for yourselves.

What is Creativity

This is a question that many are trying to answer and fortunately each new attempt to answer it adds new insight to the problem and suggests new leads to follow. The more I study creativity it seems the less I know, at least percentage-wise. I may be making a steady growth in understanding but the subject matter, the related fields of interest seem to expand at an exponential rate. Every field of human thought and behavior gives rise to problems that can and should be solved in a creative fashion. All of these can be examined and studied profitably if a full understanding is to be achieved.

It seems, however, that all of these problems can be classified into three quite distinct groups: analytical, judicial, and synthetic. They can best be distinguished on the basis of the number of concepts involved in their definition and solution and in the number of correct answers that can be obtained. Analytical problems are stated quite precisely and involve, both in statement and solution, a relatively few basic concepts which lead to one, and only one, right answer. How do you spell cat? What is the sum of 2 plus 2? Who won the Battle of Hastings in 1066? What is the integral of x^2 dx? Or, what is the deflection in the center of an 18” 70# steel I beam, 20 feet long, uniformly loaded with 150 pounds per foot and freely supported at the ends? In all cases, correct processes of logic or experiment will yield the one right answer; all other answers are wrong.

The problems of judgment are somewhat more complex. It takes many more words and concepts to describe them, in fact, to all but the legally trained mind, the verbosity of legalese is extremely confusing. Not only must you describe in great detail the “things” that must be evaluated, but you must also be just as meticulous in stating the bases for judgment, the rules, the laws that must be followed. Even so, there can be a wide variation in the judgments rendered; there can be more than one right answer. I’m sure that it must be a rare event when there is complete agreement between the judges in a beauty contest. Even in the law a higher court can reverse a lower court decision, and in the Supreme Court minority reports are frequently submitted.

The problems that involve synthesizing, however, may involve an almost infinite number of concepts and a complete spectrum of possible solutions. The cross products of the various factors that might be combined in any one problem are almost limitless. Many right answers, many wrong ones and all possible combinations in between. Moreover, this spectrum is never completed. No matter how poor the worst solution existing in the spectrum is, a still worse one can be found; and in the same manner, but perhaps with more effort, a still better solution than the best one existing can be found. The synthesizing process is fundamental to all creative activity and the factors that distinguish problems of synthesis are much the same as those that characterize creative problems. Without too many qualifications, we could say that the two were synonymous.

I have treated the above three groups as if they were completely independent of each other. Obviously, this is not quite correct and this will be demonstrated more clearly when we examine briefly the modes of thinking involved. While I know of no definitive experiments that verify this statement, I believe that the three types of problems that I have mentioned stem from the three basic modes of thinking, analysis, evaluation, and synthesis and that they develop in the young child in just this sequence. Effective mental activity associated with any of these modes depends, in part, on the mastery of the modes that preceded it in the developmental process.

The first mode of thinking to develop is analysis. When the infant first becomes conscious of himself and the world around him, when he becomes aware of the different sensations impinging on him, when he attempts to categorize these sensations and, in effect, to change sensation into perception, he is using analysis as his only thinking tool. He is "analyzing" "one thing" at a time. Before long, however, the child can handle two or more "things" at a time, and this is basic to the process of evaluation. It is impossible to evaluate a single object or idea at a time. Occasionally it may seem as if we are, but actually we are considering two objects, one real and tangible, and the other fabricated out of the sum total of our past experience. *Effective* judgments cannot be made completely independent of analysis. This must almost be obvious. When one is comparing, making value judgments, rating, classifying, deciding, and so forth, it is essential that keen analysis be made of each of the components involved.

The last thinking mode to develop and probably the first to be lost is that of synthesizing, the bringing together of two objects or concepts for the purpose of making a new combination or whole. When this is done vicariously we call it imagination. High level synthesizing that is associated with design, art, composing music, philosophy, etc., is synonymous with creative activity and is very much dependent on keen analysis and thoughtful judgment.

Now it is not just any synthesizing process combined with analysis and evaluation that I would like to call creative activity. There are certain restrictions and qualifications that I should like to make. The creative process is primarily a mental process whereby one combines and recombines past experience, possibly with some distortion, in such a fashion that the new combination, pattern, or configuration *better* solves some need of mankind. In addition, the end result must be tangible, something you can see, feel, or react to in some way, it must be forwardly oriented in time and it must have synergetic value.

Let us look at some of these restrictions in greater detail. Admittedly, some of them are quite arbitrary and open to some debate. They have been included for very definite reasons and these will be made clear as we go on. A rather heated argument can be generated over whether or not we should limit creative activity to that which produces *better* results. Morris Stein of the University of Chicago, for example, believes that the new combination must be at least "tenable, useful or satisfying to a group at some point in time". This is certainly more inclusive and from the standpoint of the would-be creator, much more satisfying. From my position as a teacher, however, I insist on better results and that the judgment be made by the creator himself and not be left to some group at some point in time. Too many man-hours are now being wasted on gadgetry, in the physical field as well as the social, that are not more tenable, more useful or better satisfying. Many attempts are also being made to be popular, to have one's ideas and products accepted by large groups, even though these offerings may not be the best things for the individuals within the groups and not the best that the designer can produce.

The needs that we are trying to satisfy may be implied as well as expressed. The need for beauty, truth, peace, love, belonging, transcendency, and so forth are some of the implied needs that lead to great creative acts in the fields of the fine arts, literature, and philosophy. The expressed needs are those associated with man's physical environment, food, clothing, shelter, communication, and transportation. Attempts to satisfy most of these needs are being made by engineers or men with special technical training. A still better solution can be arrived at, however, if somehow some of the implied needs of man can be given consideration at the same time the more direct expressed need is being investigated. The rapid rise of the industrial stylist verifies this thesis as does the growing importance of the "Human Engineer." The ideal situation would be to have in addition to a few specialists in the various fields, a greater number of men who have fundamental training in and knowledge of a number of related fields. This person is the "Comprehensive Designer" and as Bucky Fuller first described him, he is "the emerging synthesis of artist, inventor, mechanic, objective economist and evolutionary strategist." One of the aims of Creative Engineering is to bring about a union between the physical sciences, social sciences, and the arts. In this way and perhaps only in this way can we be assured that our innovations *better* satisfy some need of man.

Admittedly the *better* stipulation is a difficult one to meet and it may have to be thought of for a while as an ideal to strive toward but not quite reach, that is, for the most of us. The genii of all times achieve the goal occasionally.

We have also specified that the end product of the creative process be tangible. Tangible to the extent that we can be made aware of it with our senses, we can react to it in some fashion. A rather large portion of talking and writing on this subject of creative thinking has been concerned with how to get ideas. This has been carried to such an extreme that some people believe that there are two distinct classes of people in the world, the "thinkers" and the "doers," those who create and those who merely carry out orders. They believe that the original "idea" is the sum total of the creative process and that its translation into wood or metal or what have you is routine engineering. One group of researchers gave me an example of one of their creative acts, the suggestion to a grocery firm that they manufacture and market carbonated drinks in pill form. They were sure that any chemist in a week's time could provide them with the pill. When asked why chemists hadn't done this already, if it was that easy, they replied that chemists didn't think in such a creative way. Looking at the long list of "Better things for better living through chemistry," to apply duPont's slogan to all chemical research, such a statement is obviously false.

Actually this group did obtain a kind of tangible result; they did communicate their idea to interested ears; they did sell the idea to a president of a company. This is ample evidence that reactions to their "creative" act were obtained. Yet I do not feel that unless they continue a direct interest in the development of the idea, that unless they make some additional contributions even in an indirect way, to the successful development of this pill, that they can take full credit for the innovation. There is "many a slip 'tween the cup and the lip"; there are many "bugs" that must be worked out of the best conceived ideas; there is ample opportunity for high level creative activity in the development of a prototype.

From the above it is probably obvious that the interpretation of the word "tangible" can be very broad. It can range from the immediate reaction of a single individual as when the president of a company communicates an idea to the director of research and says, "Go to work on this!" to the reactions of millions over long spans of time as when they view a work of art, listen to a symphony, read a classic book, or use a better machine or product.

Now the qualification that creative acts be forwardly oriented in time is probably an academic restriction. It does help to distinguish between the creative and the recreative, and, in part, helps to differentiate between activity which is primarily judicial and that which is creative. The first time that a new whole is formed out of old ideas that better satisfies, etc., the act can be called creative. The next time that this combination is formed and recognized as valuable by a person ignorant of the original act of creation, this activity would be labelled recreative. Many ideas have been recreated hundreds, even thousands of times and this activity is to be encouraged. Charles “Boss” Kettering tells of his own experience along this line.[37]

> I often tell the boys this story: I have been making inventions and taking out patents for many years. When I first began to apply for patents, most of my inventions had been patented fifty or sixty years before. Later I was only forty years behind then thirty years and so on. So I drew a set of coordinates and plotted just how far behind I was on each invention. There was a gentle slope to the curve, so I could extend it to the base line to see how old I would be when I made an original invention. It comes out to about 125 years.

Obviously, the slope of his curve was not as gentle as he indicated. The chances are very good that each recreative experience increased the slope for the exercise of creative talents has a cumulative effect. As Stein has pointed out, the process that a young child goes through the first time he fixes his own tricycle bell can be a very important and valuable recreative experience for him. As parents we should watch closely for these experiences, praise them and encourage them.

It was also indicated that the time factor could be used to distinguish between wholly judicial activity and that which should properly be called creative. A good share of legal activity, for example, is centered around solving problems of the past. The solutions to these old problems seldom contain elements that will help to prevent similar problems from arising in the future. Perhaps they may feel, however, that the maintenance of an established precedent may hopefully serve as a deterrent in the future. This is not to say that the legal profession is not creative. Some of our most respected and revered innovators (inventors in the social field rather than the physical) have been actively engaged in or closely connected with the practice of law. These men, however, established precedent rather than maintained it. They were conscious of and concerned with tomorrow’s reactions to the decisions they made today, and the vision of the future that some were able to demonstrate was almost fantastic. True creative acts, then, are forwardly oriented in time.

One more important qualification should be looked at in some detail. The creative combination must not only *better* satisfy some need of man; it must not only be carried to some end and be forwardly oriented in time, but it must also exhibit synergism. According to Webster’s Collegiate Dictionary, this is the “Cooperative action of discrete agencies such that the total effect is greater than the sum of the two (or more) effects taken independently, as in the action of the mixtures of certain drugs.” This, then, is a big word for the old concept that invention is characterized as a new combination of old parts whose new value is greater than the sum of the individual parts. Synergy is multiplication rather than addition. Something has been added to this combination; something that is hard to define, hard to see or feel and impossible to buy; something that was contributed to the combination by the mind and spirit of the inventor that multiplied immeasurably the value of the individual components and modified their character as they became structured in this new totality. Barnett describes this aspect of creativity as follows:[38]

> When innovation takes place, there is an intimate linkage or fusion of two or more elements that have not been previously joined in just this fashion, so that the result is a qualitatively distinct whole. The union is a true synthesis in that the product is a unity which has properties entirely different from the properties of its individual antecedents. If we may use a biological analogy, an innovation is like a genetic cross or hybrid; it is totally different from either of its parents, but it resembles both of them in some respects.
>
> In innovation the fusion takes place on a mental plane. The linkage is between the ideas of things. This means that the process and its result are something quite different from a union of the things themselves. Mental images are not necessarily involved; in fact, usually they are not. Neither is the fusion solely an intellectualistic process; sometimes there are ingredients other than ideas involved. Perhaps this is always so. The innovative union of ideas is a complex commingling of perception, cognition, recall and affect.
>
> Fundamental to this point of view is the assumption that any innovation is made up of pre-existing components; and, secondly, that new combinations are entirely the products of mental activity. No innovation springs full-blown out of nothing; it must have antecedents, and these are always traceable, provided that enough data are available for an analysis. An innovation is, therefore, a creation only in the sense that it is a new combination, never in the sense that it is something emerging from nothing.

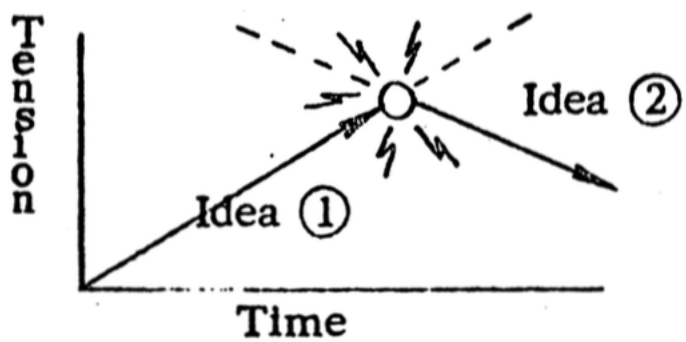
New value and new character, then, differentiates creative combinations from those that are not creative. It would be almost impossible to look singly at some lines and rectangles of color and to predict their total value or even to recognize them after a Mondrian put them together. The true value of some pots of paint and a clean piece of canvass is far below their combined value after a Titian has assembled them, and the chances are pretty good that you would not have seen much worth in combining a piece of glass, some copper wire, and a piece of charred thread until after an Edison showed how. There are lots of combinations that are not creative and they can be arrived at in a great many routine or chance ways. Later I will show you some techniques that can be used to crank out new combinations of ideas in a very routine computer-like action. This step involves no imagination, but the steps that precede and follow are very demanding of creative talent.

Pure chance can lead to new combinations that may be anything but creative. There was a group of poets in the late Twenties who wrote poetry (new combinations of words and ideas) by putting a great many words, cut out singly from newspapers, books, and advertisements, into a hat and then withdrawing them one at a time and copying them down. After five words had been written, they would start a new line. This went on until the poem was finished. It would be a rare coincidence indeed if this new combination displayed synergism. In fact, probably only criterion of creative activity could be met by this so-called poem: one that it was a new combination, and two, that it was tangible.

As I have already indicated, there are a great many ways in which one might describe the creative process. There is one definition that should be considered briefly, and this is one that Dr. Barnett hinted at in the paragraphs quoted earlier. It is one that Dr. Herbert I. Harris, Psychiatrist at M.I.T. has used on occasion. “Creative Thinking,” he says, “is the recognition and description of a tenable relationship between two or more usually disparate objects or actions.” To me it is highly significant that Harris chose to use the word disparate in describing the things that are to be brought together in combination. This harks back to one of the criterion of invention that the U.S. Patent Office used to insist upon, namely that to be a patentable invention the combination be one that would *not* normally be thought of by one skilled in the art. Unusual, *disparate* objects must be brought together to meet one of the requirements of creativity.

This would seem to indicate that the person with broad interests would have a better chance to be creative than would the specialist who limits himself to a very narrow field with which he is thoroughly familiar. The Comprehensive Designer, then, should be the creative engineer of the future. This by no means prevents the specialist from being a creative person, but the chances are fairly high that his creative work will more likely be discovery rather than invention. Discovery is first recognition and description of combinations that have always existed. Great depth of knowledge in restricted areas is essential to discovery.

Arthur Koestler[39] in his book, "Insight and Outlook" attempts to analyze the essence of humor and arrives at the conclusion that what makes people laugh is essentially the sudden abrupt change in a line of thought, guided in one direction by the story teller and suddenly diverted into a new direction by a seemingly unrelated idea. He plots curves similar to the one below where tension is plotted on the ordinate vs. time.



The juncture point, the sudden change in direction gives rise to a tension release in the form of laughter. This abrupt change Koestler calls a bisociative process, a dual association. He points out that there are four important aspects of bisociation as it occurs, both in humor and in creativity.[40]

> First, bisociation is not the same thing as ambiguity; ambiguity is merely a subcategory of it…. Secondly, in the process of bisociation, the junctional concept is connected simultaneously to two association complexes which, we said, are 'habitually incompatible.' Now, 'habitually incompatible' does not mean 'logically incompatible'.... Thirdly…(simultaneity) refers to a quick oscillation of the bisociated concepts between its two contexts, these quick oscillations accounting for the presence of both in consciousness.
>
> Fourthly, it should be noted that after a concept has become bisociated with two previously independent associative currents, these cease to be 'independent'; that is, the contact thus established between them will make them coalesce into one 'continuous' flow. What came originally as a surprise has become a thought habit. Hence a joke is only effective the first time; hence, also, a revolutionary discovery becomes a platitude after a while. In other words, a given bisociative connection becomes, after a few repetitions, if not at once, transformed into an ordinary associative connection and is incorporated into the mental habitus.

Diagrammatically this transformation may be represented as a hammering out of the original angle into a continuous curve.

Bisociative Process **Associative Process**

Bisociation ought then to be another way of describing the mechanism that takes place in innovation, the bringing together of two or more seemingly disparate objects or ideas into a tenable combination. When this is done suddenly we get a duplication of the "Eureka!" experience of Archimedes, the "aha" experience that usually a company's "insightful" problem solving. With this sudden bisociation, there is a tension release that would correspond with laughter in the case of humor.

It is important to point out that it is "habitual incompatibility" not "logical incompatibility" that is vital to the creative process. "Logical incompatibility" will result in nonsense and this is where the judgment of the creator comes into play. However, as it will be pointed out in more detail later, all possible combinations should be recorded during the process of ideation, regardless of their seeming absurdity and only after the ideas have stopped flowing should judgment be applied and the logical inconsistencies ruled out.

We have already pointed out the need for broad interests as one of the essential components of the creative personality; that the combinings of seemingly unrelated material from different areas of human activity depends on a well-filled storehouse of data, facts, feelings, and impressions. Actually it is very difficult for the average person to arrive at adulthood without having such a well-filled storehouse. Living in this dynamic world for twenty-one years or more is bound to have subjected every individual to a wide range of experiences such that, if they can be recalled and transferred to new situations, they can be a very adequate source of material for creative activity. Each person has at his command a tremendous amount of data which, if handled with confidence as well as competence, would allow him to solve a great many more problems than he now feels qualified to handle. Relatively few people have trained themselves to start the search for answers first within their own experience; rather they go to the experts, the libraries, and laboratories of the world for solutions to problems they themselves could easily answer, One of the most difficult tasks I have as an educator is to convince my students that they have at their command, prior to the time they register for my courses, sufficient information to allow them to solve rather comprehensive problems concerned with fields of activity in which, they believe, they have had no specific training. They won't believe it until they are forced to try it.

Up to this point we have defined what we mean by creative problems and given some indication of what constitutes the creative process. It must be pointed out, however, that despite the close relationship that exists between the two, this relationship is not inviolate or inevitable. It is possible, perhaps in more cases than not, to successfully solve multisolutional creative type problems in anything but a creative fashion. The machine designer who chooses from the many possible fastening devices to use a spline in attaching a gear to a shaft is tackling a creative problem in a routine prosaic manner. On the other hand, a scientist may be faced with a highly analytical problem (by definition), searching for the one right answer from nature, but if he solves it with an open mind, great imagination, daringness, and enthusiasm, he is being highly creative. The process you use is the deciding factor in large measure as to whether or not you are creative. The problems you work on and occasionally even the products that result can be worked on and solved by non-creative techniques. Pure chance, for example, could produce seemingly creative results. It has been said that fifty million monkeys with fifty million typewriters could reproduce all of Shakespeare in fifty million years. W. Ross Ashby made a similar calculation.[41]

> It has often been remarked that any random sequence, if long enough, will contain all the answers. Nothing prevents a child from doodling
>
> $$\cos^2 x + \sin^2 x = 1$$
>
> or a dancing note in the sunlight from emitting the same message in Morse or a similar code. Let us be more definite. If each of the above thirteen symbols might have been any one of fifty letters and elementary signs, then as 50^{13} is approximately 2^{73}, the equation can be given in coded form by 73 binary symbols. Now consider a cubic centimeter of air as a turmoil of colliding molecules. A particular molecule's turnings, after collision, sometimes to the left and sometimes to the right, will provide a series of binary symbols, each 73 of which, on some given code, either will or will not represent the equation. A simple calculation from the known facts shows that the molecules in every cubic centimeter of air are emitting this sequence *correctly* over a hundred thousand times a second. The objection that "such things don't happen" cannot stand.

Some science fiction writers have in their stories suggested that "white noise" be used as a source of information, for it must contain *all* possible answers to *all* possible questions. The generation of the data is simple enough, but the filtering of sense from nonsense is no easy task and at the moment must be done by men of vision, wisdom, and imagination.

Probably one of the most difficult things to do in this present subject would be to try and define the various levels of creativity that we know must exist. If we are very strict and stick to the very rigorous definition first given and insist that all the limiting conditions be met, we would probably have only a few categories that would include only the works of men of demonstrated genius. This would be just the upper end of a spectrum which is undoubtedly continuous. Removing the qualification that the new combination must exhibit synergism would increase quite markedly the number of acts that might be called creative; and then, one by one, removing the other restrictions until we finally reach the point where any new combination, new, that is, to you, might be classified as rather low-level innovation. The person who is just starting to learn to apply the creative process will find it very difficult at first to meet all the qualifications that we have set up for true, high level creative activity. But he should not be discouraged. If, in arriving at his solution, he does meet some of the factors we have listed, his work in some measure may be classified as creative. It is conceivably true, also, that some problems may not be worth the time and effort that must be expended to meet all these qualifications, and therefore, the ultimate solution should fall short of the ideal goal. Thoughtful judgment should go into the choice of problems as well as in deciding how much effort should be devoted to their solution.

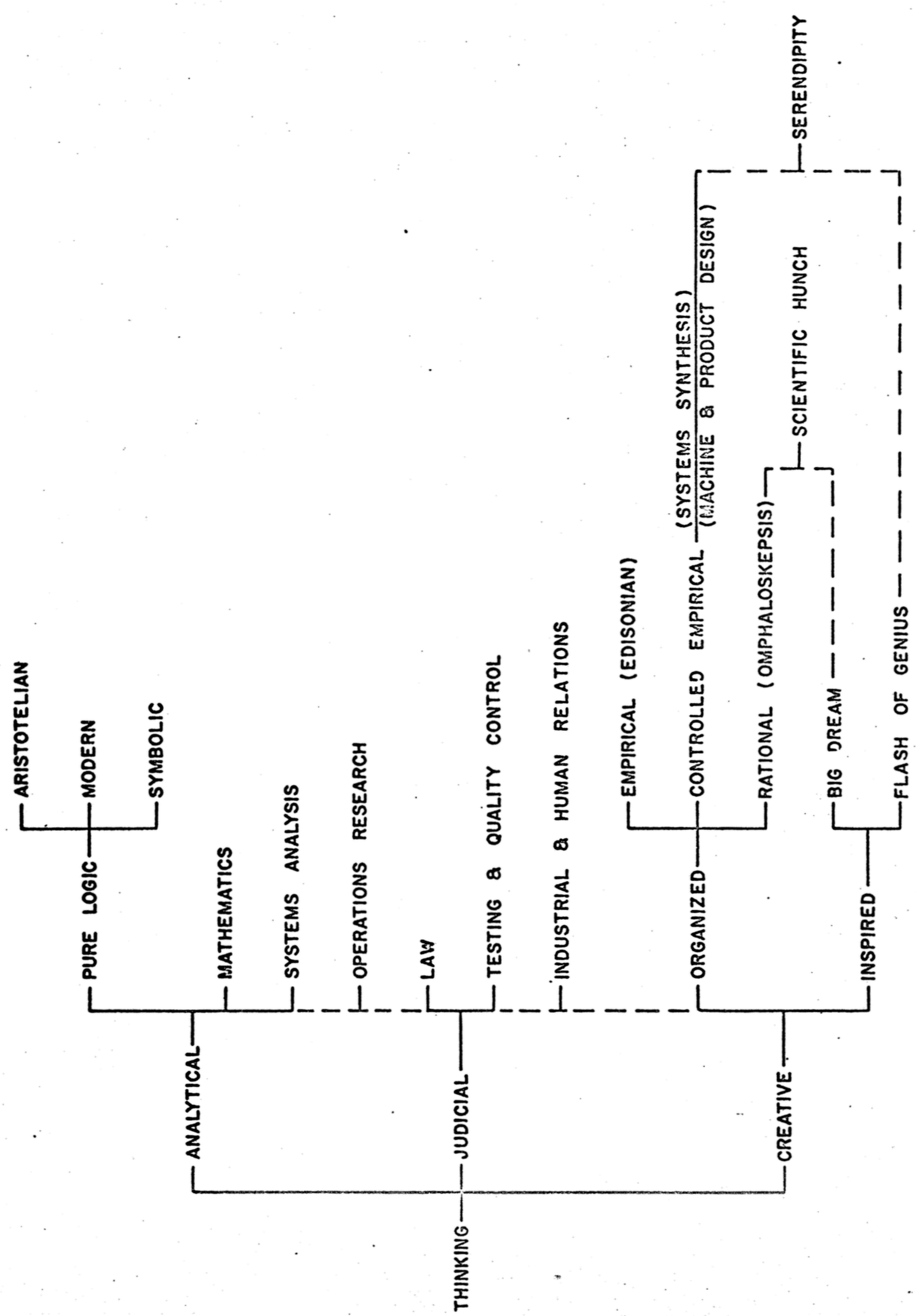
Before leaving the question of creativity, it might be worthwhile to look briefly at the included chart in order to get a clearer picture of the spectrum of thinking (p. 74). Under the analytical heading, I have included pure logic, mathematics, and systems analysis as examples. It must be obvious that these three do not exhaust the list of possible examples. In using logic and mathematics as a tool, no imagination or judgment is needed, although they would probably help. I have seen students who considered themselves to be quite capable mathematical computers end up with answers that might be a factor of 10 off and be completely ignorant of the nonsensical answer until they find their error in calculations or someone points it out to them. Judgment in this case would merely involve having some feeling for the physical processes that their mathematical formulas refer to. For some, though, this is asking too much.

I have included operations research close to analytical thinking, but separate from it. It is also connected to the other two modes of thinking by a dotted line, indicating that while operations research is primarily an analytical tool, yet the effective researcher must draw heavily upon judgment and imagination.

Under the judicial heading, I have included two examples, that of law and testing and quality control. Both of these areas of activity depend primarily on making good judgments, making right decisions, but, as we have pointed out, they also depend upon keen analysis, for the two or more things that are to be compared or evaluated must be completely understood, and this understanding can be gained only by analysis. Independent of judicial yet closely related to it is industrial and human relations. This too is connected to the creative classification by a dotted line.

Under the creative classification, I have included two subheadings which refer to the two general categories of approaches that are used in carrying out creative work. The group of organized approaches is so named because they usually exhibit a logical, orderly, step-by-step type of problem solving technique. While it includes primarily all the research activity done by large industrial groups, it does not get its name from this fact. The scientific method is essential to these approaches; the thinking processes are organized. The other category of creative approaches is labelled inspired. The approaches that would be classified in this category are those closely associated with the art of creativity rather than the science. Big leaps in knowledge are apt to occur using these approaches, as compared with the slow but steady step-by step advancement made using organized techniques.

The category of organized approaches might be broken down into a number of more restricted classifications. Three examples are shown here. The empirical approach, frequently called the Edisonian approach, consists mainly of an endless number of trial-and-error experiments. Edison's name is given to this classification because he frequently used this method in arriving at solutions to his problems. It has been said that in his search for the best material out of which to make his incandescent filaments, he tried over sixteen hundred different materials, even including Limburger cheese. He was a tireless experimenter, and it was because of this attribute, perhaps, that he is supposed to have once said that invention was two percent inspiration and ninety-eight percent perspiration.



A more modern example of the Edisonian approach is the late Tom Midgley of General Motors Corporation. His search for a knock inhibitor for internal combustion engines lasted for many years, and during that time he and his group tried an almost fantastic number of items and combinations of items in their search for a good solution.

Again, every conceivable type of compound was tested, even many that seemed at first glance wholly absurd. But, it was one of these absurd ideas that finally led to the discovery of the knock-inhibiting qualities of tetra-ethyl lead.

The controlled empirical series of approaches includes the majority of industrial research and development activity. Trial-and-error is resorted to at times, but a lot of wasted motion and effort is prevented by a more thoughtful approach to the problem solving situation. The ratio of mental effort to physical effort is increased in this category. Careful thought is given to the statement of the problem and the setting up of seemingly logical hypotheses to be later tested by experimentation.

The rational approach is a further extension of the amount of mental activity that is carried out prior to physical testing. Charles Nicolle, the French Biologist is an excellent example of this, and Hans Zinsser, writing about him said:

> Nicolle was one of those men who achieved their success by long preliminary thought before an experiment was formulated, rather than by frantic and often ill-conceived experimental activities that keep lesser men in ant-like agitation. Indeed, I have often thought of ants in observing the quantity output of "what of it" literature from many laboratories. Nicolle did relatively few and simple experiments, but every time he did one, it was the result of long hours of intellectual incubation during which all possible variants had been considered and were allowed for in the final test. Then he went straight to the point without wasted motion. That was the method of Pasteur, as it has been of all the really great men of our calling whose simple, conclusive experiments are a joy to those able to appreciate them.

Strangely enough, some men can adapt themselves to a number of different approaches, and Midgley, whom we have already mentioned seemed to be one of them. He arrived at the solution to the problem of getting a better refrigerant in three days' time. Most of this time was spent in contemplating the periodic table and synthesizing, analyzing and evaluating mentally. After he had decided what the new combination should be, he made one and only one experiment, and, fortunately, this experiment verified his hypothesis and Freon was developed. Midgley, in his Perkins Medal Lecture, told the story of how chance also entered into the discovery of Freon. He needed a certain rare chemical compound to carry out his one test of verification and discovered that there were only three small samples available in the country. These were quickly ordered and when the first of the three samples arrived, he set to work on his test, which did verify the hypothesis, so he immediately sent his report to "Boss" Kettering, and, in effect, forgot the matter. Sometime later, however, he happened to notice the other two samples of this chemical that had arrived too late to use, and he thought he might repeat his test. These new tests, however, failed, and he was quite disturbed. He couldn't figure out what was wrong, for at that time, Freon was behaving as his first test indicated it would. The trouble was finally located in that these last two samples of the rare compound were discovered to be contaminated. Had one of these two samples arrived first, his original hypothesis would have been denied, and he might have gone on to something else. This, of course, is pure speculation, but it does seem that at times chance does play a part in the creative process. Pasteur, of course, said that chance only favors the prepared mind.

A British officer is supposed to have given a special name to this rational approach to creative activity. He calls it "omphaloskepsis." This means deep thought and contemplation of the navel. This army officer thought that certain Occidental habits closely paralleled this Oriental process with the substitution of “feet on desk” for the navel.

Under the inspired heading, I have listed two subcategories, similar in some respects, yet different in others. The first I have called the big dream approach, and this is carried out by asking yourself the biggest question you possibly can, by dreaming the biggest dream that you possibly can, by sort of soaring off into space with a grand idea, and then expending every possible effort to answer this big question, to make this big dream come true, to get some tangible tie between your flight into space and solid reality.

Those who practice this approach, and Dr. Edwin Land of Polaroid Corporation is an excellent modern example, say that on occasion they have to step down a dream or two before the final realization can be achieved. This was the technique that he used in inventing the Land Camera. His biggest dream was a camera that would give a full color picture in a matter of a few seconds after exposure. In trying to make this big dream come true, he ran into a number of seemingly insurmountable difficulties. So, he stepped down a dream to a black and white picture in a few seconds after exposure. But again, at this early stage in the invention process, he ran into blocks that he could not seem to get around. And so, he stepped down one more dream and finally settled for the original sepia-toned print that first came on the market. Dr. Land conceived and carried out this invention entirely on his own and with the help of a few technicians built the first working model and constructed bread boards that would demonstrate the techniques for making the film. At this point he turned the models over to his research staff and they, using the controlled, empirical approach, have made steady improvements of the original invention. Orthochromatic black-and white films have been developed. A few months ago very high speed panchromatic black-and-white film was made available and rumor has it that before long they are apt to come out with a full color film. A large, creative step was made using the big dream approach. This was a functional innovation and looking back through the history of invention, it seems that a large share of the functional changes was brought about in this fashion. Less creative acts, improvements to the big dream, are usually made in a step-by-step fashion, following one or more of the organized approaches.

The flash of genius is another type of inspired approach. It occurs in many types of problem solving situations, and is called insightful behavior. It ranges from the common experience of trying to remember a forgotten name to Archimedes running naked down the street shouting “Eureka “ (we have already discussed it under the bisociative process). It is important to note, however, that in most creative work the best way to court insight is to thoroughly immerse yourself in your problem, to have a clear understanding of the nature of the problem, all its data and all its limitations, and then to conscientiously strive for a period of time, to develop all the possible, acceptable hypotheses that might be useful in solving the problem. After periods of unproductive hard work, it is then suggested that you forget the problem completely. Do something else. Relax and let the subconscious take over and incubate this new problem along with all your past experience. Suddenly, when you least expect it, a day, a week, or a month later, an answer will pop into your mind. Why and how no one knows, but this is the flash of genius.

Combining the flash of genius with the controlled empirical approach gives rise to a process that has brought back an old word into popular usage – serendipity – the happy faculty of stumbling upon things of value when looking for something else. I am sure that this approach exists and that it has proved fruitful on many occasions, but not exactly in the fashion that the definition indicates. I believe, like the Greek, Heraclitus, that you never find the unexpected unless you are looking for it. You do not stumble upon things of value unless your mind, at least subconsciously, is prepared to recognize it. You must be sensitive to problems and to solutions; you must be keenly observant and highly associative in your thinking so that these things of value will be recognized when they are seen.

One other combination of approaches should be mentioned, that of the scientific hunch. I have shown it as a combination of the rational approach and the big dream approach. It arises out of deep contemplative thought, yet thought that is frequently quite speculative and dream-like in character. It is not wholly rational, for frequently it is nothing more than an emotional feeling, a "hunch" that such-and-such will occur if I carry out steps A, B, and C. This last approach has been investigated quite carefully and reported by Platt and Baker and this reference is included in the Bibliography.

Summary

In this section we have tried to define the types of problems men face in everyday life and have classed them as analytical, judicial and creative. Analytical problems have one and only one right answer, while creative problems have a complete spectrum of possible solutions. The creative process involves combining and recombining past experience into new patterns and configurations that better solve some need of man. The need may be implied or expressed. In all cases the new solution ends up as a tangible result, it is forwardly oriented in time and exhibits the quality of synergism. The new combinations that we called invention or innovation usually involve bringing together into a tenable relationship two or more seemingly disparate objects or ideas. Disparate in that they are habitually incompatible not logically incompatible. This process Koestler calls bisociation as distinct from association. In order to be creative, mastery in use of the process is more important than the type of problems that you work on. And finally the results of creative activity can be arranged in some kind of value sequence or spectrum, depending on whether or not you meet and satisfy all of the limiting qualifications.

Factors Influencing Creativity

There have been waxings and wannings in the productivity of creative and imaginative people throughout recorded history. This may be due in part to the inherited creative potential of the individuals, but more probably is due to the changes in the cultural environment. We will devote some time during the next two weeks to discussing the influence that culture has on the productivity of creative people. And I am sure that one of the reasons why there is an increasing interest in the creative process in certain circles today is that some people are becoming aware of the tremendous pressure that is being exerted on them to conform. In some areas, the "herd" state actually exists and the area that this thinking influences increases daily. Our country is by no means immune to this kind of thinking, and there are many signs showing that we are becoming a culture, as David Riesman would put it, "of other directed people rather than inner directed people."

John Steinbeck said in *East of Eden,*[42]

> I don't know how it will be in the years to come. There are monstrous changes taking place in the world, forces shaping a future whose face we do not know. Some of these forces seem evil to us, perhaps not in themselves, but because their tendency is to eliminate other things we hold good. It is true that two men can lift a bigger stone than one man. A group can build automobiles quicker and better than one man, and bread from a huge factory is cheaper and more uniform. When our food and clothing and housing all are born in the complication of mass production, mass method is bound to get into our thinking and to eliminate all other thinking. In our time, mass or collective production has entered our economics, our politics and even our religion, so that some nations have substituted the idea collective for the idea God. This in my time is the danger. There is great tension in the world, tension toward a breaking point, and men are unhappy and confused.…
>
> Our species is the only creative species, and it has only one creative instrument—the individual mind and spirit of a man. Nothing was ever created by two men. There are no good collaborations, whether in music, art, in poetry, in mathematics, in philosophy. Once the miracle of creation has taken place, the group can build and extend it, but the group never invents anything. That preciousness lies in the lonely mind of a man.

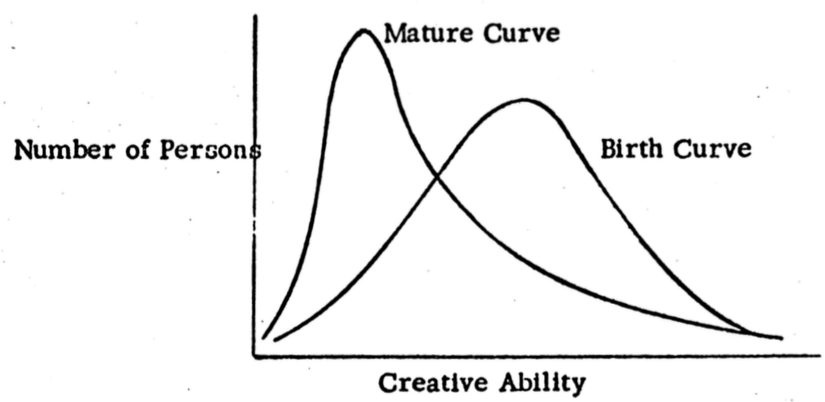
Creative Engineering, then, emphasizes the individual, the "Uncommon Man" as Crawford Greenewalt of duPont has named him. In a recent speech[43] Mr. Greenewalt said,

> Even the folklore admonishes us with pious phrases to put our trust in mass rather than man, as in the tired, old doctrine that no man is indispensable. It seems to me that this country and the world have been enriched and invigorated most conspicuously by indispensable men, for the right man with the right idea at the right vortex of history has always been the indispensable man. Think of Newton, Lavoisier, Franklin, Archimedes, Gutenberg, and a host of others. Certainly the world could ill afford to dispense with their discoveries….
>
> If I were faced with a choice between a society that sublimated the good with the bad, I think I would rather take my chances with the scoundrels than risk losing the creative force represented by the gifted individual, or what we might call the uncommon man….
>
> Try as we will, we can create no synthetic genius, no composite leader. Men are not interchangeable parts like so many pinion gears or carburetors…and behind every

> advance of the human race is a germ of creation growing in the mind of some lone individual, an individual whose dreams waken him in the night while others lie contentedly asleep….
>
> I know of no problem so pressing, of no issue so vital. For unless we can guarantee the encouragement and fruitfulness of the uncommon man, the future will lose for all men its virtue, its brightness, and its promise.

Not only are we emphasizing the individual, and we will go into this in more detail later, but we are also emphasizing the imaginative aspects, the synthesizing aspects of the Creative Process. This is being done deliberately and very much at the expense of the very necessary analytical and evaluative aspects. It is assumed, and hopefully rightly, that those attending this course have had considerable training and experience in analytical techniques and have arrived at such a position in life that they have also had some, though perhaps less, experience in decision making. The synthesizing and creative aspects have had less attention in the past, we are merely trying to even the score. But please keep in mind that analysis and evaluation combine with synthesis to make up the personality of the creative individual.

Now then, this course is based on four hypotheses, neither clearly validated nor disproven. The first and probably most important is that all men are born with a very definite, although varying from person to person, potential for creative activity. If we were to plot the distribution of creative potential inherent at birth for any large sample of the average population we would in all probability get a typical normal distribution curve like the one plotted below.



There would be some creative morons and some that would rank in the genius classification, but the great mass of us would lie somewhere in between. However, for one reason or another, and some of these will be discussed later most of us fail to realize at maturity the potential we started with at birth and the curve will be distorted as shown. A few will realize their total potential and again it will be the moron and the genius. No matter what we do to the genius, the pressures we apply to him, the blocks we place in his path, he will somehow get around them all and make his gift to society.

The second and almost as important hypothesis is that it is possible to materially increase the degree to which one realizes his total potential by understanding, practice, and exercise. The increase can vary from ten percent to several hundred percent, depending in part on your position on the two curves and also on the effort you expend in study and practice. If the average increase in effectiveness were only twenty-five percent, the manpower shortage in research and development labs would be eased tremendously.

The third and fourth hypotheses deal with the speculation on the universality and uniqueness of the creative process and on the partially established fact that the three modes of thinking are partially, if not wholly independent of each other, each made up of still more basic mental factors. It seems most plausible to me that there should be something universal about the creative process. This is not saying that there should be a single right answer to the question of how to be creative, but that the creative poet, artist, scientist, engineer, businessman, housewife, what have you, should be able to drink at the same fountain and be revitalized. The one common experience that these diverse groups share is the creative process, the process of innovation, and it is here that they should be able to meet and communicate with each other to their mutual benefit. Not only is this interchange possible, but it is also highly desirable, more—it is absolutely necessary. Bronowski has shown quite clearly in his book "The Common Sense of Science" that it is only in those cultures where science and art complemented each other, where the two walked hand-in-hand that progress is inevitable. We must have some common experience, some universal referents if we are to communicate intelligibly and intelligently and the creative process is that common experience.

Dr. J. P. Guilford of the University of Southern California has been working for a number of years now under an ONR[44] contract in an effort to define some of the basic factors make up the mental equipment of high level personnel. He first hypothesized the three modes of thinking as analytical thinking, judicial thinking, and creative thinking. His factor studies of the creative mode seemed to identify and isolate a number of basic factors unique to the creative personality. Four of his factors will be discussed here, problem sensitivity, fluency of ideation, flexibility, and originality.

Problem sensitivity, as originally conceived and defined by Guilford was that ability that made men sensitive to their surroundings. Rogers and Mooney[45] speak of this as "openness to experience," possibly a more inclusive term. It is being aware that a problem exists. Sometimes it is no more than a feeling, a hunch, that can't be clearly defined until a great deal more investigation and study is carried out. It is also the ability that can distinguish between basic, fundamental error and experimental error. It is looking for the unexpected and finding it. It is the "prepared mind" that is apt to be treated kindly by "chance" or "serendipity."

I have found from my own work, however, that problem sensitivity involves more than an awareness of problems, for it also seems to be associated with problem statement and the development of a spirit of inquiry and the ability to ask meaningful and answerable questions. Problem statements may limit or free the imagination of the solver. They may precondition his thinking along such narrow and rigid lines that very desirable solutions are precluded. At the other extreme, I suppose they can be so nebulous and ill-defined that no one knows what is wanted or where to start. Graham Wallas said, "Our mind is not likely to give us a clear answer to any particular problem unless we set it a clear question, and we are more likely to notice the significance of any new piece of evidence or new association of ideas if we have formed a definite conception of a case to be proved or disproved."

Once you are aware of a problem, however, you must then be able to state it clearly and precisely and be able to communicate it to others. Industry is generally interested in four types of problems, depending on whether they are *specific* or *general*, and of *immediate need* or *long range need*. Emerson is supposed to have said that if a man builds a better mouse trap, the world will beat a path to his door. Let us take this little problem and see if we can state it so that it will fit into the four classes I have just mentioned.

The first thing to do, however, is to make sure that we know exactly what need we are trying to fill, what goal we are trying to reach. I think that we can decide right at the start that our goal is not "to have a path beaten to our door," but it might not be quite so easy to decide that our goal might not be building a better mouse trap either. Actually, our prime goal is to get rid of mice in some way or other and when stated in this way, we don't care whether we trap them, electrocute them, drown them or scare them to death, anything to get rid of them. The basic goal usually defines the general, long-range problem. In this case, devise a better means of getting rid of mice. The words that you use in defining the general problem have to be chosen very carefully so that the referents of these words or their connotations do not limit the thinking of the designer to whom you assign the task. The wrong word can unintentionally predispose the thinking of the designer to follow a limited number of paths and preclude his investigation of other equally desirable and fruitful ones. I said "get rid of" rather than "kill" or "exterminate." We don't want any mice around so in addition to thinking up ways and means of killing them, we might profitably consider how we might get them all to emigrate to the South Pole or to commit mass suicide like the lemmings of Scandinavia. In the same way, exterminating, to me at least, connotes poisoning by gas or in food, and is therefore limiting.

Suppose that we are already in the mouse trap manufacturing business and are fairly successful. We will not want to spend a large portion of our research money on the very general problem that I have just stated, but we should consider it to some extent. If we don't, someone else may discover a better means of getting rid of mice and make our traps as obsolete as the automobile made the horse and buggy. We will want more *long range*, *specific* problems in trap design and one might be this: Redesign Trap Model Q2-476, and design the necessary machinery so that it can be built and assembled entirely automatically. This is quite specific and there is no question but that it is long range.

A *general problem* of *immediate need* might be: Find ways and means of cutting over-all cost of our product; while a specific, immediate problem in the same area might be: Lower assembly costs of sub-assembly B. I sincerely hope that the type of example that I chose for this part of the discussion has not detracted from the importance of the overall subject matter. Problem statement is a serious business and vital to the success of any company.

I was giving a talk a number of years ago to an AMA[46] annual convention. I was discussing some of the design problems associated with automation. One of the strong points that I tried to make was the importance of re-evaluating each product that one makes, redefining in as general terms as possible, the need that that product is supposed to fill. The point that I was trying to make was that there might be some other way of better satisfying that need, and at the same time better lend itself to automatic production. I gave a number of examples in order to illustrate the point. After the speech, one of the men approached me and said that although he enjoyed the talk, he felt, and I must admit that an awful lot of it was bunk, especially that part about redefining aims. It turned out that he was the research director for a ball-bearing manufacturer, and that his prime goal was to develop better and cheaper ball bearings. I suggested that he should, perhaps, think of his goal as one of providing better devices for overcoming friction in rotary motion, to which he immediately replied, "What the hell is that except a ball bearing?"

It is very possible that the ball bearing is at the present time the best answer to overcoming friction in rotary motion. If there is a better answer, however, this man will never find it, neither will any of his staff if he continues to channel all of their efforts into designing better and cheaper ball bearings. Some man with considerably broader vision may find a different approach that is far superior and my friend will be out of a job!

I have discovered, time and time again, working with both students and groups in industry that if you are looking for new ideas, new approaches, you should state your problem in as general terms as possible. If you state your problem as one of designing better toasters, you will, undoubtedly, get cheaper toasters, prettier toasters, and more efficient toasters, but you won't get new solutions to the problem of *heating*, *browning* and *dehydrating* the surface of bread which is your prime goal. But, as we indicated in an earlier chapter, perhaps you want to accomplish this prime purpose by actually building better toasters. You are equipped to build toasters, so how can you insure that your designers and engineers will come up with new and better ideas that can be economically translated into marketable products. Maybe one way would be to maintain the direct, specific problem statement, but then to supplement it with sub-statements or redefinitions in broader, more general terms. Perhaps even better, they might be questions rather than problem statements.

Let me give you an example. One of the case studies that we have used and that has proved effective although somewhat difficult is a case study on Box Car Design. This case study fairly briefly describes the construction of present day box cars, and how they are used in transporting freight from one point to another. Many of the problems associated with box cars are mentioned and discussed. The advantages of shipping in box cars (and there are some) are also mentioned. As in all case study work, the student carefully reads over the case, picks out a problem area in which he believes work should be done, and that he is capable of handling, defines his problem and then proceeds to solve it.

The main problem in this case is obviously to design a better box car. But better in what respect? What are some of the things wrong with the present day box cars? The student or a research worker might list five general categories of trouble, although there are others.

1. Box cars are difficult to load and unload.
2. Claims against the railroads due to damage in transit approach 150 million dollars a year.
3. Box cars are not well used. It has been estimated that only 12 percent of a box car's life is spent in going from A to B carrying a load, and almost half of this small percentage is spent going from B back to A empty.
4. Box cars are not as versatile as they could be.
5. Better techniques of handling, spotting and keeping track of cars in transit are badly needed.

These sub-problems are still good size design areas and of sufficient magnitude to challenge the best of designers and engineers. But these sub-problem statements still contain the word “box car” or refer quite directly to railroading as it is practiced today. If by restating these sub-problems in as general, non-specific terms as possible so that we abstract the essence of the problem at least during the idea stage, I believe that chances of arriving at a new and better solution will have much higher probability.

Instead of saying that box cars are difficult to load and unload, I might ask myself the question, “How do I fill or empty things?’ Under item two, I might ask the question, “How do I pack things so that they won’t break?” “How can I absorb impact?” Or, “How can I isolate things from impact?” Under item three, better utilization of box cars, I might ask myself, “What all can I do with the volume 8 feet by 10 feet by 55 feet?” Under item four the question might be, “What is convertibility in transportation?” And, under item five, “How do I sort and keep track of things?”

These, of course, are very general questions, and should produce a great many answers.

When all possible answers have been arrived at, they should then be evaluated in the light of the severe restrictions that are presently, although they probably don’t have to be, inherent in present day railroading, and those solutions that can’t be modified to fit these limitations are tossed out. I am convinced that more novel and more useful solutions can be arrived at in this fashion than when one is constantly confronted with the limitations of a more specific problem.

Mr. Killeffer, in his book, “The Genius of Industrial Research” has an interesting chapter on problem statement. While he seems to emphasize making the problem as narrow and specific as possible, he does indicate that during the stages of problem formulation, the broad viewpoint must be maintained and that eventually management must narrow the problem down for assignment to research. He states:

> Perhaps the most important step in any research is to understand the problem at the beginning. Understanding it is an essential prerequisite to stating it clearly and correctly. The significance of the terms in which an industrial problem is stated has been suggested but not elaborated in a previous chapter in discussing boiler scale. Control of the crystallization of calcium sulphate from boiler water to prevent scale in the boiler may be stated in almost any number of ways; the terms depend upon who is making the statement and for what purpose. The stockholders would think of boiler scale only if it became a question of dividends. The directors might think of it as effecting efficiency of operation. To the president, it would be a matter of diligence of the works manager, and the works manager would look to the superintendent, who in tum would question the engineer. Finally at long last, the director of research might be given the problem, but most probably in the form of a question of the efficiency of the power plant.
>
> At this point a great many solutions are still possible: the plant might purchase power; it might seek a new source of boiler water; it might exchange steam turbines for diesel engines; it might install a water treating plant; it might change the blow-down cycle of the boilers to throw out much of the scale as it is formed; and finally it might initiate a search for a method of flocculating calcium sulphate to prevent it from scaling inside of the boiler as we have noted.
>
> Only when the problem is stated in some such terms as these last is it a proper subject to turn over to an individual in the research department as soluble by the methods of

research. It must already have undergone a succession of narrowing operations to bring both problem and solution into focus.

It must be obvious from what I have already said that I see no reason why researchers or designers can't be as creative and imaginative as management and why they can't start out with a very broad viewpoint and eventually narrow the problem down. The creative designer should be expected to look into all possible approaches, to formulate and reformulate problems and sub-problems until he finds a solution that satisfies as many of the prime goals of the initial problem as time and expenses allow.[47]

I have mentioned that sometimes the awareness of a problem is only a feeling that one has and that it is hard to define. In such instances I find the following procedure to be very helpful. (See the accompanying charts [at the end of this chapter].) I start out by listing my general feeling as, "Something is wrong with_____!" Then I start out with an "organized" random attack on this nebulous feeling. With the use of every trick I can think of (some of these will be discussed in the next chapter) I list every aspect of the problem as it comes to mind without regard to sequence or relationship.

There will be theories and speculations; definitions and questions; I will search for attributes and independent variables. When as many of these are listed as I can easily think of, I start to organize them in logical groupings and then to look for some relationship between these groupings. This leads to the first Problem Statement and possibly to three or four specific substatements.

The search for a fundamental, basic relationship between the substatements should lead to the generic restatement and then to specific project statement derived from the generic restatement. The second chart is a partially worked out sample problem that will give you a better idea of how the system might work.

In the third place, problem sensitivity involves asking meaningful questions. Meaningfulness, in this case, is based on the operational definitions of modern logic. If a statement is made or a question asked that does not, at least implicitly, describe certain operational procedures that can be carried out in order to completely define the terms used or to re-experience the situation involved, the question or statement is operationally meaningless. If reasonable operational definitions are expressed or implied, but they cannot for various reasons be carried out, the statement may be indeterminate. Finally, if the predictions made in the statement are not verified by the operational procedures expressed or implied, then the statement is false.

The ability to ask questions is one that we all had as children but usually as the result of adult response we soon decided that it is a useless skill or one that causes more trouble than help and so we discard it. We are told to keep our eyes open and our mouths closed, or worse still, that "curiosity killed the cat." But the spirit of inquiry is basic and essential to the creative personality. The art of asking good questions must be revitalized if we are to be successful innovators. This is all a part of problem sensitivity.

Another Guilford factor is that of fluency. He hypothesized and later verified that the creative person is more fluent in his ideation than the less creative; he has more ideas per unit time. Guilford seemed to uncover different types of fluency depending on the limitations imposed on the goals and the approaches to the goals. I am inclined to believe that there is only one fluency factor but that fluency is definitely facilitated or inhibited by the absence or presence of simultaneous evaluation. Evaluation must be restrained temporarily while one is thinking up ideas or hypotheses, and in the same fashion the limitations of the problem should be temporarily forgotten. This applies just as well to economic limitations as it does to mechanical feasibility or to the adaptability of man or machine. Fluency then, ties in with correct problem statement. But even with a highly restrictive problem fluency can be obtained if the limitations are relaxed for a short period of time. I recently gave my students a short case problem aimed at getting people across the Harvard Bridge in comfort and safety and with little expended effort on their part. Those who tried to think of ways and means of transporting "feeble old ladies" safely across the bridge under the worst possible conditions had a very difficult time of thinking up any suitable solutions. On the other hand, those who realized that the above limitations might have to be applied to the final solution, but who temporarily laid them aside and considered every possible means of getting something from one place to another came up with over 75 different ideas in a little under twenty minutes. It is true that when those 75 ideas were evaluated in the light of severe restrictions, most of them had to be eliminated (shooting people from one side of the river to the other with a cannon, for example). Yet, five of the ideas looked as though they had great merit and possibility.

Schiller recognized this and explained it very clearly in a letter to a friend.

> The reason for your complaint lies, it seems to me, in the constraint which your intellect imposes upon your imagination. Here I will make an observation and illustrate it by an allegory. Apparently, it is not good – and indeed it hinders the creative work of the mind – if the intellect examines too closely the ideas already pouring in, as it were, at the gates. Regarded in isolation, an idea may be quite insignificant, and venturesome in the extreme, but it may acquire importance from an idea which follows it; perhaps in a certain collocation with other ideas, which may seem equally absurd, it may be capable of furnishing a very serviceable link. The intellect cannot judge all those ideas unless it can retain them until it has considered them in connection with these other ideas. In the case of a creative mind, it seems to me, the intellect has withdrawn its watchers from the gates, and the ideas rush in pell-mell, and only then does it review and inspect the multitude. You worthy critics, or whatever you may call yourselves, are ashamed or afraid of the momentary and passing madness which is found in all real creators, the longer or shorter duration of which distinguishes the thinking artist from the dreamer. Hence your complaints of unfruitfulness, for you reject too soon and discriminate too severely.

"Flexibility" of thinking is the third Guilford factor that I want to mention. This ability reflects itself in the wide variety of approaches that the creative person chooses to investigate. The non-creative person's past experience provides him with a comfortable little rut in which to operate and he has great difficulty getting out of that groove. There are many ways in which to measure the flexibility of one's thinking. Dr. Guilford did it very dramatically by asking people to list as many uses they could possibly think of for very common, every-day items such as a red brick. People could show a great deal of fluency in their thinking by listing a long column of uses, but they all fell into one category such as construction or ornamentation, they showed little flexibility. Actually there are some fourteen categories under which you might list the uses of bricks and the flexible thinker gives some thought to most of them. Bricks have mass as well as spacial dimensions. They make good doorstops or bookends, or are useful in drowning cats or throwing at enemies. Bricks have color and they might be ground up to form pigment for paint. The ground up particles have abrasive properties. They might be used in grinding compounds or be sprinkled on icy walks to increase the coefficient of friction. Bricks have thermal capacity. They might be used in lieu of a hot water bottle, or in heating a quantity of water that can't be placed over a flame.

Flexibility is having many tricks in your bag along with confidence in your ability to use them effectively. It is the ability to change pace used so successfully by athletes. It is also the ability, that can be consciously developed, that allows you to be both an observer and a participator at the same time or in alternation. It is most desirable to have this duality of personality be constant in time if the observer half is not acting as a judge or evaluator; if it is not being your conscience. Perhaps the alternating roles would be the safest at first. This would allow you to step back every so often and review what you have done to date and to reconnoiter and determine the best path to continue along. This survey should be made from a number of different vantage points if it is to provide the greatest measure of flexibility.

The last Guilford factor that I want to discuss here is that of originality. It must be obvious that the highly creative person makes more novel and original combinations than the less creative. He consistently brings together "seemingly disparate" or "habitually incompatible" ideas or objects together to form tenable and useful new combinations. He has developed the healthy skepticism so essential; he has a strongly motivating "spirit of inquiry," and he is interested in all areas of human thought and activity. In addition he has the ability to relate, to associate ideas in one area with similar ones in another. He is a past master in thinking by analogy.

Aristotle first enunciated the three laws of association, and there has been little or no change in them since that time. We associate by seeing contrast, by seeing similarity or by contiguity of ideas, nearness in space or sequence in time. Problem sensitivity helps us see differences, and we have seen that this is very important for the creative worker. Seeing similarity helps us to form concepts, and if we are very generic in our observations and associations, the information that we do obtain becomes more useful to us in that it is more easily transferable. Many psychologists have pointed out that it is not sufficient just to obtain and retain information, but that the information be in such a form that it is easily transferred to a wide range of situations.

Free association is a term we are all familiar with. It is the sparking of one idea by the immediately preceding one, and if one could observe one's own mind as one allows it to wander freely, one would note that some of the associative links were the result of similarities, others of contrasts, and still others due to the fact that similar events are taking place at the same time or in the same place. The subconscious mind undoubtedly works in some free association fashion when it is searching for a solution to a problem. Why some of the combinations it freely makes eventually creep into the conscious area no one knows as yet, the important thing is that they do.

We then experience what is called "insight." Once we have become aware of this new combination that the subconscious mind has brought together we can frequently trace back and see how the associations might have been made.

This subconscious, associative process that results in "insightful" solutions to problems is called "incubation" by Wallas and Osborn, but it rarely, if ever, takes place unless one has expended a great deal of conscious effort in the search for a solution in the first place. If one did nothing more than to define a problem, and then immediately turned it over to the subconscious for solution, the probability that one would be eventually forthcoming would be extremely small.

The mental attributes that I have listed are necessary but not sufficient to the creative personality. Along with them there are a number of emotional attributes that many of you, I am sure, would list as primary rather than secondary. First of all, a man must be motivated before he will begin to attempt to solve any kind of problem, analytical or creative. We have ample evidence that over-motivation is extremely disastrous, in that it inhibits creative activity, but I am afraid that more of us suffer from under-motivation rather than over-motivation. Passivity is probably the original sin, and initiative is what most of us lack, for once into a problem, most of us can generate enough interest to keep us going until the problem is solved.

Many studies have been and are being made on motivation, initiative, and so forth, and the new insights give us a more complete picture of their phenomena. For the most part it seems however, that the highly creative person just loves to solve problems. The great inventor invents because that is what he likes to do best; the great painter creates great works of art because that is what he likes to do. It is true that lesser lights are motivated by prestige or wealth or power and these must be taken into consideration for the number of genii that we will be concerned with is a very small one. However, at all levels of competency it is definitely helpful if, no matter how small or restricted a certain problem may be, it is somehow related to a larger, more comprehensive picture that, in turn, relates back to some basic need of man. This helps in the matter of orientation as well as providing initiative. If one can see clearly where one is headed and how his specific tasks contribute to a larger, more inclusive whole, he will be more highly motivated to make this task his own and to solve it successfully.

Willingness to take a chance, to gamble, may be another form of initiative. But it is an important aspect of the creative person's personality. The creative person has to be daring. He has to be a leader in his group for society, and he must constantly take calculated risks in his attempt to find better solutions to the problems that face mankind. He cannot stick to the safe, the tried and true, the prosaic approaches, and he must pioneer in new areas in a very daring fashion. Creating, unfortunately, also involves destroying. The man who is seeking a new, better solution to an old problem is doing so, in part, because he wants to destroy a present, possibly adequate solution. As John Steinbeck has pointed out, many people resist change and innovation not so much because they fear the new approach, but because to accept the new they must first give up the old, familiar, and seemingly adequate ideas that they have held for some time. The creative individual, then, must be a leader, he must be daring.

Properly motivated and willing to take a chance, the creative worker must, in addition, have self-confidence in his own ability to come up with a new and better solution. This is an extremely important emotional attribute and can only be developed through experience and exercise. It has been said that nothing breeds success like success. And this is probably true, but the corollary that failure breeds failure need not be true. If through continued application failures can be corrected, high orders of self-confidence can be developed. Actually, the fear of making a mistake is a very devastating emotional block to creative activity. People should realize that progress is made through failure as well as through success. I have had better success in training creative designers by helping them develop this spirit of self-confidence than I have in imbuing them with special design techniques or tricks of the trade.

The last emotional attribute which I will mention at this time is drive. Many people have indicated that they feel that this is the *prime* requisite of all creative workers. Edison, for example, has said that invention is two percent inspiration and ninety-eight percent perspiration. I am not quite sure that he had the percentages accurately distributed, but I do know that there is a great deal of work associated with the polishing and re-polishing of an idea before it becomes an acceptable, tangible result. I am somewhat disturbed and upset by the great number of people who are writing and speaking today on this general subject and who seem to believe that the idea is in itself the beginning and the end of the creative process. Ideas can frequently be a dime a dozen. It is only when these ideas are translated into workable prototypes that I believe they have value.

There are so many ways in which a good idea can be destroyed or made quite impotent that confidence in one's cause and the physical and emotional energy that allows one to develop and the idea is a prime requisite to innovation. It involves, as we shall see, the conservation of energies so that they are not dissipated in non-productive areas but are concentrated in the daring, vital, and productive areas. Drive also connotes a very definite enthusiasm for work; again this love of problem solving. I have a very dynamic, energetic friend who has proven himself to be a very successful inventor. He is a highly imaginative and original thinker, but he believes that erudition and imagination play second fiddle to the force which is commonly referred to as *drive*. He feels so strongly about this that he once said to me, "I hate inertia. I want men to move. Men who will move backwards and destroy themselves are much more desirable than those who stand still. At least they are out of the way. I feel that stupid men who have drive, energy or the will to accomplish get much further and do much more for the world than the scholar who wastes that which has been taught him."

We could go on and on listing attributes, one after another or expanding and modifying those we have already listed. I would like to close this section, however, with a brief listing of the attributes that Dr. Carl Rogers of the University of Chicago believes are essential to the creative personality.[48] First of all, he believes that the creative person must develop an openness to experience. This is not only an openness or an awareness of all the events occurring in his external environment, but also an awareness of the changes that take place within himself. He has developed this problem sensitivity, this questioning attitude. He is keenly observant and has the ability to be generic, so that he can make wide associations. Secondly, the creative person has developed an internal locus for evaluation and criticism. He is not forced to conform by outside pressures, and what is probably more important, he can turn on or off his judicial thinking at will. Lastly, Rogers points out that the creative individual has the ability to play or toy with ideas and concepts. He gets pleasure out of arranging and rearranging materials and ideas into new patterns and configurations. He is not afraid of fantasy.

Now then, it is possible for an individual to have a rather highly developed potential for creative activity and who is potentially able to balance his ability to analyze, synthesize and evaluate, and to have the necessary initiative and drive to complete his novel ideas, yet to find himself in situations where it is almost impossible for him to work efficiently and effectively. These factors that tend to inhibit and prevent productive and creative activity we will call blocks. We can loosely group them under three headings, loosely because the things that affect thinking and action rarely if ever appear in pure culture. The headings I would suggest are *Perceptual Blocks*, *Cultural Blocks*, and the

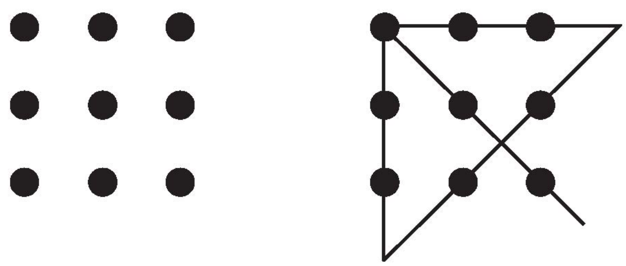
Emotional Blocks to creative activity. The blocks refer to all the ways in which we fail to get true, adequate, and relevant information about the outside world. As a gregarious living organism, we must associate with other living organisms and with the products of their hands and minds. These other individuals, both living and dead, and the things that they have created, have a tremendous influence on our own thinking. Many inhibiting factors arise out of this cultural area. The emotional blocks are by far the largest grouping, and they include all our fears, and most of the defense mechanisms that we build up in order to make our lives seemingly more tolerable. The emotional blocks influence and contribute to the blocks in the other two areas.

Let me give you just a few examples that will help define these categories more exactly. Many of the perceptual blocks arise out of the problems associated with what the psychologists call the *figure-ground* relationships. Two extremes would be, one, failure to distinguish the figure from the background, and two, concentration on the figure alone. A very dangerous tendency most of us humans have is that as we become more familiar with a certain area, we begin to label things within it as "obvious," and from then on pay little attention to them. Once a certain field of activity is labelled obvious or trivial, we limit our ability to separate figure from ground, and, as a result, our chances for productive and creative activity in that area is hampered, if not completely inhibited. It is only when some outsider or some amateur enters the field, a person who does not know what things are obvious or trivial, that any chance for innovation in this area can take place.

On the other extreme, familiarity with certain objects or concepts is frequently apt to establish a functional fixedness in our minds and we are unable to see this object as part of a number of figure-ground relationships. Dr. Bruner of Harvard reports experiments in which young high school students were given a number of problems of electrical circuitry. They had training and became very proficient in wires, buzzers, and knife switches in many combinations, but in the process became thoroughly imbued with the idea "switches are used for making and breaking electrical circuits." Later, when they were asked to make and perform a pendulum experiment, the only object that had any appreciable weight that was available to them was the knife switch, and they were unable to make the transfer from knife switches which are used for electric circuits to knife switches which might be useful for pendulum weights. The figure was too strong in their minds, there was functional fixedness.

Some interesting little demonstrations can be carried out to illustrate certain perceptual blocks. To point up the importance of getting true information consider the following example. Ask someone supposedly trained in science and engineering the following question. "Why is it when you look into a mirror you get a right and left reversal but you don't get an up and down reversal?" If they are typical of ninety-nine percent of those I have tried this on, they will scratch their heads and probably say, "Well, it's probably because your eyes are on a horizontal plane…. Now if your eyes were arranged vertically…." Or, "It's probably because one is symmetrical about a vertical axis and asymmetrical about a horizontal axis." They will give you a wide range of pretty wild solutions. You will be amazed to hear some of the new theories of optics that result! It will be rare when you get a right answer for all have accepted a false problem statement. The mirror actually provides a one to one reflection and no reversal takes place. We think of it as a reversal because we have oriented right and left to ourselves while up and down is a universal aspect of our earth. It must be obvious then that you cannot expect to get a correct answer from false data.

Taking in too much data, data that don't really apply, can also be disastrous. Consider the nine dot problem below[49] and its adjacent solution. You mark nine dots on a piece of paper in the shape of a square, making sure, however, that you do not use the word square as you describe the problem to the person who is going to solve it. You ask him to cross out all nine dots by drawing four straight lines without lifting the pencil or retracing a line already drawn. They will usually struggle for some time and then give up saying that it can't be done. When you show them the solution, their first reaction is that you cheated, you went outside the square. The square arrangement of the nine dots had such strong figure quality for them that they assumed (took in data that weren't specified or applicable) that they could not go outside of the square in the solution of the problem.



One last example that illustrates the need for searching for the most minute and almost subliminal clues in order that you have all the data that applies to the problem. I will print in block letters the words shown below using red and blue ink.

G E R M A N I U M   D I O X I D E
(red)   (blue)

I have a little prism with a yellowish cast to it and explain that the yellow coloring is due to using germanium dioxide in the glass melt. If I then place the prism over the two words a strange thing happens, the word germanium is inverted and the word dioxide is not…why? Here again is a good opportunity to get new and unusual theories on optics. Actually of course, both words are inverted but since all the letters in the word DIOXIDE are symmetrical about a horizontal line they read the same in either case. This little clue is missed by most.

There are any number of examples which we might quote to show how our culture influences our thinking and our activity. The ways in which we have been raised, influences of our elementary and secondary and advanced schooling, influences of our friends, our church, our political groups, may help and may often hinder our most effective, creative work. Certain things are done in our society, other things are very definitely tabooed. We may not know *why* they are tabooed, or when and how exceptions can be made, we have unconsciously and often consciously trained ourselves to avoid thinking in certain areas. For example, an experiment was run at Swarthmore a number of ago in which students were led, one at a time, into a medium sized room, in the center of which there was a two-inch pipe, about a foot long, bolted to the floor. Inside this pipe there was a ping-pong ball. The students were given a limited time in which to get the ball out of the pipe. There were a number of tools lying around the room—hammers, pliers, screwdrivers, crow bars, soda straws, pins, strings and so on. None of them were especially useful in extracting the ball from the pipe, although all the tools were tried by one or another of the students. However, in one corner of the room there was a pail of old dirty wash water, and eventually most of the students saw this water and floated the ball out of the pipe. But the important thing to note is that when the only water in the room was crystal clear ice water in a crystal pitcher, placed on a table covered with a white linen table cloth and surrounded by crystal goblets, not one of the students thought of using this water to float out the ping-pong ball. Ice water is for drinking, it is not for pouring into dirty pipes in order to solve problems.

The emotional area, as I have indicated, is by far the largest. The blocks contained therein are many and varied. They may arise from our fear of making a mistake, or our fear of making fools of ourselves, or our almost pathological desire for security or for conformity. Many of them stem from over-motivation, our desire to succeed quickly, and Bruner lists four blocks that may arise when we are over-motivated. First of all, there is a damaging tendency to narrow our field of observation. We look for and grab hold of only those clues that seem to be highly relevant to the solution of our problem, and we pass up many things that may lead to more novel and better solutions. Secondly, we give up what the psychologists call "vicarious-trial-and-error." We don't consider a number of possible alternatives in an attempt to pick the best one, but grab the first one that seems at all plausible. Thirdly, we fail to be generic in our observations. We fail to see or list the basic attributes or the specifications of the things or ideas that surround us. Knife switches are knife switches. They are not composed of a number of physical properties or a number of different materials, each of which has its own special list of properties and possible uses. Lastly, we fail to make use of the redundancy that co-exists with almost all information. We are apt to become too literal.

One interesting example of emotional blocks is that associated with detour-type problems. In animal experiments, for example, if you place a chicken inside a U shaped enclosure with some grain just on the other side of the base of the U, the chicken will try for hours to poke her head through the fence to try to get to the grain. She will make slight excursions to the right and left, but notice as she does this that she gets further from her goal. She immediately comes back to the nearest point and tries again. A dog, on the other hand, placed in the same enclosure with a bone on the outside, will very quickly discover the open end and reach his goal by way of the detour. Unfortunately, Mr. C. E. Wilson[50] to the contrary, I believe people are more like chickens than they are like dogs. Very few of us are willing to take a detour, to go in the opposite direction to reach a goal that seems almost within our grasp. This is a typical emotional block.

The subject of blocks will be covered in more detail later in the program so that these few examples should suffice at this time. Listed below, however, are examples that might fall into the three categories that have been set up.

PERCEPTUAL BLOCKS

1. Difficulty in isolating the problem (can't separate object from field).
2. Difficulty in narrowing the problem too much (paying little or no attention to the environment).
3. Inability to define terms or isolate attributes.

4. Failure to use all of the senses in observing.
5. Difficulty in seeing remote relationships (inability to transfer).
6. Difficulty in not investigating the "obvious."
7. Difficulty arising from not recording "trivia."
8. Difficulty arising from conceptualizing on the basis of superficial likeness (over emphasis on past experience).
9. Failure to distinguish between cause and effect.
10. Difficulty in working with false data (using concepts derived in one field and applied to another where they don't apply).

CULTURAL BLOCKS

1. Desire to conform to an accepted pattern.
2. Must be practical and economical above all things so that judgment comes into play too quickly.
3. Not polite to be too inquisitive and not wise to doubt everything.
4. Overemphasis on competition or on cooperation.
5. Too much faith in statistics.
6. Difficulties arising from over-generalizations.
7. Too much faith in reason and logic.
8. Tendency to follow the all-or-nothing attitude.
9. Too much or too little knowledge about the field that you are working on.
10. Belief that indulging in fantasy is a waste of time.

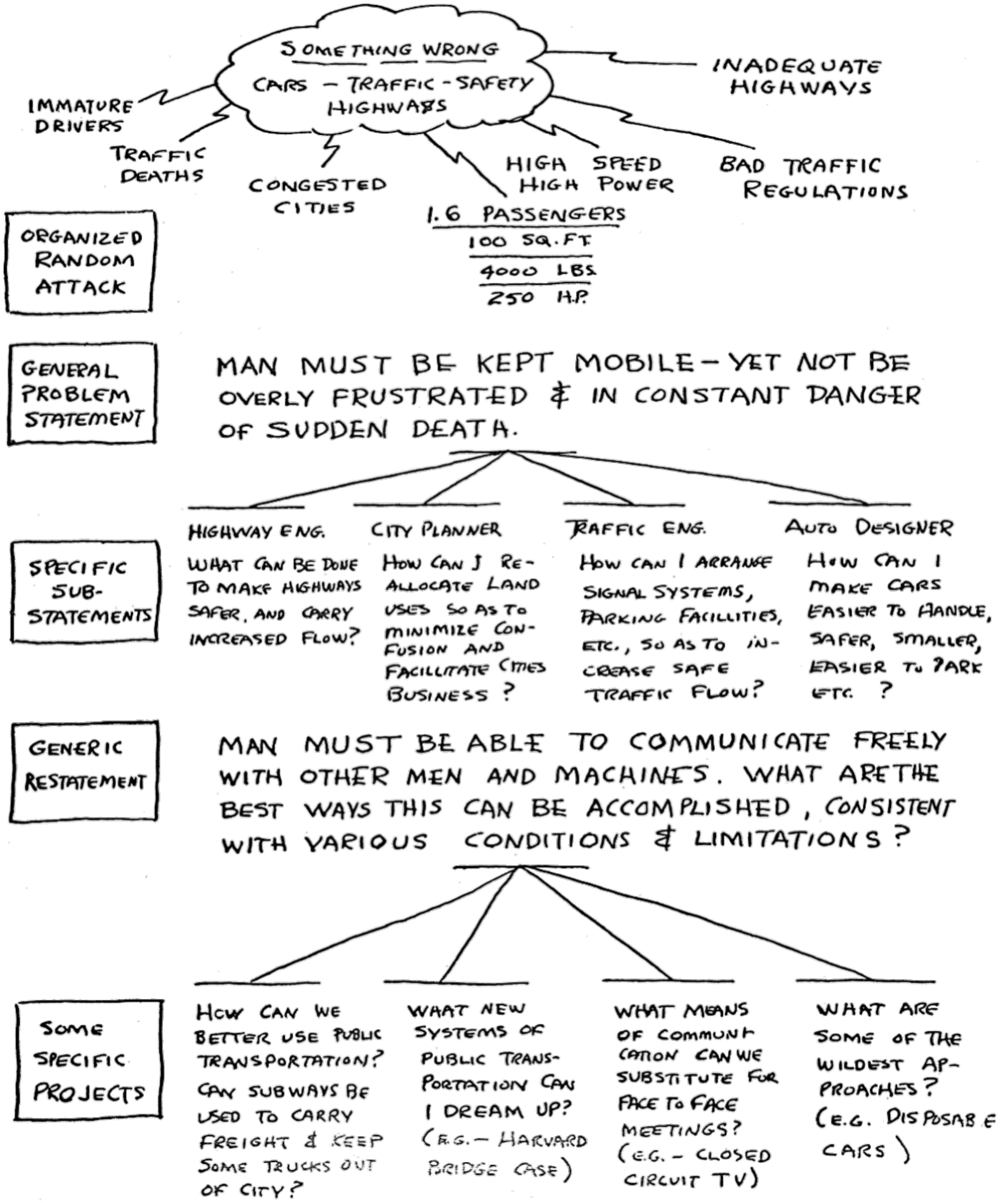
EMOTIONAL BLOCKS

1. Fear of making a mistake or making a fool of yourself.
2. Difficulty in rejecting a workable solution and searching for a better one (grabbing the first idea that comes along).
3. Difficulty in changing set (no flexibility, depending on biased opinion).
4. Over-motivation to succeed quickly.
5. Pathological desire for security (no desire to pioneer or gamble).
6. Fear of supervisors and distrust of colleagues and subordinates.
7. Lack of drive in carrying problem through to completion and test.

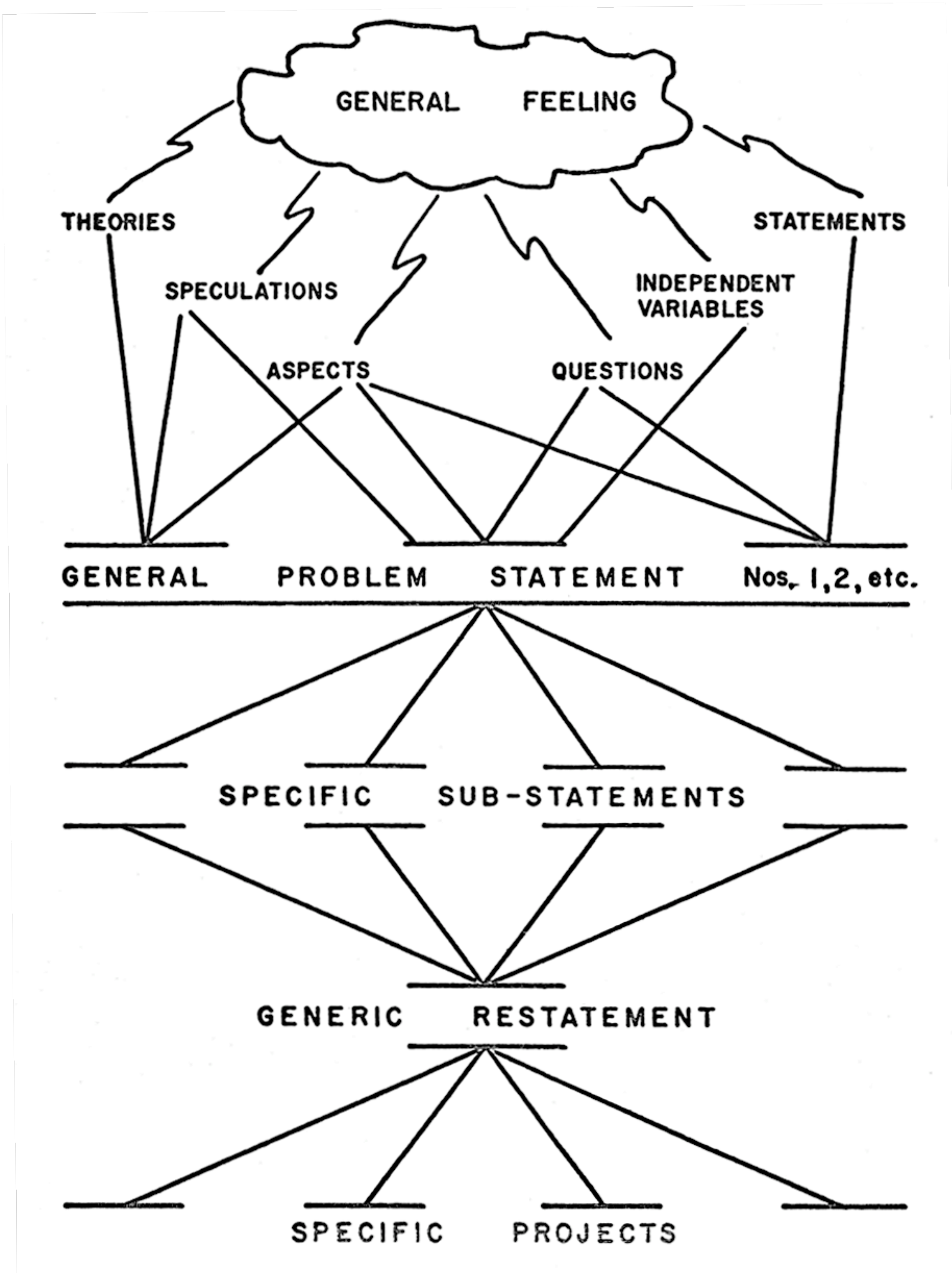
8. Lack of drive in putting solution to work.
9. Inability to relax and let "incubation" take place.
10. Refusal to take detour in reaching goal.

As a sort of summary to this section on factors influencing creativity, I am including below a list of some key words arranged in alphabetical order that relate to the creative process. Use it occasionally as a "checklist."

A—associate - attributes - attitudes - altruism - anthropology - analogy - anxiety - analysts
B—blocks - brain - "brain storm"
C—consciousness - culture - concepts - create- comprehensive - confidence - curiosity - craftsmanship
D—daringness - determination - design – drive - decision - deduction - difference
E—energy - enthusiasm - environment - extrapolation - encouragement - experience - empathy - emotion - exercise - evaluation
F—fear - finish - freedom - faith - fantasy - foresight - fluency - flexibility
G—gamble - game theory - group dynamics – generosity - gestalt
H—human relations - humor
I—information theory - imagination - induction - insight - individualism - innovation - interests - independence - introspect
J—jokes - judicial thinking
K—knowledge - know thyself
L—logic - learning theory - liaison
M—motivation - management
N—newness - nonconformity
O—observe - operational definitions - operations research - originality
P—prediction – perception - personality – projection - probability – presentation - practice penetration - philosophy - psychology - physiology - problem statement
Q—question
R—resistance to innovation - relationships - retrospection - rationalization - reverie
S—skills - semantics - synthesis - subconscious -safety - sensitivity - symbolic logic - sympathy - statistics - sets
T—tricks - traits - therapy - thinking
U—uniqueness - universality - understanding
V—value theory - vision
W—work - working backwards - writing
X-Y-Z—yourself



EXAMPLE OF PROBLEM STATEMENT THINKING


GENERAL FEELING
THEORIES
STATEMENTS
SPECULATIONS
INDEPENDENT VARIABLES
ASPECTS
QUESTIONS
GENERAL PROBLEM STATEMENT Nos. 1, 2, etc.
SPECIFIC SUB-STATEMENTS
GENERIC RESTATEMENT
SPECIFIC PROJECTS

Useful Creative Techniques

The techniques discussed here are those that are applicable primarily to organized approaches, although, by no means are they confined to them. Some or all of the seven steps Osborn lists occur in every creative act: orientation, preparation, analysis, hypothesis, incubation, synthesis, and verification. All of these steps can be benefited from continuous questioning, keen observation, generic relationships, and daring predictions. These techniques, when applied conscientiously and repeatedly, will help awaken and strengthen your own creative potential. The checklists, for example, will spur the questioning spirit, and attribute listing and morphological analysis will help develop the powers of observation in the search for generic, basic relationships.

It is probably not necessary to give this warning, but to assure that there are no misunderstandings, remember well that there is no one right answer to creative problems. The search for aids to problem solving is a highly creative task. The approaches suggested in this chapter are not sacred and they should be modified and changed to fit the individual needs of the person using them. They are not the one right answer. It is hoped, in fact, that you will never rely on one or two rigid patterns, but that you experiment just as much with the processes by which you solve problems as you do with the problems themselves. Obviously no attempt is made here to describe all of the techniques that have proved useful to specific individuals. The search for additional approaches is left up to the student.

The four Guilford factors of 1) problem sensitivity, 2) fluency, 3) flexibility, and 4) originality appear repeatedly in almost all of the literature on creative thinking, imagination, and innovation, although not always under the same names. You would not, however, until Guilford isolated them in his factor studies, know that they have been recognized as basic mental attributes, and ones essential to the creative, imaginative thinker. This is true whether he be a poet, an artist, an engineer, or a physicist. They are part of the inherited potential of each individual, and combined with certain emotional attributes make up the personality of the innovator.

Being basic, these factors may individually vary from person to person, both in the amount of inherited potential, and also in the degree to which this potential has been realized and developed. This latter point would seem to indicate that these mental attributes can be developed through training and exercise, and certainly my experience with students and industrial groups during the past few years tends to prove it.

There is no question but that "problem sensitivity" is a prime requisite of the creative person, and that it must be closely tied up with the development of a "questioning attitude." This healthy skepticism of the creator introduces one of the many paradoxes or contradictions that make up his personality. He refuses to accept existing answers to creative problems as *the* answer, but at the same time firmly believes that he can come pretty close to *the* answer. He doubts the existence of universals, but is constantly searching for them. He is unhappy with the condition he finds around him, yet he can tolerate these ambiguous conditions, and finds happiness in his attempts to improve them. He must be a wide-eyed dreamer, and yet at the same time, a practical, sensible man, and on and on.

Dr. Carl Rogers of the University of Chicago refers to this attribute as "openness to experience," and while this is a very descriptive phrase, it is a much more inclusive one, for it involves not only questioning, but also observing and associating. Since it is so general, it is probably not as basic an attribute as problem sensitivity. In some respects the openness-to-experience phrase is better and more descriptive than problem sensitivity, for it quite definitely implies that both internal and external experience must be considered. This, of course, should be considered a part of Guilford's phrase, even though at first it is not immediately apparent. Many of the problems associated with creativity are in the form of emotional blocks within one's self, and they must be solved first before effective and productive problem solving can take place.

I have already indicated that closely associated with problem sensitivity is problem statement. This will be discussed in more detail later. Our immediate concern is questioning. How it can be developed and exercised, and how it influences creative work. A very easy and effective way of developing the questioning habit is to use, at least for a time, some kind of checklist. The one listed below was developed by G. Polya, of Stanford University, for guidance in solving single answer mathematical problems, but, with slight modification, it can be applied equally as well to multi-answer creative problems. It first appeared in his book, *How To Solve It* in 1945. Use of this checklist not only exercises questioning, but also fluency, flexibility, and originality through increased observation and association. Try it out on any problem facing you at the present time.

First—UNDERSTANDING THE PROBLEM

You have to understand the problem. What is the unknown? What are the data? What is the condition? Is it possible to satisfy the condition? Is the condition sufficient to determine the unknown? Or is it insufficient? Or redundant? Or contradictory? Draw a figure. Introduce suitable notation. Separate the various parts of the condition. Can you write them down?

Second— DEVISING A PLAN

Find the connection between the data and the unknown. You may be obliged to consider auxiliary problems if an immediate connection cannot be found. You should obtain eventually a plan of the solution.

Have you seen it before? Or have you seen the same problem in a slightly form? Do you know a related problem? Do you know a theorem that could be useful? Look at the unknown! Try to think of a familiar problem having the same or a similar unknown.

Here is a problem related to yours and solved before. Could you use it? Could you use its results? Could you use its method? Should you introduce some auxiliary element in order to make its use possible? Could you restate the problem? Could you restate it still differently? Go back to definitions.

If you cannot solve the proposed problem, try to solve first some related problem. Could you imagine a more accessible related problem? A more general problem? A more special problem? An analogous problem. Could you solve a part of the problem? Keep only a part of the condition, drop the other part; how far is the unknown then determined, how can it vary? Could you derive something useful from the data? Could you think of other data appropriate to determine the unknown? Could you change the unknown or the data, or both, if necessary, so that the new unknown and the new data are nearer to each other? Did you use all the data? Did you use the whole condition? Have you taken into account all essential notions involved in the problem?

Third—CARRYING OUT THE PLAN

Carrying out your plan of the solution, check each step. Can you see clearly that the step is correct? Can you prove that it is correct?

Fourth—EXAMINE THE SOLUTION OBTAINED

Can you check the result? Can you check the argument? Can you derive the result differently? Can you see it at a glance? Can you use the result or the method for some other problem?

A second example of a checklist is this one taken from Alex Osborn's book, *Applied Imagination* and it is the list responsible for the little decks of Checklist Solitaire cards handed out this morning. These little decks were originally made up for Christmas cards from the M.I.T. Creative Engineering Laboratory.

<u>CHECKLIST FOR NEW IDEAS–Alex F. Osborn</u>

Put to other uses? New ways to use as is? Other uses if modified?

Adapt?

> What else is like this? What other idea does this suggest? Does past offer a parallel? What could I copy? Whom could I emulate?

Modify?[51]

> What to add? More time? Greater frequency? Stronger? Higher? Longer? Thicker? Extra value? Plus ingredient? Duplicate'? Multiply? Exaggerate?

Minify?

> What to subtract? Smaller? Condensed? Miniature? Lower? Shorter? Lighter? Omit? Streamline? Split up? Understate?

Substitute?

> Who else instead? What else instead? Other ingredient? Other material? Other process? Other power? Other place? Other approach? Other tone of voice?

Rearrange?

> Interchange components? Other pattern? Other layout? Other sequence? Transpose cause and effect? Change pace? Change schedule?

Reverse?

> Transpose positive and negative? How about opposites? Turn it backward? Turn it upside down? Reverse roles? Change shoes? Turn tables? Turn other cheek?

Combine?

> How about a blend, an alloy, an assortment, an ensemble? Combine units? Combine purposes? Combine appeals? Combine ideas?

Many other examples of checklists can be found in the literature, and they may apply to a very general or to a very specific application. Probably the best checklist, as far as any individual is concerned is the one that he makes up for himself. This can be easily memorized, with repeated use, becomes part of second nature. Question, Observe, Associate, Predict, is in effect the checklist for me. So also is the area approach to design that we have developed, even though it was designed, primarily to help flexibility of thinking, rather than to develop the questioning attitude

It is interesting, yet somewhat pathetic to note the results of the limited and restricted use of a checklist. I had an interesting session with the director of research of a large company that manufactures power shovels. He was recounting the tremendous progress his company had made in their "research." Their first shovel handled only one-third of a cubic yard of material, and now they have them capable of handling thirty cubic yards. A hundred-fold increase through "research." Their checklist contained only one question: "Can we make it bigger?"

Professor Robert Crawford of the University of Nebraska proposes a technique that is frequently useful in arriving at original and novel solutions, and he calls it "Attribute Listing." In this technique, Crawford lists the attributes of various objects, or the specifications or the limitations of certain need areas, and then by changing or modifying one or more of the attributes or specifications, he brings originally unrelated objects together to form a new combination that better satisfies this need. It is a much simplified form of what Fritz Zwicky of Aero-Jet Corporation would call Morphological Analysis. This latter we will go in to in more detail later on. As an example of attribute listing, one might take the old wooden-handle screw driver of a few years back. These attributes are the descriptive phrases that would completely define the objects under consideration, and are:

1. Round, steel shank.
2. Wooden handle riveted to it.
3. Wedge shaped end for engaging slot in screw.
4. Manually operated.
5. Torque provided by twisting action.

Now each one of these attributes has been changed, not once, but many times, and each change has supposedly resulted in a new and better screw driver. The round shank was changed to a hex shank, so that a wrench could be used to increase the torque. The wooden handle has been replaced by a molded plastic handle, and thereby cutting down on breakage and danger from electrical shock. The end has been modified to fit all kinds of screw heads. Pneumatic and electric power have been substituted for manual power, and the "Yankee" type driver provides torque by pushing.

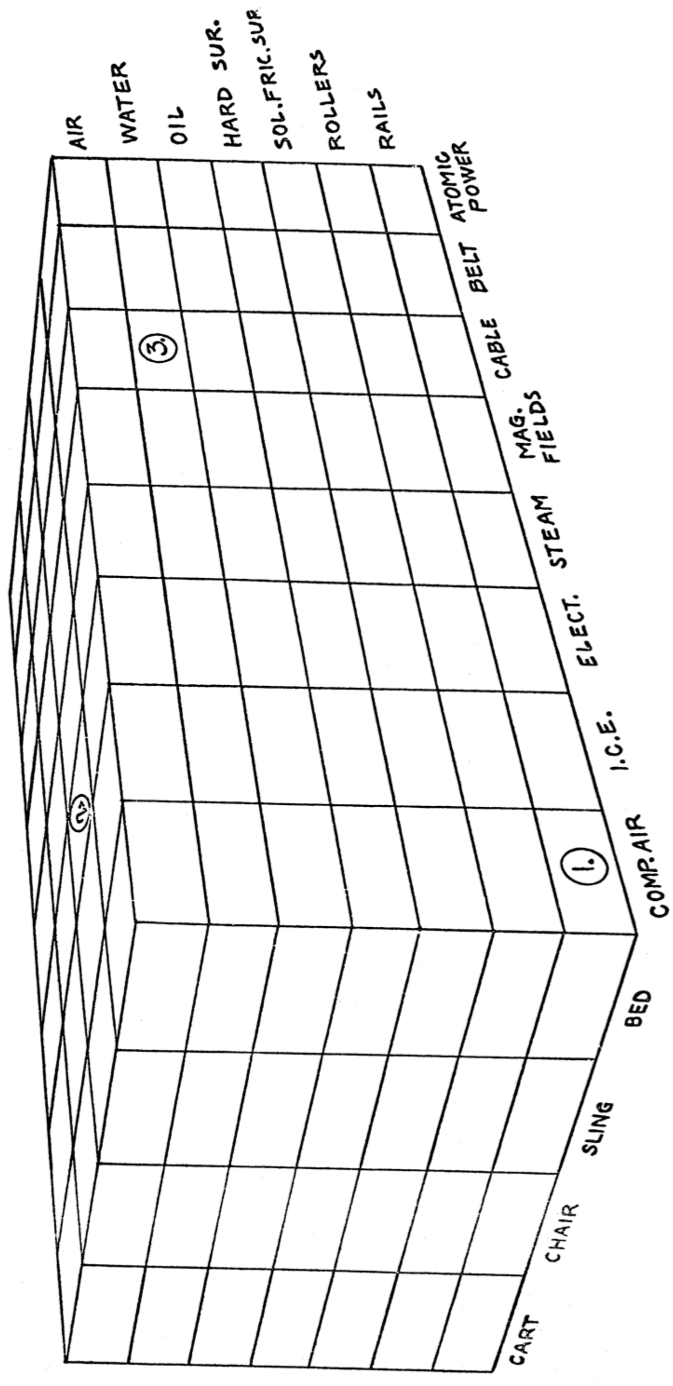
In trying this technique out with various groups, I have discovered something that at first appears to be a strange phenomenon. The more familiar the members of the groups are with certain products, the more difficult it is for them to agree on the basic attributes of that product. The group at the AC Division, for example, had no difficulty in listing the attributes of a hammer or a bicycle, or still more complicated products, but they could come to no agreement on the basic attributes of a spark plug. A group of top designers from the Farrel-Birmingham Company, manufacturers of heavy machinery for the rubber and plastics industries, had no trouble with the spark plug, but failed to describe to the satisfaction of the majority, the attributes or essential features of their Banbury Mixers which they had been designing, redesigning, and manufacturing for thirty or more years.

On second glance, this is not so strange, and it points to a danger that we are all susceptible to, but of which we are probably completely unaware. Familiarity need not breed contempt, but it certainly places things in the classification of "obvious," and from then on we can neglect questioning or observing them. At least it certainly has the effect of limiting the flexibility of our thinking along certain lines. It establishes a very limited number of fixed approaches, and it prevents us from standing back and viewing the object in its entirety from new vantage points and in new lights. This is all right in line with the statement that has been quoted many times that "it is only the amateur or tyro who invents anything, the expert knows too many reasons why something can't be done, so he never tries."

Morphological Analysis, as described by Dr. Zwicky, is a very useful tool for organized creative activity. It replaces checklists and attribute listings, although both can probably be useful in setting up a Morphological Chart. The procedure is as follows: The statement of the problem should be as broad and general as possible, and then all of the independent variables must be defined as broadly and completely as possible. Each one of these independent variables becomes an axis on the morphological chart, and if there are "n" independent variables, we will have a chart of "n" dimensions. Each of the independent variables can probably be expressed a number of different ways, and these are laid out with unit dimensions on each of the "n" axes.

This all can be best explained by following through a simple example and developing a morphological chart for a problem that we have already mentioned: that of the Harvard Bridge case. On the following page you will see this chart partially worked out. The statement of our problem will be as all-inclusive as possible, and we will list it as The Problem of Getting Something From One Place To Another Via A Powered Vehicle. Certainly, one of our independent variables would be the type of vehicle used, and we could subdivide that into 1) some kind of cart, 2) some kind of a chair, 3) a sling, and 4) a bed (we could list many others, but this will be enough for our example). A second independent variable might be the media in which our vehicle operates, and here we might list air, water, oil, hard surface, rollers, rails, and a solid, frictionless surface. A third independent variable would be the power source, and this could be broken down into compressed air, internal combustion engine, electric motor, steam, magnetic fields, moving cables, moving belt, and atomic power.

Let us assume for the moment that these are the three independent variables that will completely describe some device for getting something from one place to someplace else. This may be an over-simplification, but it helps move our chart making much easier, for a three dimensional body is easily visualized and sketched on a two dimensional sheet. Our chart then becomes a three dimensional body which can be thought of as a filing cabinet with drawers operating or opening in all three directions. The contents of each of these drawers will be defined by one of the variations of each of the three independent variables. Note the three drawers arbitrarily singled out on the chart. Drawer #1 is characterized by a bed-type vehicle, moving over rails, powered by compressed air. Drawer #2 would be a sling-type vehicle, moving through air and powered by electricity, and Drawer #3 would be a bed-type vehicle, moving through water and powered by a moving cable.



MORPHOLOGICAL ANALYSIS.

With the subdivisions we have chosen for the three independent variables, we have constructed a morphological chart that contains 224 drawers, which is more combinations than the average person could produce by any process of free association or than most groups could assemble by “brainstorming.” We could, of course, easily increase the number of variations along each axis and thereby greatly increase the possible number of combinations.

On opening up some of these drawers, we will find that they are filled with some already invented transportation device, for example, the cart-type vehicle, powered by an internal combustion engine, and moving over hard surfaces, is our automobile. A cart-type vehicle moving over rails and powered by electricity might be our street car or subway or electric locomotive. And the sling-type vehicle moving through air and powered by a moving cable would be a chair lift for a winter ski resort. However, the great majority of these drawers will be empty, mainly because the combinations themselves are absurd or impractical. (For example, a sling-type vehicle moving through oil, powered by a moving belt.) But some of the drawers may be empty because no one has ever thought of combining the variables in just that fashion, or, if they had thought of it, their first reaction was to apply judicial thinking and because the combination seemed silly, they gave it no serious consideration. While this chart provides one with a mechanical aid for listing alternate approaches for solving any specified problem, it will take a great deal of imagination to take the specifications for any given drawer and work them into a worthwhile, practical, economical solution to the problem of getting people across Harvard Bridge safely and comfortably. It will require a great deal of daring and a great deal of persistence. The aim, of course, should be to come up with the best possible solution, not just something different.

One more word about morphological analysis. Should you find, as you go through the drawers in your "n" dimensional model, that some of the drawers contain two or more quite distinct solutions, this would give you a clue that you had not chosen enough independent variables. The feature that distinguishes the two solutions to the one drawer would be a variation of the additional independent variable needed and the new model should be constructed with this new variable in mind. This morphological analysis is the most comprehensive way that I know of to list and examine all the possible combinations that might be useful in solving some given problem. I recommend it to you very highly.

While "attribute listing" and "morphological analysis" seem quite similar in many respects, they do have one important and fundamental difference. Attribute listing is usually and, I believe, most affectively applied to very specific problems or needs. The specifications are listed with a very definite object in mind like the screwdriver example previously stated. If you were to use this process in order to improve wire staplers for fastening papers together, for example, you would try to describe the basic components of a very definite, single, existing stapler. It would probably be the best one your company or client now manufactured. You definitely would not define your problem as one of devising ways and means of confining thin, flexible sheets to a predetermined relationship. This would be the problem statement you would use for morphological analysis. Using the morphological approach you want to be as basic, all-inclusive and generic as you possibly can be. This is the fundamental difference between the two techniques. Both should be tried and modified to fit your own or the problem's particular needs.

The four specific techniques that have been described above are especially useful in the various organized approaches. All of them require the use of pencil and paper, two vital tools in solving any problem, and all of them provide ideas for solutions, not solutions themselves. A great deal of polishing and re-polishing will be needed before the ideas suggested by these techniques end up as finished products.

These rather analytical, methodical, and systematic procedures for piling up alternate solutions of a problem can be very useful in "inspired" approaches. In the statement of the problem (orientation), the gathering of data (preparation), and in the listing of possible answers (hypothesis) these techniques will be very helpful. These steps are, of course necessary if the subsequent step of incubation is to lead to an insightful synthesis that can then be verified. Keen analysis and "organized" techniques preceded and accompanied Land's invention of the Polaroid Camera, even though it was a "Big Dream" and "Inspired" type of activity. A similar example might be cited, that of Gillette's invention of the modern safety razor.

King Camp Gillette was a natural-born tinkerer and had a number of patents to his credit before he finally developed the one on which his fame rests today. He was not an engineer, nor had he any training along that line, he was a moderately successful salesman of Crown Cork Seals for beverage bottles, etc. He was always driving himself, though, to make a big, outstanding invention, and was always talking about his ideas with his friends. He was also a person deeply concerned about human problems and did a great deal of thinking and writing in the field of sociology and even established an organization, dedicated to setting up a Utopian kind of society that would do away with the strangling effects of big business. His interest in sociology, however, was kept quite separate from his life as either a salesman or an inventor. He was almost a split personality in the way in which his diverse interests had no effect on one another.

His "big dream" was born one day in the "Nineties" in a conversation with a fellow salesman. They were discussing Gillette's favorite topic, that of inventions, when this friend said, "King, what you should invent is something like the Crown Seal that is used once and then thrown away, so that as you establish a market, it will expand almost automatically on repeat sales." This was the dream he was looking for, and it never left his mind until it was realized. It is interesting to note how he went about trying to define this dream, trying to decide the field in which he would work. He used what he called the "alphabet system" which he had used successfully in the past. He would go through the alphabet, letter by letter, listing every product that he could think of that began with each letter. He would go through the alphabet listing needs or human activities that might involve the use of products. He would repeat the process over and over but with no success. (This alphabet system is another form of checklist and it has proved useful to a number of people in their search for products or needs that could be satisfied in a better fashion. I know of some designers that use the Sears Roebuck or Montgomery Ward catalogue as a kind of checklist. The products list, included at the end of this section, was hurriedly made up from some of the listings in the classified section of the Telephone Book.)

Finally in 1899, this hazy dream that he had became suddenly clear in a "moment of insight," and while he was shaving one morning, he conceived the idea in a matter of seconds and clearly visualized it in a form little different from the present day razor. He immediately sat down and sketched out the idea as he perceived it in his mind, and that very afternoon stopped in at a Boston hardware store and bought brass and strip steel, along with the necessary tools and started right to work on his first model. But it was not successful and neither was the second and third and many other subsequent models. He could not seem to get a good enough edge on the strip steel to last even one shave. He consulted with many experts and they all said that it couldn't possibly be done. I am ashamed to say that he even consulted with members of the M.I.T. Staff, and they gave him the same negative answer.

He, however, carried on. A company was finally and somewhat reluctantly formed and five years after he had conceived the razor idea, the first successful razor was produced and sold. A great deal of the final success is due to the inventive genius of a young engineer by the name of Nickerson, who saw the possibilities in Gillette's idea and who, like Gillette, refused to accept the reasons why it couldn't be done. He devised the means for heat treating and sharpening the blades, and designed the machines that would make them at a reasonable cost. It is interesting to note that the first Gillette blades sold twenty for a dollar, now they are twenty for ninety-eight cents. In addition to Gillette's and Nickerson's contributions, the company owes a great deal of its success to imaginative marketing methods and sound business management, but that is another story, and needn't concern us at this time.

Let us look, for a moment now, at this example of Gillette and the one previously given of Dr. Land, and see what is similar in their inventions and in the personalities of the inventors. It is obvious that both of these innovations are in the area of increased function; new needs were filled, startling new features were added to existing products, or old needs were satisfied in an entirely new way. While it wasn't specifically brought out, "moments of insight" played an important role in both cases; the entire problem or major parts of the problem were solved in moments after long periods of "incubation" that were preceded by equally long periods of hard work and preparation. In both cases, reason and analysis (the experts) said that it couldn't be done. In Land's case, this was not explicit, but the fact that Eastman hadn't done it was almost the same to him as if Eastman engineers were saying that it couldn't be done. In both cases, a certain amount of confidence, or intuition or faith provided the emotional energy or drive to carry the project through and make the big dream come true. To me, this last point is most significant probably the most important. It differentiates them from less successful dreamers.

We all have dreams; we all have big thoughts; but most of us do nothing about them. How many of you have had the experience of seeing an idea that you had had a year or two or five years earlier come on the market and be successful. I have, and I've thought that I could have done the same job if I had had the confidence in myself and the idea, and had applied sufficient drive to make the idea a reality. It is for this reason that I insist that the creative process is not complete until one has some tangible evidence to prove it. Some time ago, a number of patent attorneys (176), research directors (78), and inventors (710), were asked to list the mental characteristics that were necessary and vital to the successful innovator. The patent attorneys and research directors listed originality and imagination, analytical ability and perseverance at the top of the list, and in that order. The inventors, on the other hand, changed the order slightly, and I am inclined to agree with them. They listed perseverance as number one by a wide margin, and then originality and imagination and finally analytical ability. Without the drive to carry a project through to completion, in spite of all obstacles, the idea has little or no value. This is probably why some research directors have been overheard to say that ideas are a dime a dozen, they want men who are doers not thinkers.

One of the most useful tolls of organized creative activity, especially for organized *group* activity is that of "brainstorming." What is brainstorming? It is a word coined by Alex Osborn, founder of the advertising firm, Batten, Barton, Durstine, and Osborn, and author of the new book, *Applied Imagination*, to describe a kind of activity that many men have used for many years, but now in a somewhat modified and changed form. Mr. Osborn developed this idea-getting technique for the use of his advertising business. It has proven so successful there that he heartily recommends it for any kind of situation where ideas are needed to help solve problems. Due to Mr. Osborn's crusading efforts, and to those of his many converts, a great many companies are now using brainstorming in one form or another to help them pile up alternatives that can, at a later date, be evaluated and eventually implemented and then verified.

Let me describe for you how brainstorming, as proposed by Osborn, works in his company. In almost every office of BBD&O there is one or more brainstorming group, men in the office who meet when the occasion demands, to think up ideas to help solve some client's problem. The men, from six to ten in number, represent different phases of the company's activity. In some cases they become permanent members of this group, and in other cases the assignment to the group is a rotating one. In addition, they have a list of alternates who can be called upon, should one of the regular members be unable to attend. One of the permanent members is the chairman of the group, and one of the members is appointed recorder for the session, although this latter position rotates from session to session.

The system works as follows: A client may come to the company with a request for ideas on new ways to open up a drug store. The chairman of the brainstorming group will notify his members that in two days or so they will hold a brainstorming session on this problem, and will describe the problem to them briefly. This disclosure of the problem is to help the men in the group orient themselves, and to look up any material they think is pertinent, prior to the time the group meets. At the beginning of the session, the client or his representative may open up the group meeting and outline for a very short period of time the problem and some of its limitations. He then leaves the room and the group goes to work. The chairman usually speaks up saying, "Remember now, men, we want as many ideas as possible – the wilder the better, and remember, *no evaluation*." (Evaluation is the big enemy of all brainstorming sessions, and must be avoided at all costs. Members of the group who can't help but judge or evaluate ideas as they are presented are usually asked to leave the session and are not asked back to subsequent sessions.) Then the group goes to work. One idea after another is suggested by the men and taken down by the recorder. One idea seems to spark another idea. Some are pretty wild, and some provoke some good laughs (a kind of evaluation), but on they go for an hour or more, until they seem to be milked dry of ideas. In this example, they might have piled up one hundred fifty or more ideas before they seem to run dry. Obviously, a lot of these ideas will be foolish and impractical. A smaller group might be listed as questionable, but there always seem to be five or ten that are really "hot" new ideas, that are eventually submitted to the client for his final choice.

This evaluation or selection of ideas from the large group thought up during the session is never done on the same day the session is held. This job is done one or two days later, and the group members are allowed to bring in new ideas that occurred to them between the time of the original session and the evaluation session, for the same group usually evaluates their own ideas. While they were as wildly imaginative as they could be during the thinking up session, they become coldly calculating and practical during the evaluation session, and carefully scrutinize each idea and toss it out if it seems impractical or silly. As I have already indicated, they may end up with a group of five or more suggestions that they agree are novel, and possibly better than any solution previously attempted. These are finally submitted to the client for his final choice and then one or more are carried out to their conclusion. Osborn claims that when his rules are applied, brainstorming never fails to come up with new and useful ideas.

Now, what are these rules? Osborn lists four essential rules, and then suggests a number of supplementary ones. The main rules are as follows: First, no evaluation of any kind is allowed in a thinking-up session. He is convinced, and I am sure he is right, that if you judge and evaluate as ideas are thought up, the person whose idea is questioned will be more concerned with defending his questioned idea than he will be in thinking up new and better ones. Evaluation must be ruled out. Second, all are encouraged to think of as wild ideas as possible, for Osborn claims that it is easier to tame down than to think up. Actually, if wild ideas are not forthcoming in a brainstorming session, it is usually evidence that internal evaluation is going on in the minds of the individual participants. They are thinking twice before they spout an idea for fear that they may come up with a silly one, and therefore look like a fool. Third, Osborn encourages quantity of ideas. He is convinced that quantity eventually breeds quality, but probably more important, quantity also helps to rule out evaluation and in that fashion eventually breeds quality. Fourth, and last, everyone is encouraged to build upon or modify the ideas of others, for combinations or modifications of previously suggested ideas often lead to new ideas that are superior to those that sparked them.

The above rules are the major ones that Osborn insists must be followed for successful brainstorming sessions. He makes additional suggestions, however, for example, he says that too many experts in a group is not a good idea. It is too difficult to eliminate evaluation. He has frequently found that rank amateurs, those who know nothing about the field under discussion whatsoever, frequently come out with suggestions which, in themselves, may be exceptionally fine solutions, or be the ones that spark the mind of the expert in coming up with the winning solutions.[52] He also believes that the group size should not be smaller than six, or larger than ten, and many other researchers in this same area have come with this same suggestion. Six or seven member is probably the ideal group size. Osborn also feels that in certain problems, a mixed group, as far as sex is concerned, is very productive of new ideas. Brainstorming sessions may be held at almost any time during the day, although Osborn feels that those held in the morning are most effective, and one hour is probably the average length of time devoted to brainstorming sessions. Some may be as short as fifteen minutes, and others may extend up to two hours. However, fatigue sets in fairly early and limits the effectiveness of the group in a long session. A final word of warning by Osborn is that the problem chosen to brainstorm should be quite specific and of a fairly limited range, so that all the men participating in the session can aim their ideas at a very definite target, and not be tackling too many different aspects of a very broad problem. This latter point should be well noted by beginning groups, thought I am sure that with experience, groups can tackle broader and more nebulously stated problems, and with good results.

Now let us look at some of the analyses that have been made of the brainstorming technique to see if we can determine why it works as effectively as it does. Dr. E. K. VonFlange of the General Electric Company makes the following comments on why the brainstorming techniques work so well:[53]

> 1) The problem posed is simple and easily understood. 2) No one bothers to really evaluate the ideas that are presented. At the moment no one cares whether the scheme could actually be made to work or not. 3) Since no one judges or evaluates the soundness of ideas presented, none of the participants feel restricted in any way. Their minds roam in search of any idea with no thought of practicality to hinder them. 4) Having witnessed the reproving comments and chuckles the idea first receives, everyone does his best to top it. Competition has entered the picture. 5) One person's idea suggests similar ideas to others, thus building on what has gone before.

Quite similar to these comments are those made by a group of Harvard Business School students who have recently looked into the question of creative thinking in industry, and who are carefully evaluating some of the techniques that are now being used. They list the following advantages of brainstorming:[54]

> 1) Less inhibition and defeatism. Rapid fire of ideas presented by the group quickly explodes the myth, which the individual often casts up that the problem overwhelms him, and that he can't think of a new and different solution. 2) Building upon the ideas of others. What may seem absurd to one may stimulate another to a new and useful idea. 3) Contagion of enthusiasm. 4) Development of competitive spirit. Everyone wants to top the other's idea.

The Harvard group, while extremely enthusiastic about the use and benefits of brain storming, were themselves creative in that they saw ways and means of modifying or changing the procedure so as to insure even better results. For example, they state:[55] "While we feel that a pleasant, relaxed type of atmosphere is helpful, we also feel that the lack of such an atmosphere does not greatly affect the efficacy of brainstorming sessions. In our opinion, the sessions should be kept as simple as possible. Props are not necessary, though at times they do contribute." Osborn, himself, feels that better results are obtained if the problem is stated several days before the session is to be held. The Harvard group does not agree with this and feels "that in thinking about the problem, a participant considers many solutions. Some of these he discards before the meeting because they do not appear suitable to him. Some of these ideas may have been the ones that would trigger off a worthwhile idea by another. Another disadvantage of early disclosure is that the participant may become egocentrically involved with the idea he thinks worthwhile. He then becomes a less effective contributor." They continue:

> The personnel involved in brain storming techniques should always include some amateurs. People without experience in a field bring a new point of view. Their thinking is not restricted by any of the dos and don'ts that experts may have developed. They are not afraid to present unorthodox ideas that often provide a stimulus to radical new developments. Mixed groups are also very effective at times. Mixing rank can have a very disturbing effect on brainstorming sessions at times, so this should be done very carefully. Don't pick just those men who have a great many ideas per unit time as members of brainstorming panels. Very often, a man who is less vocal will attempt to think more deeply about the problem. The few ideas that he does throw out are often more acceptable as solutions. An hour is about the optimum length for a brain storming session.

As I have indicated, the Harvard group was very enthusiastic about the brainstorming procedure, for they feel that it dramatizes new ideas and makes people focus their attention upon them, and realize the importance of ideas. It also tends to show people that they can and do have imagination and the *ability* to *have* new ideas. This, of course, is very beneficial to individual ego and self-confidence.

I too am convinced of the usefulness of brainstorming in the idea-getting stage, but, as I have indicated more than once, the idea is only the beginning of the creative process, and some tangible result must be obtained before the process is brought to a successful conclusion. I believe brainstorming is so successful because it is a form of group therapy. Here you have an ideal environment for being yourself. You set up an artificial environment that contains most of the essentials required for what the psychologists call "psychological safety" and "psychological freedom."[56] External standards of evaluation are completely absent. You have no fear of being thought or being called a fool. Even internal evaluation is effectively ruled out because you are specifically asked to think up as wild ideas as you possibly can, and as many as you possibly can. To meet the speed and quantity demands, you don't have time to evaluate your own ideas. Lastly, you set up a condition where, in effect, no holds are barred. You can take anyone else's idea, and by a slight twist or modification, call it your own. In fact, you are encouraged to do just this. Strangely enough, this last point goes quite counter to the essentials for psychological safety, namely that of establishing the integrity of the individual. Apparently in brainstorming, the integrity and success of the group is more important than that of the individual. And it is this last point that leads me to believe that possibly brainstorming should be extended to the extremes in both directions.

I am convinced that it is possible, for I can do it, and I know many others who can also do it, that an individual can form a brainstorming group with himself as the only member. In this case, the elimination of the internal as well as external standards of judgment and evaluation and the proper use of checklists, area thinking, or attribute listing, or what have you, can result in a great many ideas and alternatives that can, at a later time, be evaluated as possible solutions for some problem that is facing you. Some people don't need (though they may be helped by) a group to spark them in to thinking up a long list of different approaches to solving a problem. Individual brainstorming should be encouraged and developed, not as a substitute for, but as a supplement to group brainstorming activity. Morphological analysis might be considered as a kind of individual "brainstorming."

In the same way, the brainstorming rules can be applied and should be extended to a much larger group than the original six or ten. There is no reason why a modified form of these rules can't be applied to a whole research section or even to a whole company. If all members of an organization were encouraged to think as daringly as possible, without fear of immediate evaluation or possible ridicule, and without fear of making a mistake, I can't see but how the company would benefit. The ideas suggested would eventually be individually evaluated, the wholly "crack-pot" schemes would be eliminated before damage was done, but the resultant activity would be much more daring and imaginative than that which occurs in many organizations today. If all members of an organization could be treated as individuals with dignity and integrity, but with varying potentials, and their evaluation were based on to what degree they had realized their own potentials and their actual tangible accomplishment, rather than on what they said, psychological freedom and safety would in part be insured and the number of new and better solutions to old problems would rapidly increase.

While brainstorming was originally proposed for small group activity, it should be extended to the extremes of the organization. An individual can brainstorm and so can a company. The rules that were essential to the well-being of the small group can be modified to fit the individual or the total organization.

There are other ways in which brainstorming can be effective, and in one of the earlier chapters we listed the seven steps that Osborn feels are essential and part of the creative process. This starts out with problem statement, that of orientation, on down to final verification of the accepted solution. During each one of these steps, brainstorming can prove effective and useful. A group might get together to list all the possible problems associated with a certain need area in an attempt to pick out the one or two best problems of immediate consideration. The group can brainstorm and eventually evaluate the types of information that should be investigated. We have already mentioned how brainstorming should be used in the hypothesizing stage, that of thinking up alternatives and possible solutions to the problem. It can be useful in analysis and in test and verification. Osborn calls this a “sandwiching” technique. Brainstorming and eventual evaluation sessions are sandwiched or interspersed between active work periods of varying lengths. In the same way the brainstorming technique, individually or group applied, can be useful in tackling and solving small specific problems, part of a larger and more comprehensive picture. Brainstorming may have been originally applied in the search for alternate methods for keeping lawn grass from exceeding a certain desirable height, and later specifically applied to the source of power that would be used in driving a device for accomplishing this purpose. (I still would like to see someone come up with a steam powered lawn mower. I think it would have tremendous appeal to the “young fry,” especially if it were equipped with a large brass steam whistle.) Brainstorming can benefit from all the tricks or aptitudes that help the individual become a more creative personality. Problem sensitivity and awareness, fluency and flexibility, and originality will all contribute to the effectiveness of a brain storming session. In the same manner, the person who can question, observe, associate, and not be afraid to predict will be a more effective brainstorming member than the person not so equipped.

There have been many variations of the brainstorming technique developed and put into operation. There have also been a number of independent developments that led to programs in some respects similar to brainstorming. One of these developments is worth looking at fairly closely, for it recently cropped up in the news (April, 1955 issue of *Collier’s Magazine*) and is a program that I am quite familiar with. This program was developed by William J. J. Gordon, Director of the Design Synthesis Group of the well-known consulting firm of Arthur D. Little Company in Cambridge, and he has refined it to a high degree. Bill Gordon’s program developed out of his original concern with his belief that the lone inventor was rapidly losing out in industry because of the growing complexity of the problems now facing industry. He felt that the freedom, the daring, the imagination of the lone inventor must be recaptured and maintained, but now in a group of some kind, a group that could span the multiple fields of knowledge now involved in any one invention. Strangely enough, there are no real engineers in Gordon’s group, although some of the men have had some kind of engineering training. He leans most heavily on those who have had a philosophic or an aesthetic background, because he feels they are more fluent and flexible in their thinking, and the approaches they take to problem solving. Gordon says this about his technique: "We derive our new conception principles from group sessions where much of the communication is carried on in a psychological climate. Absolute license of expression, free association and release from resistance are emphasized to keep the discussion on a plane of big ideas and away from the egocentric predicament of the particular solution."

Bill Gordon felt that the main weakness of the Osborn-type brainstorming sessions was a solution too soon arrived at. Brainstorming starts producing solutions right at the start. To prevent this, Gordon devised a different type of group approach in which only the chairman of the group knows the nature of the problem being discussed or for which a solution is being sought. This was Gordon's first approach to what he calls "operational creativity" and it proved to be very successful, not only in the production of ideas, but also in the training and the development of his staff. The men in his group became so well versed in this technique that he was able to modify his original procedure and keep it just as effective if not improve it. The procedure described below is Gordon's first approach to the problem of group invention and it is included here because it has great merit and is highly recommended as a group activity or an individual procedure. The following is a hypothetical example of Gordon's method.[57]

> Suppose the problem is to find a new way to park automobiles in a crowded city. The subject the chairman might choose to describe the discussion might be "storing things". The session would probably start off with a discussion of what storing means. This might lead to a discussion of the desirable features that a good storage system has. Features such as a minimum of low cost space and ready availability when wanted. Next, the discussion might move on to the methods of storing things that are used in nature, the home, or industry. Someone might mention how bees store their honey. Conceivably this could be a possible solution to the problem. Some sort of a honeycomb structure for parking cars, or, another person might say that things are often stored by hanging them up. This might lead to a solution in which cars are hung on hooks like sausages. If someone brings up the fact that an object often takes up less space when it is stood on its end, this might suggest the development of a device to park cars on their noses, rather than on four wheels. As initial areas of thought become exhausted, Gordon interjects the limited facts which further define the problem. This opens up new fields to explore and the discussion continues as before. Finally, when he senses that the group is close to the best solution, Gordon reveals the exact nature of the problem. The session is so conducted that by the time the problem is revealed to them, a high level of excitement runs through the group. From this point on, the principle behind the problem's solution is crystallized and the group starts to develop the new idea in some detail. Gordon says that three hour sessions are the minimum for the following reasons:
>
> 1. Sufficient time must be available to cover all the broad areas affecting the peculiar, particular problem. Rushing a session may result in the overlooking or neglecting of the best solution.
>
> 2. The best ideas come when the men are "thought out". At this stage, superficial blocks which dampen thought are broken down by fatigue. This release from resistance allows free association between the conscious and the subconscious mind. The result is better ideas.

These three hour sessions *can* be very fatiguing. I know, for I have sat through a number of them. But there are a number of tricks that can be used to relieve the fatigue. One I have already mentioned, the interjection of facts. A long session of free association almost to the point of fantasy can be relieved by listing some hard, cold facts. Statements that you feel are real and unquestioned are almost as life preservers when you find yourself almost overwhelmed in the sea of imagination. Another fatigue reliever is humor, although this seldom has to be forcibly introduced into the group. Any imaginative group is always cursed or blessed with it, depending on your viewpoint. Gordon frequently uses one trick which I believe is very novel and effective, and that is to provide one less chair than the number of people attending the session. This means that one man stands or sits on the edge of a desk or even on the floor. Should any man seated in a chair get up to move around or leave the room for any reason the unseated man quickly takes the vacated chair and so there is a continual, though imperceptible movement throughout the session, therefore no one becomes physically or mentally fixed during the three-hour period.

To repeat, Gordon is the only one who knows the exact nature of the problem that is being solved. He does not disclose the nature of the problem to the group when they meet in very specific terms, but starts out the discussion with the basic concepts associated with the need area in which this problem lies. (Similar to the generic problem statement associated with morphological analysis, but without giving the problem away.)

So, Gordon lists some of the problems that might be encountered in his creative sessions:

1. *Guilt*: This sometimes arises in the minds of some of the workers because they are being paid for, and yet enjoy this work which is, at times, almost pure fantasy. He however believes that enjoyment is necessary if productive work is to be accomplished, and that it must be encouraged.
2. *Inhibition*: This arises in a few out of the fear of being too impractical. They want to get down to the facts right away, and this fear limits thought, preventing perhaps a better solution. Impracticality must be encouraged at points in the session to eliminate this fear.
3. *Fatigue*: Prolonged sessions produce the fear of mental fatigue. Some relief is necessary if the members are to continue productively. Too much relief, however, is dangerous, as a superficial rationalization broken down by fatigue may be rebuilt.
4. *License*: Group members must be given license to do as they wish. Their thoughts and actions must be unrestricted. This, of course, is a problem dependent on the resourcefulness and the policies of the company.
5. *Problem statement*: Technical terms have been found a source of trouble with non-technical members, and should generally be avoided whenever possible. Clarity is of the essence.
6. *Choice of a Director*: A director, capable of participating with the group exercising theatrical control, and allowing free exchange among members of the group is most desirable.
7. *Choice of Groups*: Groups of highly specialized individuals, groups locked up in themselves, and groups having a limited emotional response should be avoided.

The operation of Gordon’s Design Synthesis group consists of two primary phases. The first is the idea-conception phase, during which time the idea for a product is born. This we have already described in some detail. Due to the great mental fatigue generated in these sessions, they are limited in frequency to no more than one per week. At the present time they are running these at two per month. Gordon has found that the most advantageous times to hold these sessions are during the morning hours when the group members are mentally fit. If a session should prove unsuccessful and a satisfactory idea is not generated, additional sessions may be called, and a different approach used by Gordon, or the job may be refused if a solution is not deemed possible.

The remainder of the group’s time is devoted to the second phase, that of implementation: to research conferences, consultations, and experimentation. Here as a group, or individually, the members strive to make the idea a reality. In the conception phase, they are quite unified in their effort to exhaust concepts in search for acceptable solutions. However, in the implementation phase, arguments and differences of opinion arise concerning the best method of realizing the idea in a tangible form. However, their willingness to work together, coupled with Gordon’s leadership has minimized this problem considerably. The results of the implementation phase include not only the finished product, but also recommendations as to methods for its manufacture and sale. A complete package is presented to the manufacturer. Little restriction has been placed upon the group, either in the methods of working or in the jobs undertaken. Free reign is given to the group on all phases of their work, so that the various mental blocks described will not arise.

Why is Gordon’s system successful? I believe that in large part it is due to the fact that Bill Gordon himself is a highly imaginative, creative person. If he were not so, I am sure the system would be far less effective. Note that Bill is the only member of the group who knows the exact nature of the problem that is being discussed. He, after giving the group the basic generic concept that they are to discuss, must by subtly asked questions and directed statements eventually guide the group into the specific problem area without their knowing it, so that their free associations will have meaning and lead to an eventual solution. When he, and only he, feels that the group is close to a desirable solution, does he lift the veil and let them know what they are working on. Bill feels that this is necessary, for he fears a solution too soon arrived at, and he is afraid that his men will become egocentrically involved in only moderately acceptable solutions and refuse to search for the better ones he knows exist. But because of his own fear of egocentric involvement, he, in effect, stifles what I believe to be the major attribute of group activity, that of one person stimulating another, that of one idea sparking off another. While I believe Osborn’s technique discloses the problem much too soon, Bill Gordon waits much too long, and a compromise of some kind must be arrived at. Both systems have points of extreme merit, and attempts should be made to combine them into a program best suited to each individual company. Once this compromise has been established, however, and this is true for all the techniques suggested so far for improving creative activity, it should be frequently reviewed to see if there aren’t ways and means in which it can be improved and made more effective and productive.

PRODUCTS LIST

A—adding machines - air brushes - air conditioners - air compressors - airplanes - alarm clocks - albums - amusement devices - aquariums - archery equipment - artificial limbs - ash removal - athletic goods - atomizers - automobiles - automobile washers - awnings

B—baby carriages - bags - bakers equipment - ball bearings - ball pens - bar equipment - barbecues - barometers - bathroom accessories - bathtubs - beauty shop equipment - beds - bed pans - beverage dispensers and vendors - bicycles - billiard equipment - binoculars - bird feeders and houses - blackboards - blankets (electric) - blenders - blowers - blue print equipment - boats bookcases - bookbinding - bottles and caps - bowling alley equipment - boxes - bricks - brushes - brooms - bulletin boards - burglar alarms - burial vaults - buses - butchers' supplies and equipment

C—cans - can openers - cabinets - canisters - coffee makers - china - chairs – cameras - coffee vendors - cocktail vendors - clocks - closet equipment - clothes dryers - cocktail shakers calculators - carpet sweepers - circular saws - camping equipment - cash registers - check protectors - Christmas lights - cigarette lighters - cigarette vendors – cleaners' equipment - clothing - coat hangers - coffee mills - coin changing devices - compasses - computers - concrete mixers - concrete vibrators - controllers - convertors - cooking utensils - cooling systems - cork products - cosmetics - counting machines - cranes - crutches - cuspidors - cutlery

D—dishes - doorknobs - doorbells - deep fryers - dryers of all kinds - dust pans - desks - desk lamps - disk recorders - degreasing equipment - dental equipment - dials - dictating machines - dining cars - dishwashers - disposal equipment - door checks - doors - door openers - drafting room equipment - drills, hand - drinking fountains - dumbwaiters - duplicating machines - dust collectors

E—electric appliances and equipment of all kinds - earphones - easels - electric switches electronic equipment - elevators - engines

F—floor polishers - food mixers - fountain pens - freezers - food blenders - floor lamps - furnaces - fans - farm equipment - filing equipment - filters - fire alarms - fire extinguishers - flashlights – floodlight - floor sanders - furniture

G—games - garage door openers - gas burners - garbage disposal equipment - generators - glass - golf equipment - grinding equipment - gummed tape machines - gymnasium apparatus

H—hot plates - hair dryers - hair curlers - hampers - hardware - hearing aids - heaters - hoists - hospital equipment - hotel equipment - humidifying equipment

I—instruments of all kinds – irons - ironers - ice makers - ice cream freezers - ice cream vendors - incinerators - induction heaters - intercom systems

J—jig saws - jacks - juke boxes

K—kitchen equipment of all kinds - knives - kennel equipment

L—lawn mowers - lawn sweepers - lavoratories - lamps - light fixtures - laboratory equipment - laundry equipment - lighting equipment - locks and lockers - lubricating equipment - luggage

M—mops - musical instruments - mixers - machine tools - magnets - mailing equipment - massaging equipment - meat market equipment - meters - microfilming - milk handling equipment - mimeographing equipment - motion picture equipment - motorcycles - motors

N—numbering machines

O—ovens - oil burners - office equipment - optical goods - organs - outboard motors

P—pianos - plates - polishers - projectors - packaging equipment - painting equipment - paper converters - parking meters - phonographs - photographic equipment - photoelectric equipment - plastic products - playground equipment - plumbing equipment - pneumatic equipment - popcorn machines - poultry equipment - power transmission - printing equipment - pumps

Q

R—radios - record players - rug shampooers - refrigerators - ranges - recorders - radar equipment - railroad equipment - razors - regulators - restaurant equipment - road machine - rubber products - rubbish removals

S—sinks - silverware - shower cabinets - shower mixer valves - space heaters - sanding machines - saws - scales - sewing machines - slicing machines - snow plows - soap dispensers - soda fountain equipment - sorting equipment - speed reducers – speedometers - sporting goods - spray equipment - sprinklers - stapling machines - sterilizers - stills - stokers - stoves - surgical equipment

T—television sets - three dimensional equipment – toasters - toilets - tables - table lamps - typewriters - telephones - tape recorders - temperature controllers - testing equipment - timing devices - tools - toys - tractors - trailers trucks

U

V—vacuum cleaners - valves - vending machines - ventilating equipment

W—washing machines - window washers - wire recorders - watches - water heaters - water softeners - water coolers - welding equipment - wheel chairs - windshield wipers - woodworking machinery

X-Y-Z—X-ray apparatus

Creative Product Design

So far in this program we have tried to define the creative process, indicate the nature of some of the factors that influence it, and to tell you about and demonstrate some of the techniques that might prove useful. The problem of how you solve creative problems is a creative problem in itself and I am sure has a great many right answers. Yet at the same time I am also convinced that there is something unique and universal about the creative process. The procedures that lead to innovations in science and engineering, art, music, philosophy, business, social life, what have you, have something in common and we should search all of these areas in an attempt to learn more about the process. Creativity provides a common meeting ground for diverse specialties, it supplies a common experience on which to base a language for communicating our ideas to one another. As we will try to point out in this section, Product Design provides an almost perfect vehicle for experimenting in the effectiveness of bringing people of diverse backgrounds together in a creative effort. The scientist, engineer, artist, philosopher, psychologist, sociologist, anthropologist, salesman, and advertising man must contribute their know-how to insure a successful product development. Most often this will be done as a team, although it is hoped that occasionally we can develop a person who is familiar with all these fields, the comprehensive designer.

We have already stated Osborn's seven steps in the creative process: 1) orientation, becoming aware of and stating a problem; 2) preparation, gathering data, facts, and limiting conditions; 3) analysis, making sure that the data and conditions are sufficient and relevant; 4) hypothesis, piling up as long a list of alternate solutions as possible; 5) incubation, letting the subconscious work on the problem; 6) synthesis, drawing together the best aspects of possible solutions into a final solution; and 7) verification, putting the final solution to test and acceptance. These steps are re-listed here so that they can be more easily compared with similar lists prepared by other groups. For example, there is a great similarity between Osborn's general approach and that one that has emerged over the years in General Electric's Creative Engineering Seminar approach.[58] G.E. has developed an eight-step list for creative work on product development. It starts out with 1) recognizing and 2) defining the problem; then, 3) searching for all possible approaches or solutions; 4) evaluating this list of alternate answers and 5) selecting the most feasible for further study; and finally the solution is arrived at through 6) the preliminary design, 7) a verifying demonstration, and 8) a follow-up program.

This General Electric approach can be best illustrated by one of their own examples. The following was presented by C. F. Hix and D. L. Purdy in the *General Electric Review* for May 1955.

Step 1: RECOGNIZE - Although electric range manufacturers have found that five specific heats are sufficient to perform all surface cooking operations satisfactorily, a need has been expressed for in-between heats to compensate for differences in heat transfer that result from the type, quality, and condition of cooking utensils. It is generally the feeling that the consumer will not pay a premium for this additional flexibility, and the problem, therefore, is to develop a low-cost infinite heat control for the surface units of an electric range.

Step 2: DEFINE - The engineers considered the purpose of the device; the necessary functions, and approaches for providing an infinitely controllable supply of heat. A word definition would be: “A new low-cost control for the electric range is desired to promote the ease of cooking and sales appeal.” Specifications were:

Infinitely variable control of heat
Retention of console theme and control-panel design
Easily cleaned control panel
Long life
Reliability
Low cost ($1.50 per control)
No radio interference
Fast heating
No burning feature desirable.

The investigation that followed added to the understanding of heat transfer, consumer expectation of a range, required heat magnitudes, and the like.

Step 3: SEARCH FOR METHODS - To find a method that would meet the specifications arrived at in Step 2, the engineers applied creative techniques for making a number of possible suggestions to solve their problems. Of the 65 ideas suggested in the report, a few of the categories and some of their resulting ideas follow:

1. *Mechanical On-Off heat controls*
   Common cycling methods: Motor driven, Solenoid driven

   Constant- or variable-frequency oscillators: Thermal bellows, Time-delay relays, Electrostatic clutch, Thermistors, Bimetal Oscillators

   Vibrating or resonant devices
   Escapement devices
   Variable damped resonators

2. *Electrical methods of heat control*
   Potentiometer spanning small increments
   Autotransformers
   Variable core reactors
   Gas-tube saw-tooth generators
   Rectifiers
   Induction heating

3. *Other methods of heat control*
   Vary losses from heating unit
   Vary mass of heating unit

4. *Types of actuation*
   Turn a dial
   Move a slider
   Press kinky tube
   Press hydraulic tube

Step 4: EVALUATE - A long list of thoughts and ideas has little value unless it can be turned into a useful concept for a final product. Thus a constructive evaluation of the ideas was made. Analytical and empirical methods were used in determining the feasibility of operation of the suggested ideas, and much creative thought was needed to properly combine and integrate the good ideas into worthwhile proposals. Seldom of value by itself, one idea must combine with many to make one composite practical suggestion. In this problem, the engineers, through a series of combinations and recombinations, arrived at six theoretically practical proposals.

Step 5: SELECT - The selection of the basic idea to be developed later was made by comparing the six proposals of Step 4 with each other, thereby establishing a reference for judgment. The selected idea—a bimetal reed that alternately applied and removed electric power to the heating element—resulted from combining three of the ideas in the Search-for-Methods phase. The reed completed the power circuit at both ends of its oscillation, the total power being varied by changing the reed's length of travel, thereby varying the proportion of on time to off time. The resultant control[59] was infinitely variable and independent of line voltage and ambient temperature.

Step 6: PRELIMINARY DESIGN - A prototype was constructed, tested, and redesigned to provide low cost and ease of manufacture. From a sketch of a manufacturing floor plan, the cost appeared to be 38 cents on an annual production of 25, 000 units—considerably less than the goal of $1.50.

Step 7: DEMONSTRATE - After seeing results and model, engineers in the range development section of the Company's Range and Water Heater Department, Major Appliance Division, Appliance Park, Louisville, Ky., were immediately attracted by the low-cost solution to this old problem achieved through application of the creative approach.

Step 8: FOLLOW THROUGH - Additional work by the engineers at the Range and Water Heater Department has demonstrated the feasibility of the solution that is currently undergoing refinement.

This eight-step process now used by General Electric is the outgrowth of a more limited approach concept used by them up until 1950. The earlier concept was Define, Search, Evaluate, and Solve, and this bears a close resemblance to the four key words that I find especially useful for my thinking: Question, Observe, Associate, and Predict. For my own case, I do not feel that I have to break these four broad steps into smaller intervals. In fact I don't actually like to think of them as steps of a process that are followed in a certain definite sequence. To me these four words represent attitudes of the mind or the personality of the learner, the seeker, or the creative problem solver. They represent the cognitive process as well as the process of science. The first three should be going on all the time, simultaneously or in almost any kind of combination or sequence. They represent the questioning mind, the prepared mind that finds the unexpected through keen observation as well as the mind that is generic in the relationships, the associations that it makes. Prediction typifies the daring spirit that is not afraid to fight for what he believes to be right, to stick his neck out and take a chance, to be different when it makes a difference.

Now the use of checklists, attribute listing, and morphological analysis that was discussed earlier will definitely contribute to your effectiveness as a creative product designer. They must, for they are basic enough to apply to all types of problems. They can be used as techniques within the framework of another approach we call the area method. It is a checklist of a sort. A detailed study of machines and products quickly reveals that there are four general areas or fields of design activity. These areas are: 1) increased function, making the product do more things than it did before; 2) higher performance level, making the product longer lived, more reliable, more accurate, safer and more convenient to use, and easier to repair and maintain; 3) lower cost, eliminating excess parts, substituting cheaper materials, cheaper and more efficient manufacturing methods, designing for convenient sub-assemblies, and designing so as to reduce hand labor or for complete automation; and 4) increased salability, improving appearance by making the product, its package, or its point of sale more attractive and by having a better appreciation of what the public wants. This last point involves all of the ramifications of marketing and consumer analysis.

Looking at these four points critically, it seems obvious that the first three, at least, are the primary, although by no means the exclusive concern of the engineer. During the last ten years or so the engineer, deferring to management's greater wisdom, has depreciatingly turned over the last point to the industrial stylist and marketing analyst. In this the engineer has made a great mistake, not because the industrial stylist has failed industry, far to the contrary, but because the industrial stylist, not hampered by the inhibiting factors of the slide rule and engineering handbook, has been able to view the product in its entirety and the product and man relationship that is involved in its use and is gradually taking over the whole field of product design. Joe Doakes, the engineer of company X, may take pride in the fact that the gears in his kitchen food mixer will last a lifetime, but John Smith of company Y knows that women don't buy food mixers on the basis of long-lived gears alone, and so he designs his machine so as to be attractive, easy to clean, convenient to store away and versatile in its application. So company Y sells food mixers and company X goes broke! This is in spite of the fact that the majority of the contributions of John Smith have been in areas that a moment ago we said should be the primary concern of the engineer. I am afraid that a great many engineers have been taught to believe that design is a combination of ingenious mechanisms and strength of materials and nothing more. Some even believe that if you can't weigh it or measure it or handle it mathematically, to hell with it!

Now my point is that all four areas should be the vital concern of any engineer associated with design. This is certainly true if you want to be classified as a comprehensive designer. Just note these five qualities of the comprehensive designer a moment. They will be described in more detail later. 1) Motivated by broad concepts of human thought and behavior, 2) complete understanding of the organism and environment, 3) articulate in all types and levels of communication, 4) maintains perfect balance in his ability to analyze, synthesize, and evaluate, and 5) competent in the use of the creative process.

It is a very difficult job to be a comprehensive designer. It is a very difficult job to be a good product designer and investigate all design areas with equal enthusiasm and competence. And it is a difficult job to be an expert in any one of these design areas. There always has been a need for experts in limited fields and that need is growing; but the expert in greatest demand is that one who can see his specialty as part of a much greater, broader picture and who is capable of cooperating with other specialists in the attainment of a comprehensive goal. This latter is one of the prime purposes of this two-week course and is certainly basic in my instruction of young engineers. Among you men there are experts in style, experts in tool design, experts in electronics, hydraulics, and mechanisms, experts in production techniques, etc. I imagine a good many of you are well aware of the over-all design picture and the place that your specialty has in that picture—I sincerely hope that all of you will have that awareness when you leave. But I also hope that the expert in style will be inspired or encouraged to attain competence in the fields of function, performance, and cost, and that the engineer concerned primarily with strength and long life will attempt to broaden himself by gaining some proficiency in the other areas of design.

In my work with industrial groups I have learned a great many things. (That is one reason why I like to give a course of this type.) One of the things that I have learned is that firms have personalities just as individuals do and that even though they are composed of a great many individuals they develop habits of thinking and behaving as if they were singular and these habits are very difficult to break.

I held a series of seminars on creative engineering for a fairly good-sized industrial firm whose yearly sales approach fifty million. As one of the exercises, I had the men bring into one of the seminars a chronological analysis of the design developments of any one of the company's many products. There were a few duplications of effort but we ended up with ten different products to discuss. As each man would read off his history of design changes, we would classify them into one of the four basic design areas and at the same time try to determine the motivating factors that instigated this design change. Over ninety percent of the designs of that particular company, over the past twenty-five years were in one area, that of higher performance, in their case, increased accuracy, finer adjustments, easier maintenance, and repair, and safety and convenience to the operator. In addition, these changes were generally brought about with increased cost. This large figure may be a little misleading because by far the largest motivating factor was customer request which when satisfied did increase salability, at least of that customer or group of customers.

This habit of thinking in only one area had been building up for years and even when they were confronted with this staggering evidence, their first reaction (after registering great surprise) was "but this *has* to be so in our industry!" "Our industry is different!" "We've always done it this way!" This last statement, I believe, was the only true one. They had always done it that way; but there are some men in that group who are now going to try to do it a different way, and they are going to find a way and succeed.

It is rather interesting to look over the developmental history of any product or family of products and try to classify the changes into one of the four areas. It might be a good idea for each one of you to do that for your own company's products. Your group, too, might have gotten into a rut and is inadvertently doing all of your design thinking in one area and is missing good bets in other areas. It is probably true that in certain industries one area of design is much more important the others; but that doesn't mean that you should neglect the others.

As an appendix to this paper, I am including a chronological listing of some of the developments in the American automobile industry. I compiled it from a book published a few years ago by *Motor Magazine*. I am afraid it is far from complete, but it gives some idea of the changes that have occurred. Let us pick out a few typical design changes and see if we can detect any trends. Let us start the history in 1892 when Duryea brought out the first marketable auto in the U.S. Although it is difficult to say who the actual inventor of the motor car was, here was the first marketable, tangible evidence of a radical change in *function* in the means of providing personal transportation. If you take as the main function of the automobile that of providing personal transportation of small groups of individuals and their baggage, you will find very few changes in function from 1892 to the present day. There have been some and we will discuss them shortly, but in the main, it does one thing only and in the same way, with four wheels, a body, and an internal combustion engine.

There have been a great many functional changes in the components of the automobile, and in 1900 we see three such changes with the introduction of the first marketable steam car, the White, the first U.S. steering wheel, and the first electric powered cars. In 1904, a functional change occurred in lighting when Prest-o-lite tanks were added, and a similar type change occurred in 1910 when storage batteries and generators took over the lighting and ignition jobs. In 1914, Cadillac introduced a two-speed rear axle with electromagnetic shift, a functional change that didn't last long. The gasoline tank was moved to the rear in 1915 with the introduction of the vacuum tank and this held sway until the late Twenties when the fuel pump was introduced.

The other functional changes that I would include on the list were automatic choke, vacuum operated clutch, independent front suspensions, coil springs in the rear, fluid coupling, hydromantic transmission, torque convertor, and the electronic eye. Almost all the other changes I would classify in one of the other three areas. Up until 1932, the areas of prime concern seemed to be performance and cost. With the introduction of body styling in 1932, the design area of greater salability has taken over the driver's seat and cost is hitchhiking along the best it can. This introduction of styling, moreover, seems to have brought about a subtle modification in the basic need that the motor car originally filled. The automobile now, in addition to being a transportation device, is a prestige symbol. Many people now purchase new cars every two or three years not because the cars don't provide good transportation, but because their social standing demands it. A leading automobile designer told me quite frankly that his prime purpose was to create dissatisfaction in the consumers' minds relative to last year's model so that he will want to trade it in for this year's "dream car." It is difficult to criticize industries for this, since whether we like it or not, their prime reason for existing is to show a profit.

Industries like the household refrigeration one have a very difficult design problem on their hands. The market is over ninety percent saturated and their product works faithfully with little loss in efficiency and with low upkeep cost for close to thirty years. I suppose the radio industry finds itself in a similar situation, and it won't be long before television finds itself in a similar spot. They do have a functional change, that of color which is already designed, and once costs are lowered, they will have a new product to sell. It seems to me, and this should provide a good topic for discussion, that the only way these industries can maintain high volume, profitable production, is to 1) add new features to their product, 2) look for entirely new and better ways of satisfying the same or modified needs, 3) design for greater convenience and safety, 4) lower costs, and 5) concurrent with the other four, make improvements in appearance.

Before we leave the discussion of the automobile industry, we should probably look at the few other functional changes that have occurred or are being planned. The Jeep, I believe, was quite a functional change, although not as radical as the Weasel. The Jeep, in addition to providing transportation over previously impossible terrains, was designed to provide many other features as well. Bucky Fuller's Dymaxion car was a radical, although unsuccessful functional change and I am sure that he will tell you about it tomorrow. The tentative stabs in the direction of gas turbine power plants and free piston engines will probably result in many functional changes. Then there is always the possibility of some kind of atomic power plant that might still further reduce the size and weight of the engine and thereby lead to functional changes.

I still, however, am quite concerned over the waste and "conspicuous consumption" fostered by the automobile industry and the producers of other household products. The idea that we need four thousand pounds of steel, etc., to carry a one hundred eighty pound man around the city is fantastic. It is not only a waste of materials, but it may lead to emotional disturbances and markedly affect personalities. Dr. Dana Farnsworth, then of M.I.T., pointed this out quite clearly when he talked to my group a year ago on the subject of "Emotional Blocks to Creative Activity." He said:

> Along with learning how to get along with one another when there are more of us to get along with, we have certain other problems that are related. One of them is our rather extreme mobility. We can go from here to San Francisco in a very short time now; go anywhere in the country; we can travel from here to the center of Boston in the course of one minute if there were no other cars in the way; and if there were no buildings; and if the streets were all right; and therein comes the inhibition or the frustration. Our very mobility has caused us to have a series of conscious expectations which cannot be realized because the other people have the same ideas and two people cannot occupy the same space at the same time, particularly if, as our former Dean Wurster said, "Each one of them has one hundred square feet of iron (I believe he inaccurately described it) wrapped to his behind!" Some notions are going to have to be changed. I in my own fantasy about this frustration of mobility sometimes envisage the coming of the last great traffic jam when we can all leave our cars and start building on top of them and start all over again. With this intense preoccupation with speed, we see a certain change in our way of developing value judgments, if you like. Someone said quite aptly that "we are becoming more interested in going somewhere than in where we are going!"

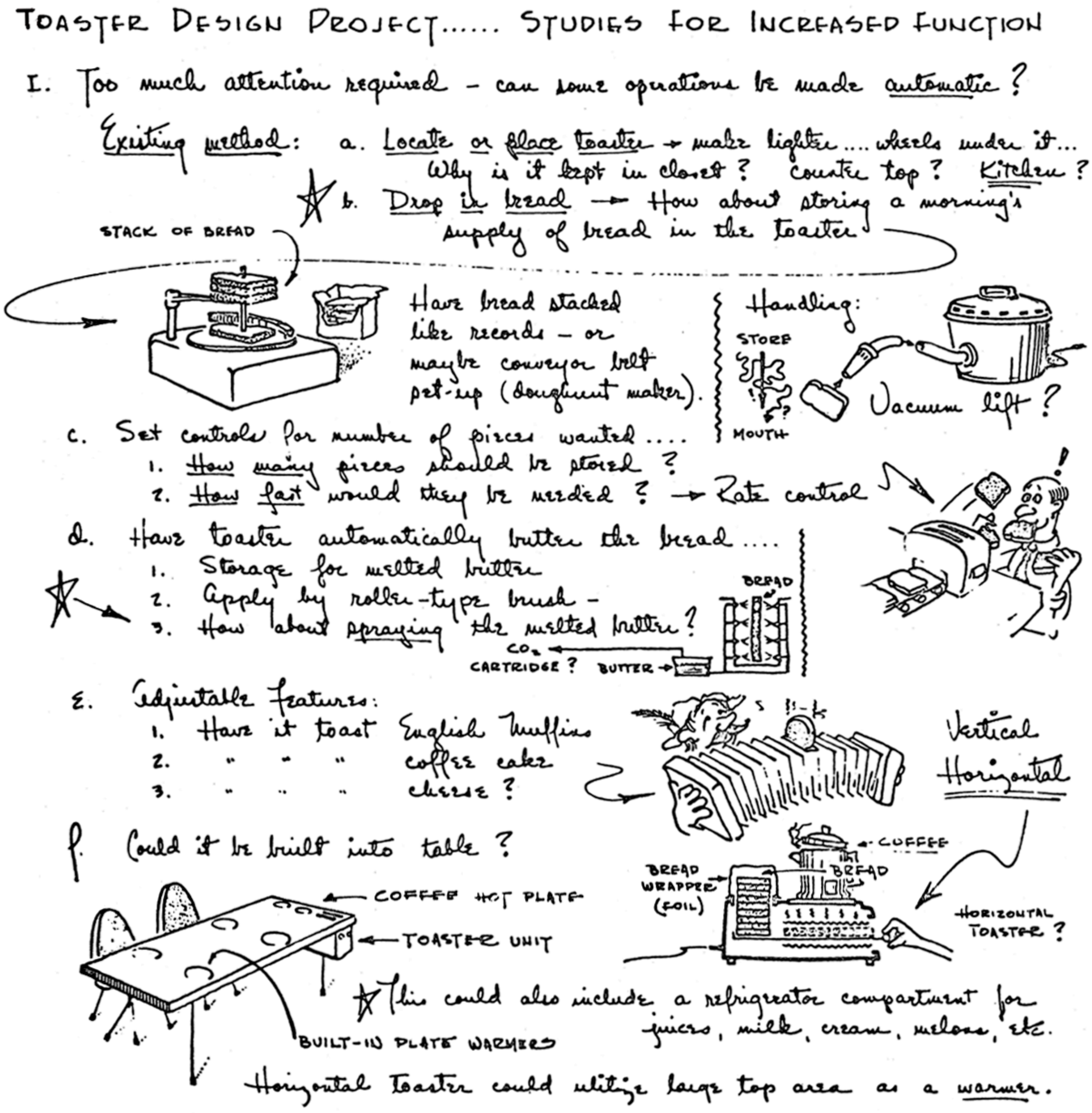
I don't mean to single out the automobile industry and say that they alone are to blame for this growing "frustration of mobility," for the problem encompasses not only the vehicles but also the streets and highways we travel on and the whole system of traffic regulation. (See problem statement example.) It is time for comprehensive designers with broad experience and global viewpoints to tackle the whole problem of personal transportation, not just the design and construction of vehicles. Industries of all types are not satisfying the basic needs. They are not stating their problems correctly. Their products often solve adequately one need, but contribute to dissatisfaction and frustration in other areas.

The automobile industry is probably not unique in its pattern of growth. The industry starts out with a major functional innovation and then in effect forgets this area of design and settles down to a long period of improvements in performance, etc. The telephone display in the first floor hallway here at Tech illustrates this point very nicely. With the exception of dial switching, no major functional changes have taken place since Alexander Graham Bell made the first innovation. Many refinements and improvements have been achieved through high-level creative thinking and the lack of functional changes should in no way detract from the tremendous gains that have been made in other areas. It seems that function design in the large requires more of the "inspired" approach rather than the “organized” approach, and men with this attribute are hard to find.

Area thinking techniques can be applied equally well to the problem of setting your original goals as to the problem of searching for solutions to an established goal. The following might be an excerpt from a designer’s notebook and sketch pad:

> *AREA I*—History shows considerable increase in function from toasting in a wire frame over gas to electric flip-down toasters (one side at a time to both sides at a time with automatic eject after various degrees of brownness, to automatic lower, control and eject). How else can function be increased? How about storing a morning’s supply of bread in the toaster? Set controls for the number of pieces wanted and the rate at which they are wanted. Toaster does the rest. Have the toaster automatically butter the toast and keep it warm until needed. Make it adjustable so as to take English muffins, coffee cake, etc. Design it so that it can be built into the table, counter, or wall. How about a special breakfast table with built-in toaster as well as heated areas under plates so that eggs, cereal, waffles, coffee, etc. keep warm. Refrigerate other areas so that Juices, milk, melons, etc. keep cool. How about snap-on units for increasing capacity as family grows. Why not build it so that it toasts horizontally. The large top area could be used as a warmer. Here I have a case with spring power, timers, and electrical heat, what else can I do with these elements?
>
> *AREA II*—Life seems adequate. Efficiency could be increased possibly by a new approach. Efficiency fairly good, however, not much maintenance required, but cleaning could certainly be made a lot easier. Repairing not easy, but seldom needed. Prevention of damage from dropping would eliminate most repairs. Cord seems to cause the most trouble. Perhaps the direct plug-in idea would eliminate the toaster being knocked to the floor. Fairly safe to operate, only danger being burns and shock. Would a fiberglass polyester shell stand up under these conditions? Increases in convenience could probably be realized through some of the function changes.
>
> *AREA III—Costs can always be lowered, says the boss*, but how? Simplify designs for completely automatic production. How about printed resistance circuits on some non-conducting reflecting base? How about using this heat producing glass for both the toasting element and the main structure? Maybe we can save money by packing our toasters as kits and letting the “Handy-Home-Owner” do the assembly job? Maybe our own sub-assemblies can be improved. Maybe we’ve got too many parts. Can I eliminate some, or combine two or three together? How many separate fasteners do I have and how many different kinds? Maybe I can buy some of these parts cheaper than I can make them, or vice versa.
>
> *AREA IV*—How can I improve appearance? What about colors instead of chrome plate? How about ceramic toasters? (My God, what an idea!) How are toasters sold? Who buys them? Who sells them or are they supposed to sell themselves? How many are given as presents and on what occasions? How about a special wedding model with twined hearts and doves engraved or cast on the God damn thing (you dog you!).

When you get to this point, you had better stop for a while and go to sketching [see figure following].



So far I have talked as if this area design technique should be applied to only the product as a whole or to the basic need that you are trying to satisfy. This of course is far from the truth and great gains can be achieved by asking yourself the questions inherent in each of the design areas as you design each part. Can I make this part or sub-assembly do more than it does now? Can X use a different and better part to do the same job? Can this part be designed for cheaper and easier manufacture and assembly? Can I make it stronger and lighter, etc.? There is little need of examples. You have already heard a number in the case histories presented and you will undoubtedly hear more. You can also very easily pick up a copy of any issue of *Machine Design* or *Product Engineering* and you will see many articles on these topics.

The procedure, then, in Creative Product Design is to first clearly define your problem and in as general terms as possible; second, gather together as much data and background information as possible; third, analyze it to bring out the desirable and the limiting features; fourth, list all the possible solutions you can think of in each of the four design areas (use checklists, attribute listing, brainstorming, every technique that you can think of); fifth, evaluate your ideas and pick out the most promising for more detailed investigation; and sixth, synthesize and verify the results.

A very useful technique for the design of products is one developed and used by General Electric Company engineers. It is called the Input-Output technique, and first serves to define the problem, and then to provide a framework for its solution. If properly handled, it first emphasizes the need and directs the thinking into functional areas rather than into those areas that are primarily associated with the modification and improvement of existing solutions. As an illustration of how the system works, I am including below an example reported in the Harvard Business School Report, *Imagination, Undeveloped Resource*.[60] The aim of the problem is to establish some means of shading a room during periods of bright sunlight.

INPUT.......................... Solar Energy

OUTPUT...................... Making windows alternately opaque and transparent.

SPECIFICATIONS….. Must be useable on various sized windows, must not admit more than 20 foot candle illumination anywhere in the room, must not cost more than $100 per 40 square foot window.

Once the definition is set up, means of bridging the gap between input and output are sought. At each step the question is asked, "Can this phenomenon (input) be used directly to shade the window (desired output)?" Using the above example once again, we observe that solar energy is of two types, light and heat.

<u>Step I</u>—WHAT PHENOMENA RESPOND TO APPLICATION OF HEAT AND LIGHT?
Are there vapors that cloud upon heating? Gases expand, metals expand, solids melt. Are there substances that cloud up in bright light? Does light cause some materials to move or curl? Light causes photoelectric cells to produce current, chemicals to decompose, plants to grow.

Step II—CAN ANY OF THESE PHENOMENA BE USED DIRECTLY TO SHADE THE WINDOW?

1) Vapors that cloud on heating.
2) Substances that cloud in bright light.
3) Bi-metals warp. Slats of a blind could warp shut.

Step III—WHAT PHENOMENA RESPOND TO STEP ONE OUTPUTS?
Gases expand, could operate a bellows, etc. Photoelectric current could operate a solenoid, etc. Solids melt, effect on electrical conductivity, etc.

Step IV—CAN ANY OF THESE PHENOMENA BE USED DIRECTLY TO SHADE THE WINDOW?
Bellows could operate a blind, etc.

Step V—WHAT PHENOMENA RESPOND TO STEP THREE OUTPUT?
Bellows, solenoid, etc., could operate a solenoid switch or valve, which in turn could operate motors to draw the blind.

In this manner a number of possible solutions can be developed for evaluation. The most direct path from input to desired output is not always the most economical. General Electric has found that given a little practice, this technique is efficient and effective for the solution of design problems.

Machine Design[61] magazine recently published an interesting article on "Successful Product Development," by P. R. Marvin of the American Viscose Corporation. This article answered a series of questions which in themselves provide a good checklist for product designers and is included here for that purpose.

1. Do we have time to do the job?
2. Do we understand all of the problems involved?
3. Do we have the ability to tackle product development programming?
4. Do we have the experience necessary?
5. Do we know how to conduct a successful product development program?
6. Will we be able to see development programs in their proper perspective?
7. Are we familiar with the practices of our competitors?
8. Can we work with an independent viewpoint?
9. Do we have the freedom necessary to work?
10. Do we have the plant and facilities for product development?

On a number of occasions during the first part of this program, I have mentioned and briefly described what I consider to be the ultimate creative engineer, the Comprehensive Designer. Let me describe him now in somewhat more detail. A number of years ago the late Henri LeChatelier, well-known and honored French engineer and educator, published a paper on the "Creation of an Intellectual Elite in Science and Industry."[62] This society of the elite would be populated by the leaders of the world, both past and present, and might have three classes of membership: the highest class would be for the men of genius whose fame and influence is recognized throughout the world during a long series of ages. Second, the great men whose reputation, although very extended at one time, is afterward eclipsed by their successors, and thirdly, the inferior elite or briefly, the elite who usefully make their influence felt around them but in a limited sphere and without attaining great fame. LeChatelier proposes an interesting hypothesis that each of these categories of the elite makes equal contribution to the welfare of society. In other words, the product of the number of men in each group and their individual contributions is a constant. So that while there are very few men of genius, their exceedingly great contributions make up for their lack in numbers.

Now while he was not serious in forming a real society of this kind, he was very serious in his belief that every effort must be made to train leaders qualifying for one of these three categories. The main body of his paper, therefore, was devoted to listing the four essential attributes of this society of the elite and defining these attributes with examples from the lives of great men. In brief, these qualities are: enthusiasm for work, imagination, judgment, and instruction. I am being brief only because these same qualities are included, somewhat disguised I'll admit, in my own list of the attributes of the comprehensive designer. I would like to point out, however, an interesting bit of mathematics that LeChatelier carried out with these four qualities. He said:

> Let us assume that only one man in ten is relatively enthusiastic about his work and that one man in ten has somewhat more than average imagination or judgment, and that only one man in ten has advanced instruction. The chances that one man will have all four qualities developed within himself to fairly high levels is $1/10^4$ or one man in ten thousand. On the other hand, it is probably reasonable to assume that no more than one man in a hundred will have any one of these four qualities developed to a very high level, so that the chances that one man will have all four qualities developed to that same high level is $1/100^4$ or one man in one hundred million. You can see then, why the genius classification is not over-crowded.

In my presentation to you today, I would like to describe the qualities and attributes of the person I call a comprehensive designer, with all due thanks to Bucky Fuller whom I believe first defined this type of person. I want to list five factors that are essential to the comprehensive designer so that we can add another hundred to the denominator of that probability figure and we can see that the chances that any one man has all five of these qualities developed to a very high level is only one in ten billion.

You may think I am being somewhat presumptuous as I stand up here and describe this very rare personage to you and when I urge you to be like him, maybe I am, but I am not embarrassed by it. I am a professor, and as you know, they are the prototype of the do-as-I-say, not do-as-I-do type of person. Bucky Fuller first defined the comprehensive designer as, and I quote, "an emerging synthesis of artist, inventor, mechanic, objective economist, and evolutionary strategist."[63] He goes on to say,

> [T]he comprehensive designer is preoccupied with anticipation of all men's needs by translation of the ever latest inventory of their potentials. Thus, he may quickly effect the upping of the performance per pound of the world's industrial logistics through institution of comprehensive re-design, incorporating all of the present scientific potentials that would otherwise be tapped only for purposes of war faring, defensively or offensively.

This man then is a sort of living example of Fuller's Dymaxion concept. This rather complex concept has been simplified by Robert Marks' definition that "rational action in a rational world requires in every social and economic activity, the maximum net performance per gross energy output."[64] In other words, the use factor of every bit of the world's goods and the world's energy should be as large as possible in order to provide adequately for the world's population. This, Bucky thinks, is the prime responsibility of the comprehensive designer.

But now let me give you my own definition of the comprehensive designer by briefly listing for you the five qualities that he must possess. I will then expand these five qualities with examples and try to show you what type of training is necessary and then try to point out some of the very necessary and vital jobs that the comprehensive designer should be tackling.

The comprehensive designer should, first of all, be motivated by very broad concepts of human thought and behavior. Broad because a viewpoint should be worldwide rather than national or local. Second, he must be thoroughly familiar with the organism for which he is designing, and the total environment in which his product must operate. Third, he must be articulate in all types and all levels of communication. Fourth, he must be able to maintain a delicate balance between his ability to analyze, to synthesize, and to evaluate. And last, he must have complete understanding of and mastery in the use of the creative process. Now what do these five statements mean, and how can we raise our own individual achievement level in each of them?

First of all, may I say this: I sincerely believe, and I'm sure that the great majority of you agree with me, that while we are all probably born with a certain limited intellectual and creative potential, very few of us develop or realize to the full our inherited capacities. This belief gives me courage to try to develop my own abilities along these lines and provides the incentive for me as a teacher to urge others to do likewise. I am sure that the small membership list of our society for the elite is due not so much to limited human potential for intellectual activity and creative activity as it is to the small fraction of these individual potentials that we have developed and realized. Education, training, and practice then can help us swell the roster of the intellectual and scientific elite.

Now then let us examine these five factors in some detail.[65] The comprehensive designer should be motivated by broad concepts of human activity and behavior. He should worry about such facts as that two-thirds of the world's population is badly under fed. He should be concerned with the fact that almost eighty percent of the world's copper supply is being enjoyed exclusively by eight percent of the world's population. He should be concerned, as Bucky Fuller points out, that while one hundred percent of the world's logistics are mined, grown, modified, and transported by one hundred percent of the world's population, their eventual use is restricted to the enjoyment and betterment of only twenty-five percent of the world's population. This means that the use factor of each pound of the world's goods and each kilowatt of the world's energy supply is increased by only a factor of four. This is far from an insuperable task. A brief survey of our technological history will quickly reveal many materials whose factor has already been increased by a thousand times or more, but this increase can come only by technological and design activity, not by political intervention or decree. The comprehensive designer then, along with his brothers, the scientists, the engineers, the business men, and even the politicians, must be a student of past and present world history. Because of his knowledge of the world's geographical and cultural groups, he should be able to anticipate and predict very closely the impact that his designs will have, and he must be ready to shoulder the responsibility if the results are not good.

Now, what do we mean by the statement that the comprehensive designer should have complete knowledge of the people who will use his product and of the environment in which it will operate? There is a new field, long aborning, but now rapidly passing through adolescence and heading for a certain and vital mature position. Due to its present young age, it can't quite decide what to call itself, but does answer to human engineering, engineering psychology, applied experimental psychology, biomechanics, biotechnology, psycho-technology, and so forth. No single name defines accurately all the things this field is interested in. This robust technical child has some very fine antecedents that include the time and motion study people like Frederick Taylor, Frank and Lillian Gilbreth, and those that followed them. While they were originally concerned with training and adapting people to existing machines, they soon found out that larger gains could be realized by re-designing machines so as to capitalize on human abilities and avoid human limitations. The personnel psychologists of World War I should be included in the list of grandparents. The work that they did in devising aptitude tests that would accurately rate the skills of different people so that they could be chosen and trained for specific tasks has had and will have continued influence on the human engineer. The last distant relative is the group represented by the experimental psychologists who started out in a German laboratory seventy or eighty years ago and became concerned with measuring certain aspects of the human mind—how did the mind perceive, how did it learn, remember things? This expanded to defining and measuring all kinds of human behavior and thought. The experimental psychologists are still closely associated with this field of human engineering and provide most of the information used and the personnel to use it. And, if my information is correct, many members of the industrial design profession have made major contributions to this field. Strangely enough, some engineers are becoming humanized to a point where they too are becoming concerned with this problem, as well they should be. There is no question in my mind but that this field should hold a high place in the comprehensive designer's training and eventual practice.

The understanding of the environment of which the product is a part and in which it must operate should include a complete understanding of the materials used in the manufacture of this product and of the manufacturing processes used in its production, as well as the physical and cultural environment that surrounds the product and becomes part of the system in which the product is only one small element. This then, suggests the whole list of engineering subjects, starting out with the elementary courses in physics, and culminating with the relatively new field of systems design or systems engineering. It would include all the specialties of the various engineering fields, such as applied mechanics, thermodynamics, and fluid mechanics in mechanical engineering, electronics and circuit theory in electrical engineering, all the chemistries, and the special subjects associated with metallurgy and civil engineering, and on and on.

The third quality required by the comprehensive designer covers an equally large range of subjects. The types of communication that the comprehensive designer must use include the language of the written and spoken word, the language of symbolic logic or mathematics, and lastly, the language of vision. In order to originate ideas, to preserve them for his own later use, or present them to others, he must use one or more of these languages. The more articulate he is, the greater will be his own efficiency and easier will be his task of convincing others of the merit of his ideas. Courses then, in literature, composition, mathematics, and the fine arts must be included in his curriculum. Not only must he be proficient in the use of these three languages, but he must also understand the various levels of communication. By that I mean, he must understand the means and method of communication within himself as a living organism. How does he receive information from the outside world? How does he organize his information and store it for future use? How does he take thought and get results in some overt behavior? He must understand the communication between man and man—what are the differences or similarities between group and individual behavior? How do the dynamics of group behavior affect their potential for good or for evil? He must understand and be able to overcome the communication difficulties that exist between man and machine. And lastly, he must be able to understand how one machine communicates with another. To be fully versed then, in the various levels of communication he must know a great deal about psychology, sociology, group dynamics, experimental psychology, cybernetics, servomechanisms, and feed-back control problems. You see, there is almost no end to the variety and to the quantity of information that this rare individual must possess.

The fourth quality, that one which involves the balance between analysis, synthesis, and evaluation, is more closely connected with the teaching methods involved and the exercise and practice carried out, rather than course content. Analyzing is the taking things apart in the search for truth and recognizable relationships. Synthesizing is the putting together of known facts into new combinations or configurations that must then be weighed and judged to determine whether or not they better satisfy the needs of man. Unfortunately, most courses emphasize and train, almost to the exclusion of everything else, the individual’s analytical ability. This is the case probably because these techniques are somewhat easier and certainly better known. Analytical problems always lead to one right solution, while creative problems, those that lean heavily on synthesis can make no such claim. Solutions to creative problems can be arrived at by many many approaches. The solutions obtained can form a complete spectrum from bad to good. You can never be sure but that the best answer that you are capable of today will not be superseded by a better one tomorrow. In any case, the choice of the best possible solution depends upon careful evaluation of the many presented for consideration. Evaluation involves comparison. You cannot evaluate a single idea by itself, for what seems like the evaluation of a single idea is actually the comparison between that idea and arbitrary absolute standards. Educational courses then, must be set up to give the strident instruction in and exercise in synthesizing and evaluating. It is obvious that design courses are ideal for this purpose.

The last quality necessary to the comprehensive designer is that he know, understand, and have mastery over the creative process. He should have a very sensitive, inquiring mind. He should be able to detect anomalies that others are unaware of. He should be sensitive to problems that pass unnoticed by others. He must be keenly observant and have all his senses so trained that their thresholds of perception can be varied at will. His powers of free and controlled association must be developed to an extremely high level so that he can search out and find extremely remote relationships that will result in the better solution of the problem he has set for himself. He must then have the drive and the emotional energy necessary to carry this solution through to a tangible result. An idea alone is not the end product of the creative process. It becomes that only when it has been acted upon and there is tangible evidence of its existence. To be a master of the creative process then, one must know what factors contribute to success in this field and what factors inhibit it. He must then seek out and develop the good factors and avoid or correct those that prevent him from doing his best. Dr. Dana Farnsworth, who was Head of the M.I.T. Medical Department and who has recently left us for a similar position at Harvard, spoke to the group of engineers attending my special summer course this past summer on the “Emotional Factors That Inhibit Creative Thinking.” He ended up his talk by saying, and I quote,

> The creative thinker or the one who by trying to be a creative thinker, is the one who can go back into the well-springs of his own existence, who can understand himself, see what

> these motives are, who can accept himself for what he is, who can recognize when he is becoming fearful, angry, jealous, suspicious, or what have you, and then direct his own energies over to the daring side of things. When he has learned that technique then he is in a position to learn to be creative.

Now then, I have very briefly sketched out the attributes of the comprehensive designer. Each one of these attributes could easily form the basis for a chapter of a book, or the sum total of one or many books. But what I have said should give you some idea of the tremendous scope of the interests of the comprehensive designer. I am sure that you can easily see why it will be extremely rare if any one man develops all of these attributes to an extremely high level. But I am sure that all of these factors are not inherited attributes, but are ones that can be developed and expanded by education, training, and practice. Each one of us has within us the power to approach this goal more closely than we do at present.

Now then, what are some of the problems that the comprehensive designer must face in the future? They are very simply stated, for they are little different from the problems that have faced mankind for hundreds and thousands of generations. They are associated with the problems essential for survival: food, clothing, shelter, and in our time, transportation and communication. I stated at the beginning of this paper the well-known fact that two-thirds of the world's family is under-fed. It is not a simple matter of not growing enough food or of not being able to transport it to the right places in time, but a very complex combination of these and many other problems. It is both input and output of complicated system that comprises large fractions of the world's area and population. Bucky Fuller once put it this way, and I quote,

> It is not just a matter of raising food, but getting food to people anywhere from zero to twenty-five thousand miles distance. And then it is not just a matter of getting food to people zero to twenty-five thousand miles away, it is a matter of getting it there at certain velocities, and it is not just a matter of getting it there at certain velocities, but it is a matter of getting it there on schedules in certain conditions; conditions of nourishing content, palatability, and vital preservation. And even then, it is not a matter of success concerning all the preceding conditions, for the dumping of a year's food supply in front of a helpless family huddled on the street curb is but an unthinkable tragedy—the maggots appear in hours. And once again the continuing energy controls providing progressive freezes, heating, and so forth, cannot be effected by refrigerators and stoves dumped in the street along with the year's tonnage of food. Obviously, a world continuity of scientific-industrial controls resultant upon comprehensive and technical re-design is spelled out as an irreducible minimum of solution.[66]

One tremendous comprehensive problem of this type, and one we are now writing up as a case study for the use of students in next term's class, is concerned with water as a vital natural resource. Many, many areas are faced with or about to be faced with the problem of inadequate water supply. Most of the approaches being followed today in an attempt to solve that problem deal with ways and means of providing more water. While this is an excellent approach, and while it should be thoroughly investigated, there is the opposite approach that should also be thoroughly investigated, that of finding ways and means for using less water. While we may develop economical processes for converting salt water into fresh water, is there any real reason why each one of us uses in the neighborhood of one hundred gallons of water per day, when all but one gallon of it forms a conveyor system for carrying away specks of dirt and rubbish on the long trip back to the sea? The comprehensive designer must investigate all possible approaches to a problem before he starts to evaluate the solutions obtained.

In the need area of clothing, great progress is being made in the control of the properties of natural fibers as well as the development of new synthetic ones. But these fibers are still intertwined and interlaced in a fashion that is almost as old as recorded history. We may do it faster and more uniformly, yet the basic process remains unchanged. The comprehensive designer must look for new daring approaches to this problem so that he can increase the use factor of each pound of material used and each unit of energy used in their conversion, if all the world's people are to be adequately clothed. I could go on and on and give further examples from the fields of shelter, transportation, and communication. In the field of communication, for one last example, tremendous effort has been and is being expended in the development of highly efficient communication transporting systems, but we are still faced with the limitations present in the human being who sends the message and the human being who receives the message. No matter how accurate our mechanical or electrical transport system is, we can never be sure that the message received is the same as the message intended. These difficulties lead to confusion, misunderstandings, cold wars, and hot wars.

Before I close, let me summarize. Here is the designer of the future, and if we are to believe Richard Neutra,[67] and I am inclined to believe him, he is vital to the world's survival. He cannot approach problems only as an engineer or only as an artist, or only as an economist, or as a politician. He must combine these viewpoints along with others if he is to fulfill the obligations he owes society. While this person I have described is an extremely rare one, and represents a goal of difficult and doubtful attainment, nevertheless the necessary and sufficient attributes are not the accidental products of birth, but those that can be acquired and developed through proper education, training, and constant exercise. The world needs as many comprehensive designers, junior grade as well as senior grade, as she can possibly develop, for her problems will never be solved. We should always be able to better yesterday's solutions today.

- Appendix To Creative Product Design -
United States Automobile Chronology

1871—First recorded steam car in United States
1892—First marketable auto (Duryea)
1893—Haynes-Apperson one cylinder "buggy"
1895—First United States race, 52 miles, won at 5.05 mph. (Duryea)
1895—Individual metal-to-metal cone clutches used to activate gears in constant mesh.
1896—First experimental Ford car
1899—Sliding gear transmission introduced (gear drive in all speeds)
1900—First marketable steam car (White)
1900—First United States steering wheel
1900—First electrics offered for sale
1902—First United States front engine car
1903—Separation of main shaft from clutch shaft permitting direct drive in high
1904—Occasional windshields

1904—Prest-o-lite tanks for headlights
1905—Cam operated valve replaces automatic intake valve
1905—Side entrance doors for tonneau
1905—First radiator grill
1905—First car to use steel panels over wooden frame (Maxwell)
1905—Clincher tire in universal use
1906—Running boards added
1907—Foot accelerator
1907—First front door (Oldsmobile)
1908—Foundries first cast four cylinders in one piece
1909—First Model T Ford
1909—First detachable cylinder head (Ford)
1909—Left hand drive (Ford)
1910—Front doors universally adopted
1910—Haynes first car to furnish windshield, headlights, and speedometer as standard equipment.
1910—“One man” top introduced
1910—Rim with detachable flange in use
1910—Selective shift introduced
1910—Make-and-break ignition practically disappears
1910—Generator and storage battery introduced for lighting and then ignition
1911—First electric starter (Cadillac)
1912—First timing chain (Cadillac)
1912—Carburetor with compensating Jets introduced
1912—Spiral bevel gears adopted for differential
1912—Electric lights almost in universal use
1914—Two speed rear axle with electromagnetic shifting (Cadillac)
1914—Left hand drive universally adopted
1914—First all steel car (Dodge)
1915—Winton, White and a few others use overdrive
1915—Most magneto ignition systems disappear (except Ford who continued until 1927)
1915—Vacuum tank fuel feed; supply tank in rear
1915—Accessory "winter top" with glass sides available
1915—Demountable rims generally adopted
1915—First V3 (Cadillac)
1916—Window concealed in body panels appears
1920—First vibration damper (Packard)
1920—Single plate disk clutch in general use
1920—Cord tires replacing woven fabric
1922—Air cleaner adopted
1922—First low priced closed car (two door Essex coach)
1923—First all steel body (Dodge)
1923—Powered windshield wipers
1924—Oil filters first used as standard equipment
1924—Duco lacquer first used (Oakland)
1924—Balloon tire standard equipment

1924—First four wheel brakes in America (Chapter 6)
1924—Present day instrument panel introduced (Chrysler)
1925—First crankcase ventilation (Cadillac)
1925—Last production of steam cars
1927—First rubber engine mounts
1927—First chrome plating (Oldsmobile)
1927—Hydraulic shock absorbers
1927—Internal hydraulic brakes with self-filling master cylinder
1927—Last Model T
1928—Synchromesh transmission
1928—First safety glass (Model A Ford)
1928—Hypoid ring and pinion gears introduced
1929—Silent helical gears for second
1929—Downdraft carburetor (DeSoto)
1929—First car radio
1929—Floating power (DeSoto)
1930—Air silencer added to air cleaner
1930—Straight through mufflers adopted
1931—First closed car with sloping windshield (Reo Royale)
1932—Free-wheeling transmission
1932—Automatic choke
1932—Beginning of body "stream-lining"
1932—Super-balloon tires Introduced
1932—First vacuum operated clutch (Buick)
1934—Overdrive revived
1934—First all steel top (General Motors)
1934—Knee-action suspension Introduced from Europe
1938—Gear shift on steering column revived by Pontiac
1938—Coil springs in rear (Buick)
1939—Fluid coupling (Chrysler)
1940—Hydromatic transmission (Oldsmobile)
1940—First air conditioning (Packard)
1948—Dynaflow torque convertor (Buick)
1952—Autronic eye introduced by Cadillac
1953—Twelve volt electric system (General Motors and Chrysler)
1953—Air conditioning revived (General Motors and Chrysler)

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READINGS

The Psychology of Thinking

Presented by J. P. Guilford, University of Southern California[68]

First, let me say that addressing a group of engineers is a novel experience for me. Perhaps being addressed by a psychologist is a novel experience for some of you. If it is, the novelty should wear off during the course of the days to follow. The distance between engineering and psychology is really not so very great. Some of our very best psychologists were trained first as engineers. Increasingly, psychologists and engineers are finding common problems in the designing of equipment and in other developmental problems of the age of space. I think that you will find that the approach to the problems of human thinking that I shall present to you is in a sense a kind of engineering job. At least, I shall point out some analogies that should be familiar to you.

You have come into this course with the expectation of learning more about how to think and particularly about how to solve problems more creatively. I have heard many fine things about Professor Arnold's courses on creative thinking, so I am sure that you will not go away disappointed.

You have all learned before now that in order to make effective use of something you must first understand it and in order to understand it you must analyze it. Human thinking is no exception. It is a very complex process and only in recent years have we achieved a very thorough analysis into useful components. For the past ten years, the Aptitudes Project at the University of Southern California, with which I have been associated, has devoted a large share of its efforts to the analysis of thinking.

Our approach has been based upon the fact that individuals differ in the abilities to solve different kinds of problems. Some individuals solve a certain kind of problem easily, while other individuals solve that type with difficulty. The same individual solves some types of problems easily and other types with difficulty. Very rarely is a person equally able to solve all kinds of problems. By a mathematical procedure known as factor analysis, we take advantage of these circumstances in order to discover the types of problems. Once we find a type of problem, we infer that there is an underlying kind of human ability or aptitude for thinking in a certain way. Our strategy has therefore been to explore all conceivable kinds of problems in order to find out all the possible unique abilities that are needed to solve them. These unique abilities are regarded as basic components, which can also account for thinking of more complex varieties.

The Structure of Intellect

Not all the factors discovered in this manner can be considered to be thinking abilities. But in order to give you the best view of the thinking abilities, it is necessary for me to speak of our entire intellectual equipment as we know it from factor analysis, showing where the thinking abilities fit into the picture. The approximately fifty factors of intellect that have been discovered thus far have been organized into a logical system known as the structure of intellect.

We find that the known intellectual factors can be classified in five categories according to the kinds of processes or *operations* involved: *cognition*, *memory*, *divergent thinking*, *convergent thinking*, and *evaluation*. The cognitive factors have to do with the discovery of information, with rediscovery or recognition, and hence with comprehension or understanding in general. In a sense, cognition is the basis of everything that we do in the form of intellectual operations, including thinking. Without having information we do nothing. Memory is simply the process of retaining or storing information for possible future use.

Two categories of factors, divergent thinking and convergent thinking have to do with the generation of new information from given information. In convergent thinking, which is better known and traditionally more highly regarded, we think toward one right answer or one best or conventionally accepted answer. In the extreme case the conclusion is unique, as in mathematical thinking. In divergent thinking the aim is to achieve a variety of answers or conclusions. Thinking of this sort goes off in different directions, in a searching or scanning kind of operation.

The evaluative abilities have to do with decisions as to the goodness of information, whether it is information that we have just cognized, information that we have recalled from the past, or information that we have produced in either convergent or divergent thinking. The "goodness" of the information may be judged in terms of its correctness, accuracy, suitability, appropriateness, or consistency, and so on. Decision making and judgment are general terms applying to this category.

Taking a different approach to the factors of intellect, we find that they can also be classified completely on the basis of the kind of *content* or material, or the form in which the information exists: *figural*, *symbolic*, or *semantic*. Figural content is information in concrete form, as perceived through the senses or as recalled in the form of images.[69] The term "figural" implies some degree or organization or structuring of the information. Symbolic content is in the form of signs, which have no significance in and of themselves. Examples are letters, numbers, musical notations, and so on. Semantic content is in the form of meanings to which words are commonly attached, hence it is most notable in our verbal thinking. The known factors fall in one of these three content categories.

Still a third, entirely different, principle of classification of the intellectual factors is in terms of what we call *products*. We might say that the contents just defined represent three kinds of *raw* materials. The six kinds of products are the kinds of *processed* materials. They come from the application of the operations to the raw materials. The six kinds of products are: *units*, *classes*, *relations*, *systems*, *transformations*, and *implications*. Units are relatively segregated or circumscribed portions of information, such as objects, words, and simple ideas. Classes are aggregates of units of information grouped because of their common properties. Relations are recognized connections between units of information based upon variables that apply to them. Systems are organized or structured aggregates of units of information, such as a problem that is understood, a temporal sequence of events, or a theory. In mathematics a group would probably be an example. In fact, in mathematics we can find good examples of all six kinds of products. Transformations are changes or modifications in existing information. Implications are extrapolations of information, in the form of expectancies, predictions, antecedents, and consequents.

The three kinds of classification of the factors of intellect, each different from the other, can be represented by means of a single solid geometric model, shown in Figure 1. In this model, which we call the "structure of intellect," each dimension represents one of the modes of variation of the factors. Along one dimension are found the various kinds of operations, along the second one are the various kinds of products, and along the third are various kinds of content.[70] Along the dimension of content you will note that a fourth category has been added on a purely theoretical basis to represent the general area that is sometimes called “social intelligence.” Behavioral units would be in the form of the feelings, ideas, desires, and intentions, of other individuals and of ourselves. These, also, are things about which we have information, about which we can think, and which we can evaluate.

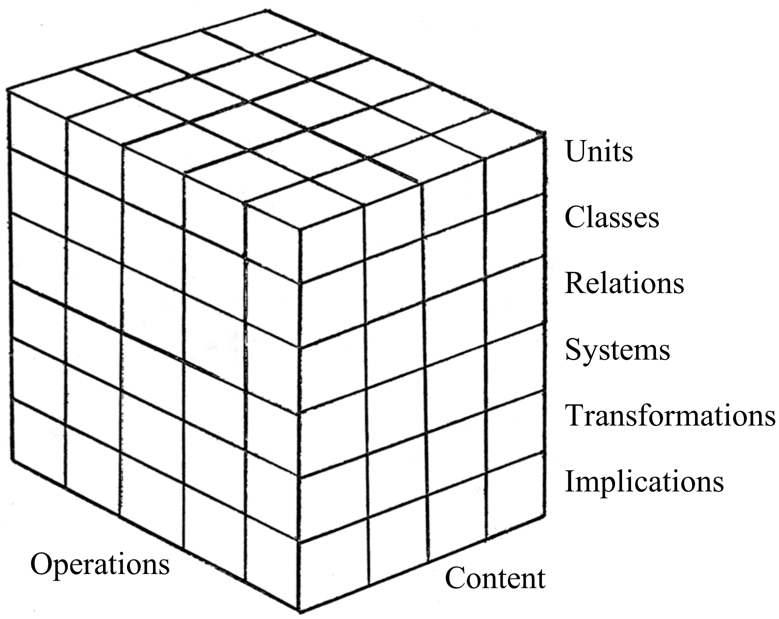


Figure 1. Theoretical model for the complete “Structure of Intellect”

In order to provide a better basis for understanding the model, I shall do some exploring of it with you systematically, giving examples of some tests that represent them. Each cell of the model calls for a certain kind of ability that can be described in terms of operation, content, and product, for each cell is at the intersection of a unique combination of kinds of operation, content, and product. A test for that ability would have three properties, accordingly. In our exploration of the model, we shall take one vertical slab at a time, beginning with the front one.[71] The first layer provides us with a matrix of 18 cells (if we ignore the behavioral column for which there are as yet no known factors) each of which should contain a cognitive ability.

The Cognitive Abilities

We know at present the unique abilities that fit logically into 15 of the 18 cells for cognitive abilities. Each row presents a triad of similar abilities, having a single kind of product in common. The factors of the first row are concerned with the knowing of units. A good test of the ability to cognize figural units in visual form is the Street Gestalt Completion test. In this test, the recognition of familiar pictured objects in silhouette form is made difficult for testing purposes by blocking out parts of the objects. There is another factor that is known to involve the perception of *auditory* figures, in the form of melodies, rhythms, and speech sounds. The presence of two factors in one cell suggests that more generally, in the figural column, at least, we should expect to find more than one ability. A fourth dimension pertaining to variations in sense modality may thus apply in connection with figural content.

The ability to cognize symbolic units is measured by test items like the following:

Put vowels in the following blanks to make real words:
P __ W __ R
M __ RV __ L
C __ RT __ N

Re-arrange the letters to make real words:
R A C I H
T V O E S
K L C C O

(The first of these two tests is called "Disemvoweled Words" and the second "Scrambled Words.")

The ability to cognize semantic units is the well-known factor known as *verbal comprehension*. It is the dominating ability represented in verbal-intelligence tests and it can be measured in purest form by means of a vocabulary test with items like these:

GRAVITY means ________________
CIRCUS means ________________
VIRTUE means ________________

For a comparison of these last two factors, it is obvious that recognizing a word as a letter structure and knowing what the word means are two quite different things. This is an excellent example to help discriminate between symbolic and semantic content.

For testing the abilities to know classes of units, we may use the following kinds of items, one with symbolic content and one with semantic content:

Which letter group does not belong?
XECM PVAA QXIN VTRO

Which object does not belong?
clam tree oven rose

A figural test is constructed in a completely parallel form, presenting in each item four figures, three of which have the same property in common and the fourth lacking that property.

The three abilities to see relationships are also readily measured by means of a common kind of test, differing only in terms of content. The well-known analogies test is applicable, two items in symbolic and semantic form being:

JIRE : KIRE :: FORA : {KORE KORA LIRE GORA GIRE}
poetry : prose :: dance : {music walk sing talk jump}

Such tests usually involve more than the ability to cognize relations, but we shall not be concerned with this problem at this point.

The three factors for cognizing systems do not at present appear in tests so closely resembling one another as in the case of the examples just given. There is nevertheless an underlying common core of logical similarity. For the figural column, the system involved is an order or arrangement of objects in space as seen by an observer. The ability is called *spatial orientation* and it is one of the most important qualities for the success of aircraft pilots or for other operators of machines. It is of importance in geometry and other phases of mathematics.

A system that uses symbolic elements is illustrated by the Letter Triangle test, a sample item of which is:

```
      d
    b   e
  a   c   f   ?
```

Which letter belongs at the place of the question mark?

The ability to understand a semantic system has been known for a long time as the factor called *general reasoning*. It is the second most important component of verbal intelligence tests. One of the most faithful indicators of status in this factor is a test composed of arithmetic-reasoning problems. That the phase of understanding only is important for measuring this ability is shown by the fact that such a test works even if the examinee is not asked to give a complete solution. He need only show that he structures the problem properly. For example, an item from the test Necessary Arithmetical Operations simply asks what operations are needed in order to solve the problem:

A city lot 48 feet wide and 149 feet deep costs $79,432.
What is the cost per square foot?

A. add and multiply
B. multiply and divide
C. subtract and divide
D. add and subtract
E. divide and add

The ability for grasping semantic systems may also pertain to the understanding of plans and organizational structures.

Transformations are changes of various kinds, including modifications in arrangement, organization, or meaning. In the figural column for transformations we find the factor known as *visualization*. Problems of engineering drawing undoubtedly involve this ability. Tests involving surface-development problems are commonly used for measuring the ability. For the ability to have transformations of semantic materials, a test known as Similarities applies. The examinee is asked to state several ways in which two objects, such as an apple and an orange, are alike. Only by shifting the meanings of both objects is the examinee able to give many different responses to such an item.

The two known abilities for cognizing implications have been known as *perceptual foresight* and *conceptual foresight*. Foresight in connection with figural material can be tested by means of paper-and-pencil mazes. The nearest analog in the work of the engineer is the tracing of electrical circuits, either in real form or on paper. Probably the art of seeing several moves ahead in checkers or chess also draws heavily upon the same ability. Foresight in connection with ideas, those pertaining to events, for example, is indicated by a test called Pertinent Questions. An illustrative item is:

> In planning to open a new hamburger stand in a certain community,
> what four questions should be considered in deciding upon its location?

The more questions the examinee asks in response to a list of such items, the more he evidently foresees contingencies.

The Memory Abilities

Although the memory abilities have less bearing upon our topic of the psychology of thinking than do the abilities in other areas, you may be interested in what we know about them as a completion of the picture. Certainly, remembered and recalled information is essential for thinking. This indicates the value of learning and remembering facts. The great industrial inventor, Kettering, sometimes remarked that things students learn in their textbooks often get in the way of creative thinking later on. I do not believe that having the information is the source of the trouble; it is the *attitude* toward the information. If the student is led to believe that what he is taught is the final word on the subject, this belief will be a definite handicap. We should emphasize an open-minded attitude toward what is said to be known on any subject.

The abilities in the top row of the memory matrix pertain to the memory for units.[72] In the figural cell we know of two abilities, one for remembering visual objects and one for remembering auditory units such as melodies and rhythms. Visual memory is a kind of photographic memory. Particular objects or figures you have seen before can be drawn or described or recognized in much the same form and detail. Remembering telephone numbers and names and the spelling of words comes in the category of memory for symbolic units. Memory for semantic units means remembering ideas. If you read a paragraph and understand it, you can write down or tell someone about them in your own words later. You are likely to be unequally able to remember these different kinds of units—figures, words, and ideas.

In testing for memory for relations, we have our subject memorize units in pairs, for example, syllables paired with numbers. Later, we test him by giving only the first member of each pair, the subject to supply the second member. This kind of test measures what is commonly called "rote memory," the memory for associations between symbolic units. A parallel ability called "meaningful memory" pertains to remembering similar pairs of meaningful words. There is presumably a third such ability for remembering associations between figures.

It has recently been found that we have two different abilities for remembering systems. The memory for a figural system may be tested by showing the examinee a page on which a number of familiar objects are scattered about. In his memory test the examinee has to say where on the page each object was seen. Memory for a semantic system can be tested by presenting items of meaningful information in temporal sequence, the examinee being tested later on how well he remembers that order. For example, the examinee might be quizzed regarding the order in which he took a list of tests on the day preceding.

The absence of factors for remembering classes, transformations, and implications should not be taken to mean that they do not exist. It is probably that those particular kinds of memory have not been investigated by factor-analytical methods as yet. The same is true of many other vacant cells in the structure of intellect. Since the classification of the factors was first conceived, a dozen factors have been found that occupy logical places within the system, and present research is aimed at determining whether other unique abilities predicted by the system will be found.

The Divergent-Thinking Abilities

The unique feature of divergent production is that a *variety* of responses is produced. The product is not completely determined by the given information. This is not to say that divergent thinking does not come into play in the total process of reaching a unique conclusion, for it plays a role wherever trial-and-error thinking takes place.

In the category of divergent thinking we have expected to find most of the abilities that contribute to creativity. It is here that we do find the factors having to do with the fluency, flexibility, and originality of thinking. Most of the factors already known in this category are in the semantic column. A study now under way is designed to explore more fully the figural and symbolic columns, where we expect to find abilities paralleling the semantic abilities.

The well-known factor of *word fluency* is tested by asking the examinee to list words satisfying a specified letter requirement, such as words beginning with the letter “s” or words ending in “tion.” The parallel semantic ability, for producing a variety of meaningful units, is known as *ideational fluency*. A typical test calls for listing objects that are round and edible, another for listing titles for a short story plot. In each case, the quality of responses does not count; only quantity. Winston Churchill must have possessed this ability to a high degree. Clement Attlee is reported to have said of him that no matter what problem came up, Churchill always seemed to have about ten ideas. The trouble was, Attlee continued, Churchill did not know which was the good idea. The last comment implies some weakness in one or more of the evaluative abilities.

The divergent production of class ideas is believed to be the unique feature of a factor called *spontaneous flexibility*. A typical test instructs the examinee to list all the uses he can think of for a common brick and he is given eight minutes. If his responses are: build a church, build a chimney, build a walk, build a barbecue, he would earn a fairly high score for ideational fluency but a very low score for spontaneous flexibility, because all these uses fall in the same general class. If another person said: make a door stop, make a paper weight, throw it at a dog, make a bookcase, drown a cat, drive a nail, make a red powder, and use for baseball bases, he would also receive a high score for flexibility. He has gone frequently from one class to another.

In our current study of the other areas, an experimental test presents a number of figures that can be classified in groups of three in various ways, each figure being usable in more than one class. An experimental symbolic test presents a few simple numbers that are also to be classified in multiple ways.

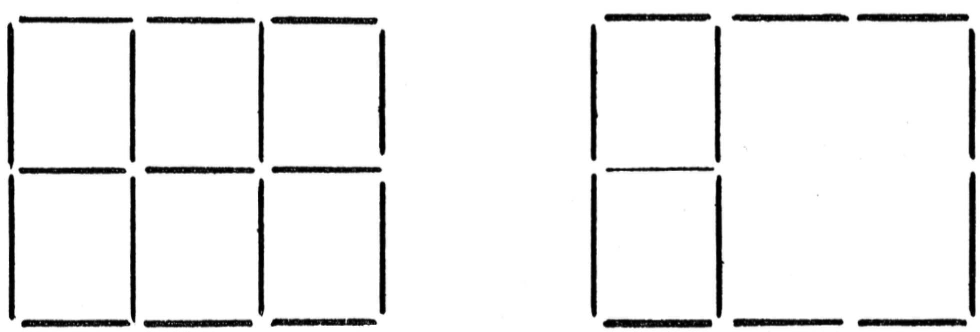
A unique ability involving relations is called *associational fluency*. It calls for the production of a variety of things related in a specified way to a given thing. For example, the examinee is asked to list words meaning about the same as “good,” or to list words meaning about the opposite of “hard.” In these instances the response produced is to complete a relationship and semantic content is involved. Some of our present experimental tests call for the production of a variety of relations and pertain to the figural and symbolic columns also. For example, given four small digits, in how many ways can they be related in order to make a sum of eight?

One factor pertaining to the production of systems is known as *expressional fluency*. The rapid formation of phrases or sentences is the essence of certain tests of this factor. For example, given the initial letters:

W________ c________ e________ n________

with different sentences to be produced, the examinee might write “We can eat nuts,” or “Whence came Eve Newton?” In interpreting the factor, we regard the sentence as a symbolic unit. By analogy, a figural system would be some kind of organization of lines and other elements and a semantic system would be in the form of a verbally stated problem or perhaps something as complex as a theory.

In the row of the divergent-thinking matrix devoted to transformations we find some very interesting factors. In the figural column the factor is called *adaptive flexibility*. A faithful test of this factor is called Match Problems. This test is based upon the common game using squares, the sides of which are formed by match sticks. The examinee is told to take away a given number of matches to leave a stated number of squares with nothing left over. Nothing is said about the sizes of the squares to be left. If the examinee imposes upon himself the restriction that the squares that he leaves must be of the same size, he will fail in his attempts to do items like that in Figure 2. Other odd kinds of solutions are required in other items, such as overlapping squares and squares within squares, and so on. In another form of the match-problems test the examinee is told to produce two or more solutions for each problem.



A **B**

Figure 2. A sample item from the Match Problems test.
The problem is to take away four matches in A so as to leave three squares and nothing left over.

A factor that has been called *originality* is now recognized as adaptive flexibility with semantic material, where there must be shifting of meanings. The examinee must produce the shifts or changes in meaning in order to come up with novel, unusual, clever, or far-fetched ideas. The Plot Titles test presents a story, the examinee being told to list as many appropriate titles as he can to head the story. One story is about a missionary who has been captured by cannibals in Africa. He is about to be boiled when a princess of the tribe obtains a promise for his release if he will become her mate. He refuses and is boiled to death.

In scoring the test, we separate the responses into two categories, clever and non-clever. Examples of non-clever responses are: African Death, Defeat of a Princess, Eaten by Savages, The Princess, The African Missionary, In Darkest Africa, and Boiled by Savages. These titles are appropriate but commonplace. The number of such responses serves as a score for ideational fluency. Examples of clever responses are: Pot's Plot, Potluck Dinner, Stewed Parson, Goil or Boil, A Mate Worse than Death, He Left a Dish for a Pot, Chaste in Haste, and a Hot Price for Freedom. The number of clever responses given by an examinee is his score for originality.

Other tests of originality present very novel tasks so that almost any response will be acceptable. In the Symbol Production test, the examinee is to produce a simple symbol to stand for each noun and verb in short sentences. In other words, he has to invent a kind of pictograph writing. In the Cartoons test, for each given cartoon the examinee is asked to write a suitable "punch line." In each of these tests an item challenges the examinee to be clever.

Abilities to produce a variety of implications are assessed by tests calling for elaboration of given information. A figural test provides the examinee with a line or two, to which he is to add other lines to produce an object. The more lines he adds the higher his score. A semantic test gives the examinee the outline of a plan, to which he is to respond by stating as many details as he can that would be needed to make the plan work. A new test we are trying out for the symbolic category is in the form of very simple equations. Given: B - C = D and z = A + D, the examinee is to make as many new equations as he can from this information.

The Convergent-Production Abilities

Of the 18 convergent-production abilities expected in the three content columns, 12 are now recognized. In the first row, pertaining to units, we have an ability to name figural properties (forms and colors) and an ability to name abstractions (classes, relations, and so on).

A test for the convergent production of classes, Word Groupings, presents a list of 12 familiar words that are to be classified in four, and only four, meaningful groups, no word to appear in more than one group. A parallel test, Figure Concepts test, presents 20 pictured real objects that are to be grouped in meaningful classes of two or more each.

Convergent production pertaining to relations is represented by three known factors, all involving the production of a unit to complete a relationship, when another unit and a relation is given, as in the item:

pots stop   bard drag   rats _?_.

A semantic test that measures the parallel ability contains items like the following:

The absence of sound is ________________ .

Only one factor for convergent production of systems is known and it is in the semantic column. It is measured by what we call ordering tests. The examinee may be presented with a number of events that ordinarily have a best or most logical order, the events being presented in scrambled order. The presentation may be pictorial, as in the Picture Arrangement test, the pictures being taken from a cartoon strip. Verbally presented events may be in the form of steps needed to plant a new lawn. Systems other than those involving temporal order could probably be utilized for measuring this ability.

In the way of producing unique transformations, we have three recognized factors, which have been known as *redefinition* abilities. In each case, redefinition involves the changing of functions or uses of parts of one unit in order to give them new functions or uses in some new unit. Figure 3 shows the kind of items for testing the figural-redefinition factor. In recognizing the simpler figure within the structure of the more complex figure, certain lines must take on new roles.

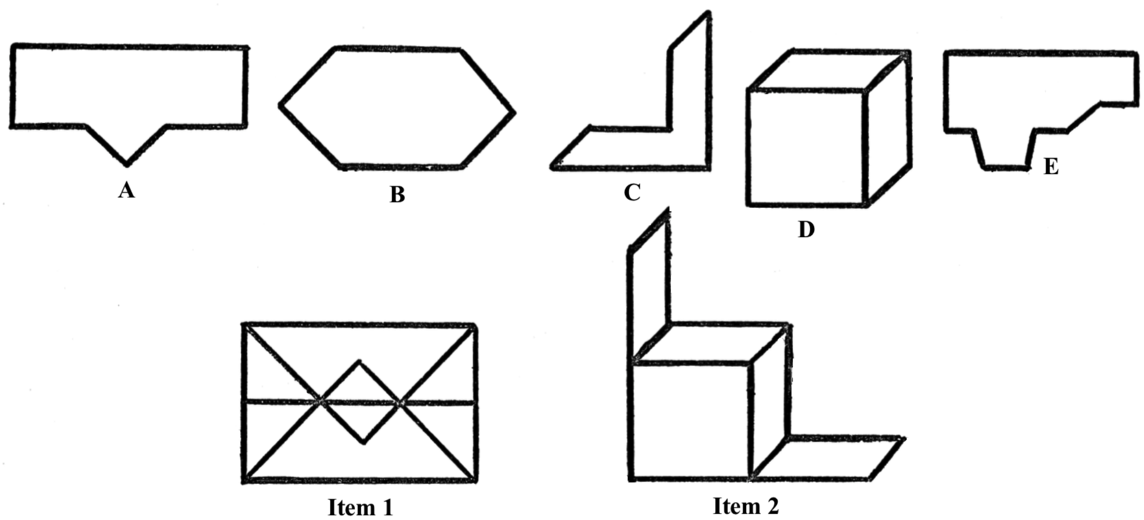


Figure 3. Two sample items from the Hidden Figures test.
Which of the five figures at the top are concealed within each item figure?

A test for measuring the ability of symbolic redefinition is called Camouflaged Words. In each item a name of a sport or a game is concealed, for example:

I did not know that he was ailing.
To beat the Hun, tin goes a long way.

For the factor of semantic redefinition the Gestalt Transformation test may be used. A sample item reads:

From which object could you most likely make a needle?
A. a cabbage
B. a splice
C. a steak
D. a paper box
E. a fish

The convergent production of implications means the drawing of fully determined conclusions from given information. The well-known factor of *numerical facility* belongs in the symbolic column. It is tested by any test involving number operations. For the parallel factor in the figural column we have a test known as Form Reasoning, in which rigorously defined operations with figures are used. For the parallel ability in the semantic column the factor sometimes called "deduction" probably qualifies. Items of the following type are sometimes used:

> Charles is younger than Robert.
> Charles is older than Frank.
> Who is older, Robert or Frank?

The Evaluative Abilities

Only eight evaluative abilities are known at present, owing to a lack of studies in this area. In each case, evaluation involves reaching decisions as to the accuracy, suitability, or workability of information. In each row of the evaluation matrix, which involves a particular kind of product, some kind of criterion or standard of judgment is involved.

In the first row, for the evaluation of units, the important decision to be made pertains to the *identity* of units. Is this unit identical with that one? For the figural ability of this kind, pictured objects are presented, some of which are identical and some are not. In the symbolic column a test calls for judgments of identity of series of letters or of digits or the identity of names of individuals. There should be a parallel ability to decide whether two ideas are identical or different. Is the idea expressed in this sentence the same as the idea expressed in that one? Do these two proverbs express essentially the same idea? Such an ability should be of special importance for lawyers, judges, and editors.

The abilities having to do with evaluations where relations are involved are concerned with the criterion of logical consistency. Does the relationship expressed by a statement follow logically from one or more other statements? As we should expect from the structure of intellect, syllogistic-type items involving letter symbols indicate a different ability than the same type of item involving verbal statements. In the figural column we might expect that tests incorporating geometric reasoning or proof would indicate a parallel ability to sense the soundness regarding figural relationships.

The evaluation of systems seems to be concerned with the internal consistency of those systems. A factor called *experiential* evaluation presents a picture of a common scene, asking the question "What is wrong with this picture?" The things wrong are usually internal consistencies, such as the smoke from a chimney going in one direction and a flag flying in the opposite direction.

A factor first known as "sensitivity to problems" has become recognized as an evaluative ability having to do with implications. One test of the factor, the Apparatus test, asks for two needed improvements in each of several common devices, such as the telephone or the toaster. The Social Institutions test, a measure of the same factor, asks what things are wrong with each of several institutions, such as tipping or national elections. I recently read about a simple invention of a plastic container for the right amount of detergent to be added to the water in a washing machine, the container dissolving completely. Somebody must have seen the implication that the customary procedure of measuring out the required amount of detergent with a spoon is not all that could be desired.

Implications for the Psychology of Thinking

As you have seen, we have distinguished some 50 different intellectual abilities and they can be organized logically in a unitary system, which, incidentally, predicts more than twice that number. What does all this mean? Are the factors relevant for thinking in everyday life? How can we use this information?

As I indicated in the beginning, analysis leads to understanding and understanding leads to use. But there are usually many steps to be taken between understanding and use. The discovery of the intellectual factors comes through what I should consider to be basic research. As basic concepts, the factors and the ideas associated with their organization should have very general application. We shall next attempt to see what some of the outcomes of this information can be.

First, let us consider what kind of creature the human organism is, when viewed from the standpoint of the intellectual abilities. From the psychological point of view, the human organism can be viewed as something much like an electronic computer. A computer gains information and stores it for future use. It generates new information from given information, perhaps in either divergent or convergent thinking, and it evaluates its own conclusions. Thus, the five kinds of operations of the structure of intellect are all represented in the work of computers.

One difference between a living organism and an ordinary computer is that the organism indulges in active searching for information. Another difference is that it can program itself by giving itself instructions. Perhaps some computers also do this; my information regarding computers is limited and not very up to date. But if I were at all concerned with the construction of a new kind of computer, I should use the structure of intellect as a guide concerning the kinds of information that should be coded for input and the kinds of operations that would be needed in order to produce the kinds of products desired.

Problem Solving and the Factors

What is the role of the intellectual factors in problem solving? At the beginning of this discussion it was stated that factors are discovered by varying the kinds of problems given in the tests. The best kinds of problems for this purpose are relatively simple ones. Only by such systematic variations of tests and by the experimental control that simple problems provide can we segregate the factors. But many everyday problems are quite complex. They do not resemble the simple test items. Can the kind of factors that we know account for ability to solve complex problems or will some additional ability or abilities be involved?

Where factor analysis is properly applied, a unique problem-solving ability has never been demonstrated. On the other hand, it has been demonstrated a number of times that individual differences in ability to do well in a complex task or to solve a complex type of problem can be accounted for in terms of individual differences in certain combinations of the known factors.[73] One example is an arithmetic-reasoning test, which consists of problems presented verbally, each problem involving a number of facts and variables. The most important contributor to total scores in an arithmetic-reasoning test is the factor of cognition of semantic systems (understanding the problem). Almost as important is the factor of producing convergent implications (numerical operations). Another significant contributor is verbal comprehension (understanding of meanings of words) and still another is visualization (comprehending transformations). Other factors may make small but negligible contributions to the differences in scores on such complex problems.

The combination of factors that play roles in solving a certain kind of problem differs according to the problem; also the relative weights of the factors differ. For example, in a test called Predicaments, the kind of problem is a very practical one. In one item the examinee is told that he has gone to a picnic and finds that the cheese that he brought along to make sandwiches is not sliced. He also has with him a harmonica, matches, a thermos bottle, and a ukulele. Can he give two different solutions to this problem? The two leading factors that are found to account for individual differences in this test are commonly known as conceptual foresight and sensitivity to problems, followed by the factors of ideational fluency and cognition of semantic systems.

Let us take an illustration nearer to your own experience. Sprecher[74] gave to practicing engineers three complex problems in their field, the nature of the problems not being described in the report that I have seen except to say that the problems have no unique answers and they call for some degree of inventiveness. Sprecher predicted that the individual differences in scores of a group of more than a hundred engineers could be accounted for, in part, by a combination of several divergent-thinking tests of factors of fluency, flexibility, and originality. A combination of five such tests accounted for as much as 27 percent of the differences in scores for one of the problems.

The Factors and Creativity

As in the case of problem solving, creative performance of other kinds depends upon the nature of the creative activity. No one factor is to be identified with creativity. Many of them contribute to creative production, depending upon the circumstances. The inventive problem solving just mentioned is one example. The problems of a composer or a writer would undoubtedly draw upon other abilities than those important in solving engineering problems.

I used to think that most of the abilities that are most obviously related to success in creative performance are to be found in the divergent-production category, which contains the factors of fluency, flexibility, and originality. I did recognize that almost any one of the other abilities might on occasion serve in supporting roles. But more recently I have been forced to recognize the importance of another category of factors, namely, the product category of the factors having to do with transformations.

During the past year, we had occasion to ask a number of individuals who are recognized for their creative contributions in research and development to rank for us some 28 of the intellectual factors.[75] We defined each factor for them as best we could and provided a simple example of mental activity that should involve the ability. We were not completely satisfied that good communication with the scientists was achieved. But for what they are worth, the results show that the operation, categories of factors that the scientists rated highest for value in their own work were convergent production, cognition, and divergent production, in that order. As to product categories, the factors rated highest were generally for transformations, implications, and systems.

The general conclusion is that, as the research personnel see it, the most important abilities in their work are not generally in the divergent-thinking area. It may be that much of their work is not highly dependent upon the factors of fluency, flexibility, and originality. It may be that they realize that much of their work is non-creative. On the other hand, perhaps the research individual is not so likely to notice his divergent thinking when it occurs. If he does, observe it, he seems not to attach as much value to it as he does to other types of thinking. At any rate, we should be ready to give any and all abilities their due in connection with problem solving and other creative activity.

Training for Creativity

In this course you will be concerned with the general question of whether individuals can learn to be more creative and, if so, the question of how this goal is to be achieved. These questions are related to a much larger one concerning whether the intellectual abilities in general can be improved in individuals with exercise of some kind. It is quite likely, although we do not know all the answers, that heredity sets the limits of development for each and every intellectual ability; limits above which the individual cannot go under the most favorable circumstances and limits below which he probably will not fall even under unfavorable but not organically damaging circumstances. Within those limits, which may be far apart in some instances, there is room for training to work. To this extent we may regard the factorial abilities as somewhat generalized, unique, intellectual skills.

Training may, in part, therefore, serve to develop those abilities that are exercised. Knowing the unique abilities and knowing their properties, we are in a position to prescribe the kinds of material and the kinds of activities that should develop them. We can give the individual exercises in discovering relationships, systems, and implications; in producing classes and transformations, either of the convergent or divergent kind; and exercises in making judgments and decisions in which standards of identity, consistency, and goal satisfaction are involved. Realizing the great range of abilities, we can ask whether life experiences and school instruction are maintaining appropriate balances and whether certain areas of intellect are being neglected.

If we apply factor-analytic theory to the problems of training, we see that learning is both general and specific. The general aspect is thought to be in the form of improvement of the learner's status in the various factors. The specific aspect is in the form of *particular* units of information, *particular* classes, relations, and so on. Another kind of specific aspect is what we can "strategy" in handling problems. Different types of complex problems can be attacked most effectively with different strategies. I will give two examples.

For several years, now, the U. S. Navy and other branches of the Department of Defense have been very much concerned about how to improve the skills of the men who handle troubleshooting problems in electronics, as you may well know. At the University of Southern California a number of psychologists have given persistent attention to this problem and have approached it in a number of ways. One of these investigators, Donald Schuster, has had much training in electronics as well as in psychology. He has recently developed a set of about a dozen rules, which if mastered and properly applied will facilitate the processes of troubleshooting considerably. This summer he has some experiments under way to determine the best ways of training men how to use his system.[76]

The other example is associated with the structure-of-intellect model. The model is of course a system involving classes and relations. I have recently learned that the production of this kind of model has been given the technical name of "morphological analysis," by the astronomer Fritz Zwicky of the California Institute of Technology.[77] He defines morphology as "the basic pattern of things."

An example that he gives pertains to the varieties of jet engines. Some of you may know about this particular model. It has three parameters or dimensions, one for different kinds of propellants, of which he has three; one for the kinds of thrust, of which he has three (internal, external, and none); and one for the kinds of motion produced, of which there are four (rotary, oscillatory, translatory, and none). The model, like the structure of intellect, provides all the logically possible cases, in this instance, of kinds of jet engines, some of which do not exist as yet but which are suggested as possibilities. This kind of model, therefore, seems to provide an excellent basis for generating new ideas. It suggests that in order to scan a field thoroughly, we should determine its parameters and the categories along each parameter.

During this course you will have experience with some other strategies that have been developed to facilitate creative thinking. In recent experiments at different universities and military posts, it has been demonstrated that individuals who have such training come out of the courses with gains on certain tests of divergent-thinking abilities. As compared with control groups, they produce a greater number of good-quality ideas. They do not always gain in producing a *quantity* of ideas, particularly ideas of low quality, but this kind of gain would be of questionable value.

I close by wishing you all success in achieving the goals you are seeking in connection with this course.

The Value Structure of Creativity

Presented by Robert S. Hartman, Research Professor, National University of Mexico[78]

One can look at creativity from many points of view. Psychologically, aesthetically, philosophically. But all these views enlightening and interesting though they are, leave something to be desired. Creativity is one of those words which may mean anything to anyone. I want to approach the subject from a different angle, a scientific angle, if you wish, but scientific, not in the sense of natural science, but of moral or human science. I would like to present to you a framework within which to think with precision about creativity, and by which you may perhaps even be able to measure creative activities.

To begin with let us mention some examples of creativeness:

First Example: I have a brother who is a mechanical engineer. (Story of Tone Arm, analogy to crankshaft dynamic dampening.)

Second Example: Heinchen seeing two-cycle application in compressor air filter.

Third Example: Engineer who looks over a blackboard full of formulae and, seeing it as one, pointing out mistakes or corrections.

Already these examples show us the outstanding feature of all creative thinking, namely, Unification. John Ruskin said that "hundreds of people can talk for one who can think but thousands can think for one who can see. There is only *one* way of seeing things right, and that is, seeing the whole of them." The creative thinker sees the totality of a large field of phenomena as one and finds the essence in it. The unity and structure he sees in what before him seemed an unrelated heap of items is really the unity and structure of his own self. As Eliot D. Hutchinson writes in his book *How To Think Creatively*, one not only *creates* something, one *becomes* something as well. "I *became* a falling body," Galileo used to say. Such creators *live* their problem; and its solution is their own becoming themselves, their own self-realization. They are, writes Hutchinson, "creators because they cannot be otherwise. The whole self not only expresses itself in a given medium. It *is* that expression, when once it is externalized." The secret of the creative person, thus, is the capacity for identification with some external material, whether canvass and paint or sound or movement or ideas. It is the limitless capacity of giving oneself and regaining oneself in a work.

The identification with some such material or ideal presupposes identification with oneself; and it is for this reason that psychologists have discussed this peculiar phenomenon. The unitary view of the field in most cases comes as a sudden revelation, when the whole new science or work is seen in one sweep. Thus Goethe saw the *Urpflanze*, the primal plant, while promenading under the palm trees of Palermo, Darwin the pattern of evolution on reading Malthus, Newton the law of gravitation on feeling the impact of the famous apple, Kekulé the benzoyl-ring on dreaming of a serpent. Psychologists have described the creative experience as the five-fold progress from preparation to frustration, incubation, inspiration and realization, and there is a large literature about the subject, especially the stage of inspiration, the "Aha"-experience when what before had been chaos suddenly falls into place, as a new Gestalt.

However, there is much more to the creative experience than what psychological literature shows. The creative view must be applied to creativity itself and the total pattern must be seen of which this experience is only a part. The psychology books see only glimpses of what actually is an entirely new world. The creative experience is one of an infinity of experiences of a world as varied as the ordinary world in which we live, the world of our senses, yet as different from it as is that other world of ours, the world of symbols, or science, with which we are all familiar and whose otherness we readily understand.

But the world of intrinsic value, to which creativity belongs, has hardly been discovered. Of all modern philosophers it is the German philosopher Husserl who has most clearly developed all three kinds of worlds— the world of the senses, of our everyday environment; the world of symbols or science, which is the world of books, thoughts, and calculations; and the world of *intrinsic value* of which the creative experience is a part. Modern value theoreticians or axiologists—*axios* means “value”—have structured these worlds with precision. I would like to give you an idea of this unitary view of the three worlds in which we constantly live, and locate the creative experience within it.

Phenomena of creativity are what is called today “intangibles.” They join in this a large number of phenomena equally important. Indeed, we may well say that the most important phenomena are intangibles. Modern axiology, or value theory, may be defined as that discipline which makes intangibles tangible. It may be called the science of the *measurement of the unmeasurable*. The most important events and choices in our lives are based on intangibles. Think, for example, of the choice of your wife. How do you choose her? What do you have to go by? You know very well that if you would have a list of specifications of wives and you would carry that along when you were looking for girls and you would find one with all the specifications, then you wouldn’t marry her because you wouldn’t like her. There have been cases like this. And there is hardly a more creative act in your whole life than choosing a wife—and all this carries with it, in continuous spontaneous creativity.

What then is it, that you base your choice upon? It is an intangible. In business, suppose you have to choose an elevator boy. There isn’t much difficulty in doing that because you can put down in writing the specifications of that job and if he can push a button and open a door and smile, or not smile for that matter, he will be a good elevator boy. But how do you choose the *president* of a company? What specifications can you write down for the president of a company like General Electric or General Motors who has to make decisions of hundreds of millions of dollars in terms of hundreds of thousands of men? How about the choice of the President of the United States? Why did you vote for Eisenhower instead of Stevenson or for Stevenson instead of Eisenhower? What did you go by? Why did they vote for Truman as against Dewey? I bet many did because Dewey had a mustache.

All these are decisions carrying with them a chain of creative events, of almost unlimited consequences. But how do we make them? Our knowledge of such creative behavior is no greater than our knowledge of the artist’s creativity, who creates in material rather than in human affairs— and it is all the same basic process. What then are these tremendously important choices based upon? Can these intangibles be known, let alone be measured? You will say, of course, no, it is impossible, it can’t be done. Well, I agree up to a point because the science of measuring these intangibles is only in its infancy. But I want to remind you that also in the natural sciences, where you have the precision measurements on which General Electric, General Motors, and the whole of modern technology are based, there was a time when all these *tangibles*, as you might call them, of measurement of today, were absolutely intangible. That was before Galileo had invented the marvelous application of mathematics to nature. For us today it seems an absolutely natural, a tangible thing, that if you go a hundred miles in two hours you have a speed of fifty miles. But for Galileo to produce the equation $\mathbf{v} = \mathbf{s}/\mathbf{t}$ was a tremendous achievement, and of such importance that it actually destroyed the medieval world. And, as you know, it almost killed him.

Why? Because he did something tremendous. He made the intangible tangible and he did it in such a way that those who liked the intangibles more than the tangibles didn't like it. What was the intangible that he made tangible? Before Galileo, motion or movement was defined by Aristotle, in his *Physics*, as the transition of potentiality into actuality. This was the Aristotelian definition of movement of things, of animals, of the soul, of God, of the limbs of the human body, and so on. This was called Natural Philosophy and on this you could not have built General Electric, General Motors, or atomic bombs.

So Galileo did something absolutely unique and at that time unheard of. First of all he said, "I am only interested in the motion of *objects*," mechanical motion as we call it today. Therewith he toppled the whole Aristotelian world picture; he "secularized" movement. Secondly, he said, "I will measure such motion with measuring instruments," and therewith he toppled the metaphysical view of the world. Since falling was too fast he put balls on inclined planes, designed a water clock and measured, and the result was the little formula, that "v" equals the mathematical division between space and time, $\mathbf{v} = \mathbf{s}/\mathbf{t}$.

Then he said the following: "If this formula is correct, and it is correct according to my measurements, then I don't have to look at observations of mechanical motion any more at all. All I have to do is to look at what this equation means. And what does it mean? For example, it means that $\mathbf{s} = \mathbf{vt}$. If this is true, then it is also true that $\mathbf{s}$ is a rectangle with the sides $\mathbf{v}$ and $\mathbf{t}$. If this is true, I will try to see what are the properties of this rectangle and that, then, will give me the space of motion."

And when you open Galileo's great book, *Two New Sciences*, 1638, all you find is drawings of rectangles, triangles and so on and, as you know, he said, "The book of nature is written in rectangles and triangles in geometrical symbols"—and this is the beginning of modern science.

Now, this was the development from natural philosophy to natural science, and on this little formula is based the whole of modern science. It formulates uniform motion, then came, the formulation of accelerated motion, $\mathbf{a} = 1/2\ \mathbf{gt}^2$, then the system of Newton, combining Galileo's and Kepler's formulae, the system of Einstein, and the atomic bomb. All this was based on the break by Galileo with Aristotelian physics. The book called *Physics* by Aristotle contained intangibles which Galileo made tangible.

The Notion of a Value Science

Aristotle also wrote a book called *Ethics*—the Nicomachean Ethics (his son was Nicomachos). Today, when we teach ethics we teach the ethics of Aristotle and similar moral philosophies. Thus, today we combine Einsteinian physics with Aristotelian ethics. We have a disequilibrium of tremendous proportions: technological development in natural science and absolute stand-still in moral philosophy. We are morally at the stage of Aristotle.

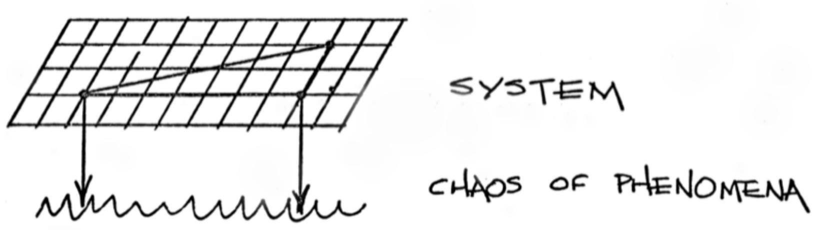
Some of us philosophers, when we were students, thought that this situation was rather lopsided and that we must do to Aristotle's *Ethics* what Galileo had done to Aristotle's *Physics*. We had to take the philosophical definition of goodness of Aristotle (and, by the way, "transition from potentiality to actuality" may also be regarded as an Aristotelian definition of value—it means just as little or as much for value as it does for motion) and we had to change it into something that meant as much for value as the Galilean definition for motion.

So our task, we figured, was to find an exact definition of value, of goodness in terms of either a mathematical or logical relation which would be as applicable and as developable as the Galilean definition of motion. This definition was finally found and I will in the little time I have give you the principles of it. We are today in the rudimentary beginnings of a science of value, you might say the first ten years of Galileo. If you remember how long it took from Galileo to General Electric, then you will understand the tremendous development that is ahead in the science of value.

The Nature Of Science

Now what is a science? A science is nothing else but the application of a formal frame of reference to a chaos of phenomena. In other words, you have the chaos of moving things. Aristotle tried to order this by words like "potentiality," "actuality," and the like, but these words themselves are disorder. For, what is *potentiality*? If you want to define it you have to define it by words, these words have to be defined, and the definitions defined, and the definitions *of* the definitions defined, and so on *ad infinitum*. Such a nest of definitions within definitions itself represents no order, or only a very rudimentary one.

However, if you take a system like mathematics—and the great achievement of Galileo was the line between the **s** and the **t** in the formula for velocity, **v** = **s**/**t** which represents arithmetical division—then you are within a framework that is systematized and you can then apply this system to the chaos. You take points in the system and apply them to points in the chaos, and the order between the points in the system is the order between the points in the chaos.



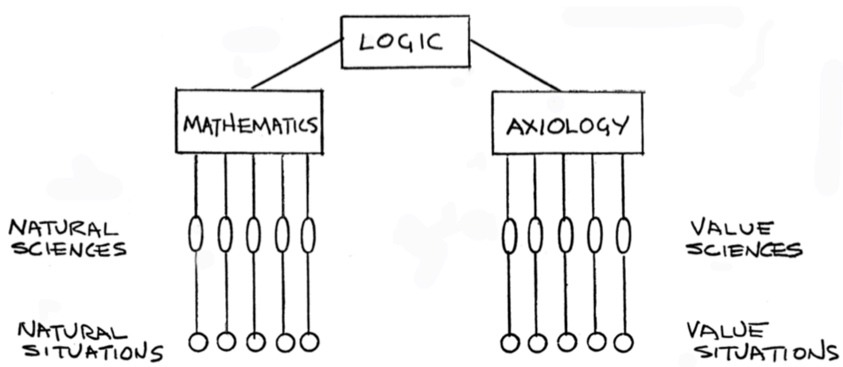
On this relationship between a formal system and phenomenal chaos is based all scientific definition. The minute a ray of light was defined as a straight line the science of optics was born: the system of geometry could be used to account for rays of light, for "straight line" is a notion in the system of geometry.

Thus a science is the combination of a formal system, whether it be mathematics in physics or theory of harmony in music or axiology in value, to a chaotic set of phenomena, be they natural phenomena or musical sounds or value situations. So that today we have the following view of science. You have the various natural sciences which are ordered by mathematics, namely physics, chemistry, astronomy, and so on, each applied to a set of natural situations; for example, a situation such as a bicyclist.

The Nature of a Value Science: Formal Axiology

Now, we figured about twenty years ago, there are also value situations, such as I said before, creating a new tool, choosing my wife, choosing the president of a company, or to give you another example, the flight of the airplane *Enola Gay* to Hiroshima. The pilot wrote in the log book the wind velocity, the weather, and everything at this exact minute we released the atomic bomb, angle so-and-so, weight so-and-so, weather so-and-so, etc., all the details mechanically, aerodynamically, meteorologically, of the flight. But at the end of these entries in the log book there are these words, "My God, what have we done?" As you know the pilot is now under psychiatric care, he has such a tremendous guilt complex that he cannot hold a job, commits petty crimes, and so on.

Now everything in this log book entry up to these last words is natural science, mathematics, physics, astronomy, chemistry; but these last words, "My God, what have we done?"—that is a moral question, something in the field of value. If we had value sciences, say, ethics, religion, aesthetics, and so on, all these value situations would be ordered by the corresponding sciences. But if they are to be sciences then there must be a formal frame of reference which must order these sciences as mathematics orders the natural sciences; and this formal frame of reference is what we call *formal axiology*, from the Greek word "axios" meaning "valuable."



This notion "formal axiology," was already coined in the year 1903, by the German philosopher Husserl. Formal axiology must be a kind of logic just as mathematics is a kind of logic but it must be a different kind of logic; and *what kind of logic*, that was precisely the question. So, what I want to develop for you very shortly and only in principle are the foundations of the science of formal axiology as *that science which does for value situations and value sciences—including the situation and science of creativity—what mathematics does for natural situations and natural sciences.*

Moral Value and Axiological Value

I shall now give you the definition of *good* or *value*, not in words which don't mean anything and which the books are full of, like *potentiality*, *actuality*, or *self-realization*, *purpose*, *pleasure*, *satisfaction*, and the like. With these words you can't do anything for they are themselves undefined. Rather, I will do it in terms of exact logical relations. Before I do that we must be absolutely clear that what will be defined is *good* in the general sense and not in the moral sense. In other words, when I say, "He is a good murderer," I do not mean that morally. I mean that he murders well. A murderer is *good* if he murders well but that does not mean that he is morally *good*; on the contrary he is morally *bad*.

If I say, "She's a good girl," I don't mean it the way you hear it, because that is the moral use of *goodness*. I mean it in the way that she's got everything that a girl has got to have, and that might be a morally bad girl. I mean axiological goodness. Or if I say, "The better your conscience the worse it is," then you have both uses in one sentence. The axiologically good conscience is a sensitive conscience. If you have a sensitive conscience then, of course, it will be a bad conscience morally more often than when you have an axiologically bad conscience which is an insensitive conscience. So, an axiologically good conscience will be more often a morally bad conscience, because it's sensitive, and an axiologically bad conscience will be more often a morally good conscience because it's insensitive. We have two levels of language here which must not be mixed up. Their mixing up has been the curse of ethics for two thousand years, although Plato already made the distinction crystal-clear; but Aristotle messed it all up.

The Definition of Axiological Value

Now then, let us define *goodness* axiologically. In that same year 1903 there was an English philosopher by the name of G. E. Moore, from whom stems the whole development that I'm explaining to you. After much reflection Moore wrote a book called *Principia Ethica*, the title patterned after Newton's *Principia Mathematica Phllosophiae Naturalis*, *The Mathematical Principles of Natural Philosophy*. Moore wrote *Principia Ethica* as the preface to any future ethics that pretend to be scientific. However, he didn't get very far in founding a science of Ethics. The gist of the book is that there is good and that it is indefinable. The book, therefore, is very short. Yet, what it says is fundamental, namely, (a) there is good and good is not anything else but good, nothing like satisfaction, pleasure, and so on; and (b) but nobody can possibly know what it is. Then Moore goes back into the history of ethics and shows how everybody had messed up things, mixing up goodness itself with things that *are* good, starting from Aristotle up to Moore—and he's right.

When we were students we thought that was an awful situation. What is goodness is not definable, and what is definable is not goodness. What we had to find then was *goodness* which is *definable*. G. E. Moore himself gave us some help. In 1922 he came up with a kind of definition and in 1943 with a little more of it, the gist of it all being as follows:

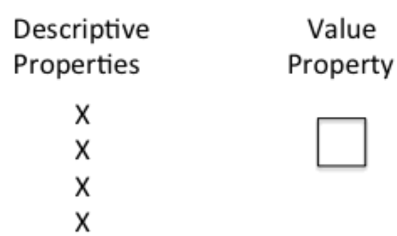
> Two things are true of goodness—(1) it is not a natural property and (2) although it is not a natural property it depends entirely upon the natural properties of the thing that is said to be good.

Let me explain this, "Good is not a natural property." A natural property is a property of the senses which *describes a thing*. This desk here is brown, high, with a microphone, and so on. These are the *sense* properties of this desk and they *describe* it. Now, says

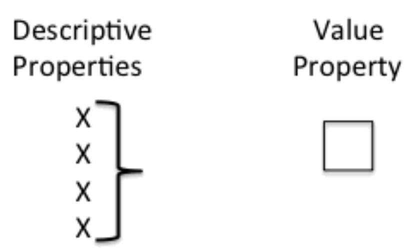
Moore, "*Good* is not a natural property." Let's take a chair. A chair is a knee-high structure with a seat and a back. These are the natural properties of the chair which describe it and which you learn as a kid. Good according to Moore is also a property of the chair, but it isn't any of these. It's a *value property*. And if only I knew, he said, how this value property *depends* upon all those natural properties then I would *know what is goodness*.

Well, we produced this definition, in a very simple way. But first let me illustrate what Moore said with another example. Let's say that I have my automobile standing out there on the parking lot and I forgot my key there and I say to one of you, "Pray be kind enough and go outside and get me the key out of the car." And you say, "What car is it?" and I say, "Oh, it's a good car." Will you ever find it? You won't. Good is not a natural property. When I say "It is a good car," I have not *described* the car. You don't know whether it's a Ford, Oldsmobile, Chevy, how many doors, what tires, you know nothing of the car. You don't know the natural properties. Yet, you do know a great deal about the car, you know it's a *good car*. What does that mean? It does have tires, it does have a motor, it does have a door, and when you push the accelerator it will accelerate, when you push the brake it will brake, and not the other way around, all that you know just by my saying, "It's a good car,"—and yet you know nothing of the car itself.

Now there's the clue. What we did was a very simple thing. For Moore, there was no relation between the descriptive properties and the value properties:



We put in a relation. What we did was this:



And we said, "A thing is good if it has *all* its descriptive properties." This is the fundamental definition of value of formal axiology.

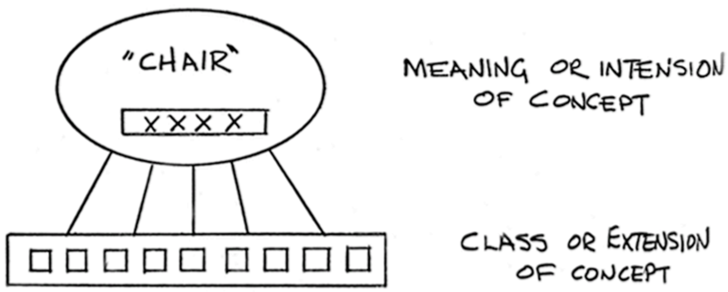
It is both simple and obvious. Take anything that you call good and you will see that you call it good because it has all its properties. This is a good chalk because it writes and has all the other properties of chalk. Anything that you know has all its properties you may call *good*. From this definition follows the system of axiology, for it is a *logical definition of value*, and logic is a system. It means that the *measurement of value is the concept of the thing in question*. This concept you have in your mind.

We are now getting close to the measurement of intangibles.

The Measurement of Value

Goodness is an intangible. It's none of the descriptive properties that you can see or hear or smell or taste, yet you can measure it with absolute precision. The measure is no more intangible than is mathematics. It's the concept of the thing that you learn by learning language. In other words, language itself has within it the measurement of value, it is value measurement. Let us see what this means.

Let's take that chair again. The concept *chair* is in quotes, the chair is standing there. The concept *chair* is not a chair. The concept is in the dictionary, you look it up if you don't know it. So the concept *chair* has one, two, three, four properties—"knee-high," "structure," "a seat," and "a back." The set of these properties is called the intension or meaning of the concept, and the set of all the chairs that are, have been or will be, is called the extension or class of the concept. The concept *chair*, then, looks logically as follows:



You learn the intension or meaning of a concept as a kid. How? By asking mother. What's this?—A chair. What's this?—A girl. What's this?—A mirror. My little boy when he came to the ocean first, looked in and said, "Daddy, mirror!" I said, "No, this mirror is liquid." I added another property. I said, "Such a liquid mirror is called water." So you learn the words of the language learning their meaning as a set of properties and *this set of properties is the measurement of value for the things named*. Those of you who have read the autobiography of Helen Keller will remember the tremendous excitement of a child on learning names, when her tutor Miss Robinson spelled into her hand the word W - A - T - E - R. The excitement is not only because the name names, but also because it values.

A good chair, then, is a chair that has all the properties you learn chairs to have. It is a knee-high structure with a seat and a back. Now if a chair is nothing but a back it's a pretty poor chair. It's a good back but a bad chair. There you have another little beautiful thing of our simple definition. Anything which is good if it has the totality of its properties is not good when it has less than the totality of its properties. But it is also true that any set of properties can be looked at in terms of some concept. Take any set of properties and you can always find a concept for them. So that a bad chair with legs and a seat but no back is a good stool because it fulfills the properties of the stool and a bad house is a good ruin, and a bad car is a good jalopy. Here you have the difference between the pessimist and the optimist. The pessimist always finds the concept which is not fulfilled by the properties at hand, and the optimist always finds the concept which is fulfilled by the properties at hand. So the pessimist says, "I have a lousy car" and the optimist says, "I have a lovely jalopy."

All this is extremely simple. But now look what's happening. Let us put a girl on the chair so we get some differences of opinion, for if four people look at a chair it is difficult to get real differences of opinion. There she is sitting with four fellows sitting around her. One says, "Boy, that's a girl!" What does he mean? She's got all the girl properties, she is **p**. Another says, "Aw, I don't think she's so hot." What does he mean? Well, she's so-so, not so hot, not so bad either. He says she's **p**/2. The other says, "I think she's pretty good." She's **p**/2 + **m**. The fourth says, "I don't know what you're talking about. I think she's awful." She's still a girl, but she doesn't have much of *girl* qualities. He doesn't mean to say she's a bad girl, that wouldn't be so bad maybe. No, to him she's **p**/2 - **m**.

Now my question is, *What is the value of the situation* of the fellows saying this about the girl? Or, what is the value of the girl in the situation with these fellows? What does what they say add up to? Very simple. The one said **p**, the other **p**/2, the third **p**/2 + **m**, the fourth **p**/2 - **m**. So let us add up what they say, **p** + **p**/2 + **p**/2 + **m** + **p**/2 – **m**. The result is 2 1/2**p**.

This is a peculiar result. Remember, **p** is the totality of all her qualities. Does she then have more qualities than she has? Indeed, she does. And this is the core definition of *value*: *Valuation is a play with pure properties*. You abstract from the thing itself and take the properties of the thing as a set with which you play around. Depending upon how you play you call the thing good, bad, indifferent, and so on. In other words, *Fact* is only one of the sets of properties that a thing has and it is that set upon which people most readily agree. This is a desk because it has all the desk properties. We all agree on that. However, when it comes to valuation, you abstract from that factual set and just take the properties of the thing by themselves, playing around with them, arranging and re-arranging them in your imagination.

Evaluation is an imaginative play with properties and not looking at the thing itself. And *fact* itself is only one set of the thing's properties. This means that valuation is a function of the imagination. You have the capacity of valuation in the degree that you have imagination. If you lack imagination you see only facts, like the dejected fellow in a Thurber cartoon about whom the ladies gossip: "He doesn't know anything except facts." But, facts being themselves sets of properties, they are not so factual at all.

To give you an example, one day I was sitting in my study, my wife came in the door and she kind of coiled back and said, "What's going on, are you here?" I said, "Sure I am, here I am." She said, "But the car isn't in the garage." I said, "What? It must be stolen." We rushed to the garage and there big as daylight stood the car. She had been looking in the garage but had not seen it because she had thought I was out. We see what we conceive to be. Even fact is a part of what we have in our mind.

So valuation is a play with pure properties; and axiology is the score of that play, just as music is a play with sounds and musical science is the score of that play.

Now, let us continue our play. I can do much more with the sets of girl properties or of chair properties or of any other set of properties than merely add. I can subtract, multiply, divide, arrange, and re-arrange these sets in sub-sets, and the result of all this is value. Let us ask ourselves how many different values a thing can have. Since the set of properties and each of the subsets of this set is a different value, and since according to a well-known formula, a set of **p** items has $2^{\mathbf{p}}$ - 1 subsets, a thing with **p** properties can have $2^{\mathbf{p}}$ - 1 subsets of properties. This number then, $2^{\mathbf{p}}$ - 1, is the totality of different values which a thing can have.

Now, look what that means. Our chair, for example, has four properties 2^4 - 1 = 15. A chair with four properties can have 15 different values. Why? Because it can have one value of goodness; there's only one set of all properties. In combinatorial analysis ${}_4C_4 = 1$. There are 6 ways in which the thing can have two properties, because ${}_4C_2 = 6$; hence there are 6 different ways in which the chair can be *so-so*; it can be knee-high and have a seat but wobble and have no back; it can have a seat and a back but not be knee-high and wobble, and so on. There are 4 ways in which the chair can have 3 properties, ${}_4C_3 = 4$, hence four ways in which the chair can be *fair*; and there are 4 ways in which it can be *bad*, for ${}_4C_1 = 4$. Thus, our chair can have one goodness, 4 fairnesses, 6 averagenesses, and 4 badnesses. In *toto*, a thing can have 2^p – 1 values because every subset of its set of properties is, by definition, a value.

Let us apply this now, say, to *job evaluation*. Suppose you have evaluated a job as so many properties, let's say, ten. Then in how many ways can the employee fulfill or net fulfill this job: In 2^{10} - 1 = 1,023 ways. There are 1,023 ways in which the employee can perform or not perform one particular job which is defined by ten properties. To be exact, there is 1 way of *good* performance, 385 ways of *fair* performance, 252 ways of *average* performance, and 385 ways of *bad* performance. By dividing the possible number of performances through the possible total of all performances we get the percentage of performance expectation: 0.098% for *good*, 37.64% for *fair*, 24.64% for *average*, and 37.64% for *bad*. The difference between this theoretical expectation and the actual performance in your shop is an objective measure of your shop performance.

The calculus can, of course, also be applied to gauge the acceptance of your product. If the product, in the mind of the public, is determined by 10 properties, the theoretical expectation of evaluation of it are 2^{10} = 1,024, adding one evaluation zero; and there are 385 ways in which the product may appear *fair* or *bad* and 252 ways in which it may appear *so-so*. These ways may in turn be broken down; of the four ways in which the thing may appear fair, there are 10 ways in which 9 properties may be accepted, 45 ways in which 8 may be accepted, 120 in which 7 and 210 ways in which 6 properties may be accepted. The corresponding percentages of expectation are, respectively, 0.98, 4.4, 11.73, and 20.53. Again, the actual acceptance as against the possible acceptance is an objective measure of your product's success.

Here already you have a calculus of value, measuring much that at present is intangible.

The Dimensions of Value

However, the calculus has much wider scope. The above application is valid only if properties can be enumerated. But how if they cannot, as in the case of that new Gestalt I want to write or the company president or my wife? Here, it seems, matters become really intangible. Yet, even these values can be made tangible, even they can be *measured*. Let us see how.

So far we have spoken only of one kind of concept, abstract concepts such as "chair" or "girl." There are two other kinds of concepts which give rise to two other kinds of values. The three kinds of values are the *dimensions of value*.

Extrinsic Value

Let us look first at the abstract concept again. Abstract concepts are concepts which are abstracted from the space-time empirical things. In other words, in the world we have all the chairs or girls or what-not and we abstract those properties which all these kinds of objects have in common. The result is the properties of the concept "chair," "girl," or "what-not" (or "X").

We had before my little boy who saw the ocean and thought it was a mirror. I had to tell him, "No, it's liquid, and such a thing is called *water* or *ocean*." I gave him a new concept. Such concepts, abstracted from sense reality, have the following important characteristic: their properties are denumerable, or enumerable, one by one. For they have been abstracted one by one. You have to take common properties and you just have to learn one by one, one after another all of these properties. A set of items which can be identified one by one is mathematically called a *denumerable set*. The properties of an abstract concept, thus, are a denumerable set. If I couldn't enumerate and thus *identify* them I would not *know* the thing. Denumerability is the essence of discursive knowledge. But, secondly, how many properties can I abstract that things have in common? If I have a huge number of things very few properties will be in common; if I have very few things they will have very many properties in common; if I have only two things I can abstract an almost infinite number of common properties. The range of the number of properties that can be abstracted, then, is between one and infinity. Or, the properties of an abstract concept are, at most, *denumerably* infinite. There is a mathematical sign for such an infinity which is "$\aleph_0$" meaning the Hebrew *A* with a zero. This is mathematically as exact a symbol as any you know.

When an abstract concept is fulfilled or not fulfilled there appear degrees of valuation, goodness, badness, as we have seen. Such values are called extrinsic values, because what is valued is not the thing in itself but its belonging to a certain class. A good chair is good because it is a good member of the class of chairs.

Systemic Value

The second kind of concept is constructions of the human mind—constructs. Have you ever wondered why there are no bad geometrical circles? Because the geometrical circle is defined with such precision in the system of geometry—as "plane closed curve equidistant from a center" that if a curve does not have all these properties and lacks just one of them, it is not what it was defined to be. It's not a *bad circle*, it's *not a circle*.

Why aren't there bad electrons? For the same reason. When a thing seems like an electron and lacks an electron property we cannot call it an electron; and the main endeavor of modern physics is to find out about these "bad" electrons and give them new names, positron, neutron, meson, and so on. Why are there no bad square roots of minus one? For the same reason. Why is there equity in the law? Because even in the law there are such exact definitions that when a thing lacks a part of the definition it is not what it is defined to be, and in order to relieve the tension between the system and reality, jurists have invented equity and other institutions. If the systemic rule remains unrelieved you have *legal injustices*, as in Menotti's powerful opera *The Consul*. Again, you have moral injustices if, for example, you define a human being by a system, say, the system of spectroscopy. If you define a human as "white," and all "non-white" as "non-human" you use a minimum of properties to define a very complex being. Such a definition is a transposition of frames of reference and hence, as we have seen, *not good*.

Constructs have the following characteristics:

> The number of properties is *finite*. It is a minimum number of properties, say, **n**. A construct gives rise to only two values, either *perfection* or *non-existence*. There are no degrees such as good, bad, indifferent, and so on. This kind of value is called *systemic value*.

I can apply systemic value to anything, say, my wife. I look at her systemically when I see her as my housekeeper and get mad when the soup isn't on the table or when she pushes the toothpaste from the top and I at the bottom. But that is not the right way of looking at my wife. I also can look at my wife extrinsically as a member of the class of wives, compare her with other wives, and so on. But that's not the right way either.

Intrinsic Value

When I really think of wife the way I should she's unique. The concept "my wife" is a singular concept. How many properties does she have? She has an infinity of properties and I cannot put my finger on any one of these properties. I see her, as the psychologists say, as a "gestalt" or as the mathematicians would say, as a "continuum." I neither abstract from nor construct her. I *live* her life, identifying myself with her. She is an *intrinsic value*. Logically, this means that the properties she has are *non-denumerably infinite*, and the sign of this is $\aleph_1$.

Let me explain this sign and then give you an example. When we come to transfinite numbers most peculiar things happen. If you take all the rational numbers to infinity you have the odd and the even numbers, 1, 2, 3, 4… Now, take only the odd numbers, 1, 3, 5, 7.... How many odd numbers are there? Infinitely many. This means that there are as many odd numbers as there are odd *and* even numbers. How many even numbers are there, 2, 4, 6, 8.... Again, infinitely many. There are as many even numbers as there are odd *and* even numbers. So the mathematical definition for a transfinite number is that the *part equals the whole*.

This is a most peculiar arithmetic, yet, it is as exact an arithmetic as any other arithmetic. Actually, it is much simpler than finite arithmetic. Suppose you deduct an infinity from an infinity, what is the result? Well, an infinity. Now add an infinity to an infinity—again an infinity. Whatever you do, you always get an infinity, $\aleph - \aleph = \aleph$, $\aleph + \aleph = \aleph$, etc. The most significant thing is that no subtraction is possible. The only thing that may significantly happen is rise to higher infinities, by exponentiation:

$$\aleph_0^{\aleph_0} = \aleph_1.$$

This is all we need as foundations of axiology. Let me summarize:

1) Value is the degree in which a thing fulfills its concept.
2) There are three kinds of concept—abstract, construct, and singular. Correspondingly, there are three kinds of value:
    a) Systemic value as the fulfillment of the construct,
    b) Extrinsic value as the fulfillment of the abstract,
    c) Intrinsic value as the fulfillment of the singular concept.

The difference between these three concepts is that a construct is *finite*, the abstract is *denumerably infinite*, and the singular is *non-denumerably infinite*.

To wrap it all up in an example, let us take a student, say, of mathematics at MIT, John. He's going on a vacation trip to Europe all alone and while he steps on board the Queen Mary he says to himself, "I'm going to have a good time." While he thinks this, he has nothing in his mind but a mathematical curve, a kind of sinus curve, belonging to the concept "girl." He does not think of any girl in particular, but, so to speak, the principle of femininity. This is a systemic valuation, construction in the mind. He sets up an ideal of some kind. The next day out on board there's a little party, quite formal as it is on these European ships; the boys line up on one side of the room, the girls on the other side. John is standing there and over there are samples of the class of girls, in space and time. Now the concept has enriched itself and, by the way, you may also define valuation as enrichment of properties. The concept now is not just a mathematical curve but quite a bit more—the curve has been filled in. In looking over there he uses the concept in his mind, "girl," with those new properties, to measure what is standing over there, the samples of the class—he weighs in his mind the members of the class in the light of the concept—and the word "axios" is our word "axle," namely, the axle of a scale. The process of weighing is reflected in his face. On one he says, "Uh uh" and on one "Mmmmm" and on this one "Ah!"' meaning "**p** properties." So he walks over, asks her to dance, and the dancing itself, of course, is a continuation of the process of valuation, weighing what he has in his arms against what he has in his mind. Well, let's say he likes her, let's call her Mary. They keep company and they do have a wonderful time. Extrinsic valuation—she's the best girl in the axiological sense.

One day before the ship arrives in Southampton there happens a most peculiar and you might say irrational and intangible thing were it not for axiology. He wakes up in the morning and suddenly he thinks, "Mary—she's not a girl at all, she's the only girl in the world." He knows very well there are one thousand million girls in the world and yet he knows with equal certainty that she's the only girl in the world. So being a mathematician and very logical, he reasons, "If she's the only girl in the world and I'm a man, and I have to live with a girl, then I have to live with her." So he writes her a letter which starts as if he had read axiology. "My one and only." Uniqueness! And the language of the letter is as foreign to mathematics as poetry: "My treasure," "my world," "the sun of my life," and the like. And he adds a "P.S. If you don't marry me, I'll jump overboard."

What has happened? Systemic, extrinsic, and now intrinsic valuation. In intrinsic valuation, since you do not abstract nor construct, how do you know it? By self-identification. He identifies himself with her. They marry and after three months or three years the process goes in reverse. He walks down Main Street and suddenly he sees, "Ah, there are girls." And then he compares Mary with them—extrinsic valuation. Then he goes home and there comes systemic valuation as his housekeeper, as I said before, the soup isn't ready and she pushes the toothpaste at the wrong end and the linens are not washed and he gets mad. He shouts at her, "I'm working all day and the soup isn't ready," and she cries and she says, "Now you're not nice to me," and he looks at her and there she is again, the one and only girl in the world, and he goes over and says, "I'm so sorry, I measured you systemically." And she says, "Yes, you were very bad. I am unique. I am to be measured intrinsically, I am *I*."

All right, this wraps up the thing. Now let us apply this to creativity. The first thing to remember is that the creative person identifies himself with something outside himself, and that this presupposes self-identification. Let us first see what self-identification means and then in which way it leads to identification with an external thing or problem. To use some Greek expression, how does auto-identification lead to hetero-identification?

Our question for the meaning of self-identification is really the question. What is a human being? We define a human being *as the only thing in the world that has its own definition of itself in itself*. That chair over there doesn't know it's a chair, but I know that I am I. And no matter how people might look on Mars, they may look like chairs with four legs, who knows? But if they can say "I" and can reflect upon this, then they are human beings. From this definition of a human being follows a far-reaching consequence. When I say, "I am I," then I am thinking of myself, that is, *I* think *Me*. But if *I* think *Me*, how about the *I* that thinks? Since it does the thinking it is not being thought. How can we think of the *I* that thinks *Me*? By making it a *Me*. So, let's think of it. I think of *Me* thinking of *Me*. But now what about this new *I*? Well, let's think of it. I think of *Me* thinking *of Me* thinking of *Me*. Again, there appears another I that cannot be thought of—and so on *ad infinitum*. By the simple definition of a human being as self-reflective it appears as an infinity. I can never completely reach myself as *thinking*. The peculiar thing is that in one of the first mathematical treatises on infinity, the German mathematician Dedekind, 1887, used this example to *prove* the existence of infinite systems! The American philosopher Royce, twelve years later, turned around Dedekind's proof in order to prove the infinity of the human being. The human being, axiologically, is an actual infinity. Moreover, he is a *non-denumerable infinity*; for what is true of *I* and *Me* is true of any thought I may have. If I think of this chair, I can think of my thinking this chair, and my thinking thinking this chair, and so on ad infinitum. *Each* of my thoughts, thus, may be an infinity. If I can have a denumerable infinity of thoughts—as potentially I can—then the infinity *of* this infinity is non-denumerable, for

$$\aleph_0^{\aleph_0} = \aleph_1.$$

Since a non-denumerable infinity, by our definition, is intrinsic value, the human being is an intrinsic value. This is an objective definition of the worth of a human being. Depending on how I fulfill it in actuality, I am a good or not good human being. If we now define moral good as the *application of intrinsic value to humans*, then the goodness in question is *moral goodness*.

Let us see what this means. Our definition of value was that a thing is good if it fulfills its definition. The definition of the human being is in himself. Hence, a human being is good when he fulfills his own definition of himself. What does this mean? It means that he is morally good if he is as he is. All the words of ethics mean this very same thing, this identification of myself with myself; being sincere, being honest, being genuine, being true to myself, having self-respect—these words mean that I am as I am, that I am myself. This seems to be a very simple thing and yet it's the most difficult to achieve. For I can define myself in all three ways, systemically, extrinsically, and intrinsically.

When I define myself *systemically* I put up a system, I construct something as myself which I'm not at all. And you probably know some people in your acquaintance whose image of themselves is very different from everybody else's image of them. They live a construct. Karen Horney and others call this the "self system." It leads to neurotic breakdowns and similar sicknesses of the self for in the long run you just can't live another's life or an imaginary construct. In the worst case, it leads to the asylum.

Also, a person can define himself *extrinsically*, as a member of some class. In our lives we are continuously in external situations, all kinds of situations, like now I am a speaker, then I'll be a listener, then an eater, and so on. I am a father, I am a commuter, I am a Rotarian, etc. I'm in millions of situations during my life time. But do these situations add up to myself?

Suppose I define myself as the best professor in the world. So what? I haven't touched the core of myself, which would be my intrinsic definition of myself not as this or that, doing this or that, but as the *gestalt* of my essential being, as simply who I am. Who am I: I am this human on this planet Earth. I was born a naked baby and I have to die. That's all. That's the gist of being myself; and being a professor or anything else for that matter is a different thing from being this human, born on this planet Earth and having to die. Any extrinsic definition of myself is really not the definition of myself. In order to make the definition of myself I must neither construct myself nor even abstract from myself but simply BE, namely identify myself, as we said before, with myself. And this is the most difficult and most important task of our moral life. It is very difficult simply to be, to be natural and not to pretend, nor be proud or ashamed of this or that. Sometimes we reach this stage when we "get away from it all" on vacations, to be alone with ourselves and to get acquainted with ourselves. To be moral is, so to speak, to bring the vacation spirit into our daily lives. The moral, in this sense, appears whenever you cannot impress anyone either positively with your achievements or negatively with your failures. It is what makes children and dogs love you—if they do, and makes your wife look at you when you are asleep. Just to Be, in daily life, is highest maturity. Also it is very powerful for it brings into play the infinity of your intrinsic self. To scramble around in the treadmill of extrinsic value is not only immature, it is inefficient. It shuts up your infinite powers and lets them lie idle. It prevents you from really Living. It is not, however, immoral; it is amoral—neither moral nor immoral. To be immoral is not-to-identify oneself with oneself—to be insincere, dishonest, not true to oneself, to lack self-respect—nor to identify oneself with any other human being, to be *indifferent* to human beings. Often those indifferent to concrete human beings profess great concern for humanity in the abstract.

All this is illustrated by a wonderful story by Tolstoy, *The Death of Ivan Ilych*. Ivan Ilych is a judge in a provincial town in Russia whose whole ambition is to be a judge of the Supreme Court in Moscow. He finally reaches that ambition, his whole family moves to Moscow, they get a big mansion, furniture and everything, and while he puts up the curtain he falls down the stepladder, breaks a rib, it goes into his liver and from that moment on he dies. The story is about the dying of Ivan Ilych. How trivial, how insignificant is the fact that he now is a judge of the Supreme Court that death is upon him. All his family falls away from him, it takes too long for him to die, all his friends fall away from him and at the end the only friend he has is his menial servant, Gerasim, the butler's assistant, a peasant lad, who makes him comfortable—here we have the transition from extrinsic to intrinsic self-definition.

The creative person lives in the world of intrinsic value. Let us now apply our new terminology and the system developed to the phenomenon of creativity. The creative view, we said is the unitary view. This means to see an infinity of items seemingly unrelated, but which we believe to be related and whose relationship is the problem before us, as one field, and finding the core, or essence, of this field. We must, in other words, see the whole field as unique. For any other but the creative person, the items in question are nothing but ordinary items of the ordinary extrinsic world. The ordinary person does not even see the problem. The creative person not only sees the problem in these unrelated items; the solution of the problem is for him a new view, he sees these items in a new configuration. He thus translates the extrinsic into the intrinsic. *We thus may define creativity as the capacity of translating the extrinsic into the intrinsic.* This intrinsic view, we said, is a kind of seeing; and seeing itself, the true seeing of everyday things, is a model of creative activity. Anything that we see in its uniqueness we interpenetrate with our whole personality, and if it is only a simple ordinary thing like a chair or a table. When Van Gogh saw a simple chair it became for him the expression of his own being. He called its picture "Portrait of a Chair" and many of you probably know it. A simple table *seen in its own intrinsic self-hood* is a most complex thing—as complex as a human being; and this is the reason one has first to be fully oneself, to identify oneself with oneself, before one can identify himself with some thing outside himself.

What is this table? It is the infinite totality of an infinite variety of aspects in which it appears to me. Let us listen to Husserl.

> Keeping this table steadily in view as I go round it, changing my position in space all the time, I have continually the consciousness of the bodily presence out there of this one and self-same table, which in itself remains unchanged throughout. But the perception of the table changes continuously, it is a continuum of changing perceptions. I close my eyes. I have now no perception of it. [My other senses are inactive in relation to the table.] I open my eyes, and the perception returns. <u>The</u> perception? Let us be more accurate. Under no circumstances does it return to me individually the same. Only the table is the same, known as identical through the [synthetic] consciousness which connects the new perception with the recollection. The perceived thing can be, without being perceived, […] and perhaps without itself changing at all. But the perception itself is […] constantly in flux; the perceptual <u>now</u> is ever passing over into the consciousness of the <u>just-past</u>, a <u>new now</u> simultaneously gleams forth, and so on…. The *same* color appears 'in' continuously varying patterns of *perspective color-variations*. Similarly for every sensory quality and likewise for every spatial shape! One and the same shape […] appears continuously ever again "in another way," in ever-differing perspective variations of shape.[79]

So each thing ordinarily appears to us only in one or two aspects; but if we want to truly know the thing, enter into its inner being, we have to fill ourselves with *all* its aspects and *become* the thing by compenetrating with the *infinity of our being the infinity of the thing's own being*. For the thing's own being is the totality of all its possible aspects, and this is infinite.

Such a compenetration of subject and object, thus, is a joining of two infinities. It produces a new *Gestalt*, a new infinity. This can be shown in exact mathematical terms; and newness, novelty itself becomes a logically necessary feature of intrinsic procedure. To understand this you have only to apply the three value dimensions—systemic, extrinsic, intrinsic—to the notion of *process*. A systemic process is a sequence within a system, like a function in mathematics or physics; and extrinsic process is one in space and time, such as evolution. But an intrinsic process is one where the part equates the whole, every moment is infinite, arises in its totality, and that means as *new*. It is an event of novelty, in the sense of Whitehead. Thus, we may simply define creativity as *intrinsic process*. Creativity is a part of the infinite world of intrinsic value. A creative person is one who is so transparent—to use a Kierkegaardian term—in his inner energies, who has grown so fully into the being of his own self, that he has himself all his energies available at almost any time and can direct them in any way he wants. He is, you might say, a variable that can take any value. This total availability, this flexibility of man is an aspect of his infinite nature which the Renaissance philosophers have stressed, especially Pico della Mirandola in his *Oration on the Dignity of Man*. The directions of such total availability—of self-giving—are again infinite. There are creative geniuses in all fields, from engineering to music, from entomology to aesthetics, from sports to prophecy. Their genius is all based on one and the same foundation: the making oneself available, the giving oneself, the actualization and mobilization of one's infinite resources.

Creativity is thus, in the last resort, the sensitivity of the fully living human person. It is the ordinary cognitive faculty infinitely concentrated and deepened. We are all *potentially* creative. We all *can* see the singular, but we cannot all concentrate to the infinite, and infinitesimal point which gives its meaning. And we do not all have the gift of penetration in the same degree. Just as cognition in general, so has cognition of the singular its degrees, which are *degrees of compenetration*: from mere perception of the singular to familiarity with it to final identification.

It is precisely the gradation of this compenetration which is the pattern of intrinsic value. Such gradation is to be found in the work of Husserl. In phenomenology, we find this pattern in the degree of "intentionality," from the mere thought of the thing to the fulfillment of this thought in "evidence," or rather in the coincidence and congruence between the various aspects of the consciousness of the thing and the thing itself, which then "gives itself in person." We also find this pattern in the work of Susanne K. Langer, where the intrinsic structure is the *internal differentiation* of the singular object. Langer calls this internal or intrinsic differentiation "non-discursive abstraction."

Since the value of the singular object results from the unity of the thing with the valuer, this unity being characterized by the compenetration of the two, the singular object will appear more differentiated when there is more compenetration, that is, to the extent that the thing is differentiated by the valuer and the valuer by the thing. We have examples of this in the experience of love, in artistic appreciation and creation, in mystic rapture, in the *satori* experience of Zen, and others.

Complete singular understanding of the thing is subjective knowledge, in the sense elaborated by Husserl and Kierkegaard; whereas the *disvaluation* of the singular thing (indifference) approaches objective knowledge, separated in a certain sense from the thing. There is thus, by the very nature of intrinsic value, a parallelism between cognition and valuation, which finds its culmination in creativity.

This parallelism does not appear in the other two types of value discussed. In them, both construction and abstraction are found apart from the person who constructs or abstracts, and the fulfillment of the concept of the thing does not involve the valuer. Thus, I can say that a chair is a "good chair" without the urgent desire to use it; but on the other hand, I cannot value it intrinsically without at the same time desiring to use it. This "desiring its use" has a wider sense than the mere desire to seat myself in it. It includes, for example, the desire to enjoy it aesthetically, even to the point of painting it. Thus, in Van Gogh's "Portrait of a Chair" the chair and valuer form a single unit, and this to such a degree that the portrait turns out to reflect the artist's own personality. The same happens in the work "The Shoes" also by Van Gogh, a work in which Heidegger re-encounters a world that the artist must have lived and enjoyed when he created, by *compenetrating and making himself one* with a simple pair of peasant's shoes.

Heidegger says that the dark mouth of the worn interior of these shoes

> …yawns the fatigue of the peasant's steps. In the rude weight of the shoe is represented the tenacity of the slow walk across the long and monotonous furrows of the plowed field, over which blows a harsh wind. In the leather is everything that the soil has of moisture and grease. Beneath the soles slips the solitude of the track through the falling evening. In the shoes vibrates the silent call of the earth, its reclining offer in the ripening wheat and its enigmatic refusal in the deserted barren winter field. Through this piece of clothing draws the dumb fear for the security of bread, the silent happiness of the beginning end of misery, the throb before the arrival of the son and the trembling before the imminence of death. This thing belongs to the earth and the peasant guards it. From this guarded belonging emerges the thing itself resting in itself.[80]

For Heidegger, as we see, the compenetration and identification of artistic creation not only has given intrinsic value to an ordinary thing, but as he says "it has put into operation the truth of being itself."

That intimate vision of the unique which Van Gogh had yesterday in painting "The Shoes," and which Heidegger has today through experiencing and valuing the work, unfortunately does not occur very often nor is it suitable to most men. There are people who possess a great sensitivity for systemic or extrinsic value and lack the capacity to value intrinsically, of seeing the intimate reality of this world in which we live and die; people who are blind and deaf before the riches and magnificence which surround us. We can see this in the "virtues" of the men of our time: high technical (systemic) or commercial (extrinsic) value, skill, and sensitivity united with indifference toward, and incomprehension of, the aesthetic, the religious, and the moral—in a word, the intrinsic, the most intimately human values.

Even though that indifference to the singular, an indifference which we qualify as intrinsic disvalue, has always existed, it appears to characterize with great force our own epoch. Thus, those stony words of Heraclitus: "The eyes and ears are bad witnesses for men if they have barbarian souls," appear to be directed with more justice than ever to all these indifferent contemporaries of ours, who stand blind and deaf in the presence of the unique.

The world today, as it has always been, is run by the managers, the uncreative, and they often make miserable the life of the creative, who are called crackpots, visionaries, and the like. They are not taken seriously because the world in which they live is unknown. To make this world known, to structure it with scientific precision, and put it into exact relation with the world of the uncreative is the task, and the accomplishment, of value theory. Once the knowledge of the three worlds of value is common to all, creativity will find its legitimate and natural phase in human affairs. And the world will be a better place to live in.

VALUE COMPOSITIONS AND TRANSPOSITIONS

SURVEY OF 150 VALUE SITUATIONS (S^S - I_E)[1]

	S^S	S_S	E^E	E_E	I^I	I_I	S^E	S_E	E^S
SUBJECT	Technical improvement Axiology out of Ethics Deduction Generalissimo	Riddle Puzzle Nonsense Intell. lack of production through improvement	“Hot Stuff” Ice cream sundae	“Mud” Honey and Sawdust	“A Real Jones” “Guts” “A Botticelli” A Baby	“We’ll always be Friends” Nazi Irma Grese (Tied women’s legs in labor)	“By This Ring I Thee Wed” Ritual Systems Become Jobs	Popularization Mistaken Reasoning Bribed Judge	Production Line Game “Legal Tender”
KNOWLEDGE	Newton Einstein	Epistemological paradox	Teaching	Popularization	Mystic Experience	Pseudo-Mystic	Gamow (Excellent Popularizer)	Bad Science Popularizer “Miscarriage of Justice”	Abstraction
TRUTH	Copernicus (Systemic Elegance) Corroboration	Systemic Non-elegance (Ptolemy) Contradiction	Corroborating Witness	Contradicting Witness	Inspired Teacher	Liar	Application of System	Wrong Application of System	Interpretation
LANGUAGE	Logic	Jabberwock	Style	Slang	Poet Inspired	Epithet	“Popular Science”	Bad Popularization	Grammar
PROCESS	Gödel Carnap	Logical Paradox	Causal Process	No Causal Process (Hume Belief)	Creative Act	Exhaustive Creative Act	Spinoza Applied Geometry	False Application	Causality understood Kant’s Categories

[1] [Key: E = Extrinsic = “practical and situational”; S = Systemic = “theoretical and normative”; I = Intrinsic = “personal and spiritual.” Definitions from Bernhard Bierschenk and Jan Mattsson, “Axiological Measurement of Human Value Factors in Mental Processes, *Cognitive Science Research*, 1987 No. 22. For discussion of the analytic scheme represented by the rows, which is not explained in Hartman’s *Creative Engineering* chapter, see Robert S. Hartman, 1960, “The logic of description and valuation,” *The Review of Metaphysics*, 14(2) 191-230, particularly pp. 198 ff. Also see: Robert S. Hartman, 1959, “Value theory as a formal system,” *Kant-Studien*, 50(1-4) 287-315. Table title states “150 situations” but the table presents ninety combinations (5 x 18).]

	E_S	S^I	S_I	E^I	E_I	I^S	I_S	I^E	I_E
SUBJECT	Uniform	"Lutheranism" Corporate Personality Morale of Army of Shop, etc.	Argumentum Ad Personum Burning Heretics Sovereignty Hypostatization of Concept	Intrinsic Choice of Extrinsic Situation My New Car Idiosyncrasies of your Auto "Peach"	Lovesick Truant Fetishist	Newton Jefferson (Constit.) "Gustav V" "Elizabeth II" Theology Axiological Value	Paranoia Color Line "The Consul" (Menotti) Professional Humans	"Mr. Republican" Selling favorite picture. Materialist God	Individuals as functions (Secretary) Selling your child "Nigger" Idol Jesus Tempted by Satan (Mat. 4:1)
KNOWLEDGE	Pedant	Mathematical Genius	Bad Mathematician	Scientific Inspiration	Fanatic	Devoted Scientist	Crackpot	Popular Philosopher (Durant, Niebuhr)	Popularizing Philosopher Revivalist
TRUTH	Wrong Application Rationalization	Subjective Truth Good Math Teacher	Phony Mystic Bad Math Teacher Bad Judge	Witness	False Witness	Systematic Understanding of Intrinsic Truth	Rationalization	Intrinsic Truth confirmed by experience "Witness" (Kierkegaard)	Intrinsic Truth devalued by experience "Show me" (Hume)
LANGUAGE	Pun	Science Fiction	Bad Science Fiction (Velikovsky)	Personal Style	Bad Poet	Poetic System (Thomas Mann)	Bad Critic of Poetry	Poetic Craftsman	Metaphor taken literally Fundamentalism Logical Positivism
PROCESS	Policeman stops your car	Logical Genius	Bad Logician Theological Heretic	Good Engineer	Love Suicide Building an Ugly Bridge	Philosophy of Creativity	Mechanical Art Teaching Painting by Machine	Creative Craftsman	"What Does Picture Mean?"

[Value Ordering of Compositions][2]

n	S^S
$\aleph_0$	E^S
$\aleph_1$	S^E E^E I^S I^E
$\aleph_2$	S^I E^I

1/n	S_S
$1/\aleph_0$	E_S
$1/\aleph_1$	S_E E_E I_S I_E
$1/\aleph_2$	S_I E_I I_I

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[2] [Table title inserted by editor based on the title given by Hartman to the first table. These tables appeared just before the Bibliography in the Creative Engineering Seminar notes; the first table is a foldout sheet. We can interpret the "Value Ordering of Compositions" table based on Hartman (1960, op cit., p. 194; 1961, op cit., p. 413): The arrows indicate increasing value, with $\mathbf{S_I}$ $\mathbf{E_I}$ $\mathbf{I_I}$ being the lowest and $\mathbf{S^I}$ $\mathbf{E^I}$ the highest. For example, Hartman writes, "Since Fred is a person, with the intensional cardinality I= $\aleph_1$, to see him as $\mathbf{E^S} = \aleph_0$ or $\mathbf{S^S}$ = **n** means a disvaluation" (Hartman, 1961, p. 416). The symbol $\aleph$ designates cardinality (the number of elements in a set), such that "metaphors of cardinality $\aleph_0$ … are metaphors of denumerable content and metaphors of cardinality $\aleph_1$ have non-denumerable content" (Hartman, 1961, op cit. p. 426). See also p. 413 regarding transpositional value, e.g., 1/n).]

Emotional Blocks to Creativity

By Dr. A. H. Maslow, Brandeis University[81]

I am a little startled to find myself in this situation, because ten or fifteen years ago when I started research with this problem of creativity, it was entirely an academic and professorial one. I've been amazed to be plucked at in the last couple of years by big industries of which I know nothing, or organizations like yourself whose work I don't really know at all, and I find myself a little uneasy, like many of my colleagues, on this score, because I am not sure what I can deliver exactly. I am not sure whether the work that I have done and the conclusions that I have come to, and what we "know" about creativity today is quite usable in its present form in large organizations. All I can present you with are essentially paradoxes, and problems, and riddles and, at this moment, I don't know how they're going to be solved.

I think the problem of the management of creative personnel is both fantastically difficult and important. I don't quite know what we are going to do with this problem because, in essence, what I am talking about is the lone wolf. The kind of creative people that I've worked with are people who are apt to get ground up in an organization, apt to be afraid of it, and apt generally to work off in a corner or an attic by themselves. The problem of the place of the "lone wolf" in a big organization, I'm afraid is your problem and not mine.

This is also a little like trying to reconcile the revolutionary with the stable society because the people that I've studied are essentially revolutionary in the sense of turning their backs on what already exists, and in the sense of being dissatisfied with what is now the case. This is a new frontier and I think what I'll do is just simply play the researcher and the clinician and the psychologist, toss out what I've learned and what I have to offer in the hope that you can make some use of it.

This is a new frontier in another sense that you'll have to dig into very, very deeply, a new psychological frontier. If I can summarize in advance what I'm going to say, what we have found during the last ten years or so is that, primarily, the sources of creativeness of the kind that we're really interested in, i.e., the generation of really new ideas, are in the depths of human nature. We don't even have a vocabulary for it yet that's very good. You can talk in Freudian terms if you like; that is you can talk about the unconscious. Or in the term of another school of psychological thought, you may prefer to talk about the real self. But in any case, it's a *deeper* self. It is deeper in an operational way, as seen by the psychologist, or psychotherapist, that is, it is deeper in the sense that you have to dig for it. It is deep in the sense that ore is deep. It's deep in the ground. You have to struggle to get at it through surface layers.

This is a new frontier in the sense that most people don't know about it, and also in another very peculiar sense that has never occurred before in history. *This is something that not only we don't know about but that we're afraid to know about.* That is, there is resistance to knowing about it. This is what I'll try to make clear. I'm speaking about what I'll call primary creativeness rather than secondary creativeness, the primary creativeness which comes out of the unconscious, which is the source of new discovery—of real novelty—of ideas which depart from what exists at this point. This is something different from what I'll call secondary creativity. This is the kind of productivity demonstrated in some recent researches of a psychologist by the name of Anne Roe who finds it in group after group of well-known people—of capable, fruitful, functional, famous people. For instance, in one research she studied all the starred biologists in the *American Men of Science*. In another research she was able to study every paleontologist in the country. She was able to demonstrate a very peculiar paradox that we'll have to deal with, namely, that to a certain degree, many good scientists are what the psychopathologist or the therapist would call, rather rigid people, rather constricted people, people who are afraid of their unconscious, in the sense that I have mentioned. And you may then come to a peculiar conclusion that I've come to. I am used now to thinking of two kinds of science, and two kinds of technology. Science can be defined, if you want to, as a technique whereby uncreative people can create and discover, by working along with a lot of other people, by standing upon the shoulders of people who have come before them, by being cautious and careful and so on. Now, that I'll call secondary creativeness and secondary science.

I think, however, that I can be of most use to you by laying bare the primary creativeness which comes out of the unconscious and which I have found in the especially[82] creative people that I have selected out to study carefully. This kind of primary creativeness is very probably a heritage of every human being. It is a common and universal kind of thing. Certainly it is found in all healthy children. It is the kind of creativeness that any healthy child had and which is then lost by most people as they grow up. It is universal in another sense, that if you dig in a psychotherapeutic way, i.e., if you dig into the unconscious layers of the person, you find it there. I shall give you only one example that you have probably all experienced yourselves. You know that in our dreams, we can be an awful lot more creative than we are in waking life. We can be more clever, and wittier, and bolder, and more original, and so on. With the lid taken off, with the controls taken off, the repressions and defenses taken off, we find generally more creativeness than appears to the naked eye. I have been roaming around among my psychoanalyst friends recently trying to get from them an account of their experiences with the release of creativeness. The universal conclusion of psychoanalysts, and I am sure of all other psychotherapists as well, is that general psychotherapy may normally be expected to release creativeness which did not appear before the psychotherapy took place. It will be a very difficult thing to prove it, but that is the impression they all have. Call it expert opinion if you like. That is the impression of the people who are working at the job, for example, of helping people who would like to write but who are blocked. Psychotherapy can help them to release, to get over this block, and to get them started writing again. General experience therefore is that psychotherapy, or getting down to these deeper layers which are ordinarily repressed, will release a common heritage—something that we all have had, and that was lost.

There's a certain form of neurosis from which we can learn a great deal in breaking into this problem, and which is an understandable kind of thing. I think I will speak about that first. This is the compulsive-obsessive neurosis.

These are rigid and tight people, people who can't play very well. These are people who try to control their emotions and so look rather cold and frozen in the extreme case. They are tense; they are constricted. And these are the people who in a normal state (of course, when it's extreme it is a sickness that has to be handled by psychiatrists and psychotherapists) generally tend to be very orderly and very neat and very punctual and very systematic and very controlled and who make excellent bookkeepers, for instance, and so on. Now these people can be very briefly described in psychodynamic terms as "sharply split," possibly more sharply split than most of the rest of the population, as between what they are conscious of, what they know about themselves, and what's concealed from themselves, what is unconscious or repressed. As we learn more about these people, and learn something about the reasons for the repressions, we are also learning that these reasons obtain for all of us in a lesser degree, and so again we've learned from the extreme case something about the more average and the more normal. These people *have* to be this way. They have no alternative. They have no choice. This is the only way in which such a person can achieve safety, order, lack of threat, lack of anxiety, that is, via orderliness, predictability, control, and mastery. These desirable goals are all made possible for him by these particular techniques. The "new" is threatening for such a person; but nothing new can happen to him if he can order it to his past experience, if he can freeze the world of flux, that is, if he can make believe nothing is changing. If he can proceed into the future on the basis of "well tried" laws and rules, habits, modes of adjustment which have worked in the past, and which he will insist on using in the future, then he feels safe and he doesn't feel anxious.

Why does he have to do this? What's he afraid of? The answer of the dynamic psychologist is—in very general terms—that he is afraid of his emotions, or of his deepest instinctual urges, or his deepest self, which he desperately represses. He's *got* to! Or else he feels he'll go crazy. This internal drama of fear and defense is within one man's skin, but it tends by this man to be generalized, projected outward on the whole world, and he is then apt to see the whole world in this fashion. What he's really fighting off are dangers within himself, but then anything that reminds him of or resembles these dangers within himself, he fights in the external world whenever he sees them. He fights against his own impulses to disorderliness by becoming extra orderly. And he will be threatened by disorderliness in the world because it reminds him, or threatens him with this revolution from the suppressed, from within. Anything that endangers this control, anything that strengthens either the dangerous hidden impulses, or else weakens the defensive walls, will frighten and threaten this kind of person.

Much is lost by this kind of process. Of course he can gain a kind of equilibrium. Such a man can live his life out without cracking up. He can hold things under control. It is a desperate effort at control. A good deal of his energy is taken up with it and so he is apt to get tired just simply controlling himself. It is a source of fatigue. But he can manage, and get along by protecting himself against the dangerous portions of his unconscious, or against his unconscious self, or his real self, which he has been taught to regard as dangerous. He must wall off everything unconscious. There is a fable of an ancient tyrant who was hunting somebody who had insulted him. He knew this someone was walled up in a certain town so he ordered every man in that town to be killed, just to be sure that the one person wouldn't get away. The compulsive-obsessive does something like that. He kills off and walls off everything unconscious in order to be sure that the dangerous portions of it don't get out.

What I'm leading up to is that out of this unconscious, out of this deeper self, out of this portion of ourselves of which we generally are afraid and therefore try to keep under control, out of this comes the ability to play—to enjoy, to fantasy, to laugh, to loaf, to be spontaneous—and, what's most important for us here, creativity, which is a kind of intellectual play, which is a kind of permission to be ourselves, to fantasy, to let loose, and to be crazy, privately. (Every really new idea looks crazy, at first.) The compulsive-obsessive gives up his primary creativeness. He gives up the possibilities for being artistic. He gives up his poetry. He gives up his imagination. He drowns all his healthy childishness. Furthermore, this applies also to what we call a good adjustment, and what Doctor Mooney described very nicely as being able to fit into the right harness, that is, getting along well in the world, being realistic, common sense, being mature, taking on responsibility. I'm afraid that certain aspects of these adjustments involve a turning one's back upon what is threatening to the good adjustment. That is, these are kinds of dynamic efforts to make peace with the world and the necessities of common sense, with the necessities of physical and biological and social realities, and this is generally at the cost of giving up a portion of our deeper selves. It is not as dramatic in us as in the case I've described, but I am afraid that it is becoming more and more apparent that what we call a normal adult adjustment involves a turning one's back on what would threaten us as well. And what does threaten us is softness, fantasy, emotional "childishness." One thing I haven't mentioned but have been interested in recently in my work with creative men (and uncreative men, too) is the horrible fear of anything that the person himself would call "femininity, "femaleness," which we immediately call "homosexual." If he's been brought up in a tough environment, "feminine" means practically everything that's creative: imagination, fantasy, color, poetry, music, tenderness, languishing, being romantic, in general, is walled off as dangerous to one's picture of one's own masculinity. Everything that's called "weak" tends to be repressed in the normal masculine adult adjustment. And many things are called weak which we are learning are not weak at all.

Now I think I can be of service in this area by helping you to become as aware as possible of these unconscious processes, of what the psychoanalyst calls "primary processes" and "secondary processes." As a matter of fact, I am writing a paper on that right now, just to get it straight in my own head. There is no good statement of this available in any literature. It is a tough job to try to be orderly about disorderliness, and rational about irrationality but we've got to do it. The following notes are from what I've been writing.

These primary processes, these unconscious processes of cognizing, that is, of perceiving the world and of thinking, which interests us here, are very, very different from the laws of common sense, good logic, of what the psychoanalyst calls the "secondary processes" in which we are logical, sensible, and realistic. When "secondary processes" are walled off from the primary processes, then both the primary processes suffer and the secondary processes suffer. At the extreme, the walling off of or the complete splitting off of logic, common sense, and rationality from the deeper layers of the personality produce the compulsive-obsessive person, the compulsively rational person, the one who can't live in the world of emotion at all, who doesn't know whether he's fallen in love or not, because love is illogical, who can't even permit himself to laugh very frequently because laughing isn't logical and rational and sensible. When this is walled off, when the person is split, then you've got a diseased rationality and also diseased primary processes. These secondary processes, walled off and dichotomized, can be considered largely an organization generated by fears and frustration, a system of defenses, repressions and controls, of appeasement, and cunning underhanded negotiations with a frustrating and dangerous physical and social world which is the only source of gratification of needs and which makes us pay very dearly for whatever gratifications we get from it. Such a sick conscious, or ego, or conscious self becomes aware of and then lives only by what it perceives to be the laws of nature and of society. This means a kind of blindness. The compulsive-obsessive person not only loses much of the pleasures of living, but also he becomes cognitively blind to much of himself, much in other people, and even in nature. There is much he is blind to in nature even as a scientist. It is true that such people can get things done, but we must ask in the first place, as psychologists always ask, *At what cost*—to himself? (because he's not a happy person); and secondly, we also ask the question about this business of getting things done—*Which things?* And are they worthy of doing?

The best case I ever ran across of a compulsive-obsessive man was one of my old professors. He was a man who very characteristically saved things. He had all the newspapers that he had ever read, bound by weeks. I think each week was bound with a little red string, and then all the papers of the month would be put together and tied with a yellow string. His wife told me that he had a regular breakfast every day. Monday was orange juice, Tuesday was oatmeal, and Wednesday was prunes, and so on, and God help her if there were prunes on Monday. He saved his old razor blades. He had all his old razor blades saved and packaged nicely with labels on them. When he first came into his laboratory, I remember that he labeled everything, as such people will do. He had everything organized, and then put little stickers on them. I remember his spending hours trying to get a label on a little probe of the sort that didn't have any space for a label at all. And once I turned up the lid of the piano in his laboratory and there was a label on it, identifying it as "Piano." Well, this kind of man is in real trouble. He is himself extremely unhappy. Now the kind of things that this fellow did are pertinent to the question I raised above. These people get things done but which things do they get done? Are they worthwhile things? Sometimes they are and sometimes they are not. We know also, unfortunately, that many of our scientists are of this type. It happens that, in this kind of work, such a poking character can be very, very useful. Such a man can spend twelve years in poking at, let's say, the microdissection of the nucleus of a one-celled animal. It takes that kind of patience and persistence and stubbornness and need-to-know that not all people have. Society can most often use that sort of person.

Primary processes then in this dichotomized walled off, feared sense—this is sick. But it *needn't* be sick. Deep down, we look at the world through the eyes of wishes and fears and gratifications. Perhaps it will help you if you think of the way in which a really young child looks at the world, looks at itself and at other people. It is logical in the sense of having no negative, no contradictions, no separate identities, no opposites, no mutual exclusions. Aristotle doesn't exist for the primary processes. It is independent of control, taboos, discipline, inhibitions, delays, planning, calculations of possibility or impossibility. It has nothing to do with time and space or with sequence, casualty, order, or with the laws of the physical world. This is a world quite other than the physical world. When it is placed under the necessity of disguising itself from conscious awareness to make things less threatening, it can condense several objects into one as in a dream. It can displace emotions from their true objects to other harmless ones. It can obscure by symbolizing. It can be omnipotent, ubiquitous, omniscient. (Remember your dreams, now. Everything I've said holds for the dream.) It has nothing to do with action for it can make things come to pass without doing or without acting, simply by fantasy. For most people it is preverbal, very concrete, closer to raw experiencing and usually visual. It is prevaluational, premoral, pre-ethical, precultural. It is prior to good and evil. Now, in most civilized people just *because it has been walled off* by this dichotomizing, it tends to be childish, immature, crazy, dangerous, frightening. Remember I've given you an example of the person who has completely suppressed the primary processes, completely walled off the unconscious. Such a person is a sick man in the particular way which I have described.

The person in whom the secondary processes of control, reason, order, logic, have completely crumbled, that man is a schizophrenic. He's a very, very sick man, too.

I think you can see where I'm leading you. In the healthy person, and especially the healthy person who creates, I find that he has somehow managed a fusion and a synthesis of both primary and secondary processes; both conscious and unconscious; both of deeper self and of conscious self. And he manages to do this gracefully and fruitfully. Certainly I can report that it is *possible* to do even though it is not very common. It is certainly possible to help this process along by psychotherapy; deeper and longer psychotherapy can be even better. What happens in this fusion is that both the primary processes and the secondary processes, partaking of each other, then change in character. The unconscious doesn't become frightening any more. This is the person who can live with his unconscious; live with, let's say, his childishness, his fantasy, his imagination, his wish fulfillment, his femininity, his poetic quality, his crazy quality. He is the person, as one psychoanalyst said in a nice phrase, "who can regress in the service of ego." This is *voluntary* regression. This person is the one who has that kind of creativeness at his disposal, readily available, that I think we're interested in.

The compulsive-obsessive kind of man that I mentioned earlier, in the extreme instance, *can't play*. He can't let go. Such a man tends to avoid parties for instance because he's so sensible and you're supposed to be a little silly at a party. Such a man is afraid to get a little tight because then his controls loosen up too much and for him this is a great danger. He has to be in control all the time. Such a person will probably make a horrible subject for hypnosis. He will probably get frightened by being "anesthetized,"[83] or by any other loss of full consciousness. These are people who try to be dignified, orderly, conscious, rational at a party where you are not supposed to be. Now do you see what I mean when I say that the person who is comfortable enough with his unconscious is able to let go that much anyhow—a little crazy in this party sense; to be silly, to play along with a gag and to enjoy it; and to enjoy being nutty for a little while anyhow—"in the service of the ego" as the psychoanalyst has said. This is like a conscious, voluntary regression—instead of trying to be dignified and controlled at all times. (I don't know why this comes to mind. It's about one person who is described as "strutting," even when he is sitting on a chair.)

Perhaps I can now say something more about this openness to the unconscious. This whole business of psychotherapy, of self-therapy, of self-knowledge is a difficult process because, as things stand now for most of us, the conscious and the unconscious are walled off from each other. How do you get these two worlds, the psychic world and the world of reality to be comfortable with each other? In general, the process of psychotherapy is a matter of slow confrontation, bit by bit, with the help of a technician, with the uppermost layers of the unconscious. They are exposed and tolerated and assimilated and turn out to be not so dangerous after all, not so horrible. Then comes the next layer, and then the next, in this same process of getting a person to face something which he is terribly afraid of, and then finding when he does face it, that there was nothing to be afraid of in the first place. He has been afraid of it because he has been looking at it through the eyes of the child that he used to be. This is childish misinterpretation. What the child was afraid of, and therefore repressed, was pushed beyond the reach of common sense learning and experience and growing up, and it has to stay there until it's dragged out by some special process. The conscious must become strong enough to dare friendliness with the enemy.

A fair parallel can be found in the relations between men and women throughout history. Men have been afraid of women and have therefore dominated then, unconsciously, for very much the same reasons I believe that they have been afraid of their primary processes. Remember that the dynamic psychologists are apt to think that much of the relationship of men to women is determined by the fact that women will remind men of their own unconscious, that is, of their own femaleness, their own softness, their own tenderness, and so on. And, therefore, fighting women or trying to control them or to derogate them has been part of this effort to control these unconscious forces which are within every one of us. Between a frightened master and a resentful slave no true love is possible. Only as men become strong enough, self-confident enough, and integrated enough can they tolerate and finally enjoy self-actualizing women, women who are full human beings. But no man fulfills himself without such a woman, in principle. Therefore strong men and strong women are the condition of each other, for neither can exist without the other. They are also the cause of the other, because women grow men and men grow women. And finally of course, they are the reward of each other. If you are a good enough man, that's the kind of woman you'll get and that's the kind of woman you'll deserve. Therefore, going back to our parallel, healthy, primary processes and healthy secondary processes, that is, healthy fantasy and healthy rationality, need each other's help in order to fuse into a true integration.

Chronologically, our knowledge of primary processes was derived first from studies of dreams and fantasies and neurotic processes, and later of psychotic, insane processes. Only little by little has this knowledge been freed of its taint of pathology, of irrationality, of immaturity, and primitiveness, in the bad sense. Only recently have we become aware, fully aware, from our studies of healthy people, of the creative process, of play, of aesthetic perception, of the meaning of healthy love, of healthy growing and becoming, of healthy education, that every human being is both poet and engineer, both rational and non-rational, both child and adult, both masculine and feminine, both in the psychic world and in the world of nature. Only slowly have we learned what we lose by trying daily to be *only* and *purely* rational, *only* "scientific," *only* logical, *only* sensible, *only* practical, *only* responsible. Only now are we becoming quite sure that the integrated person, the fully evolved human, the fully matured person, must be available to himself at both these levels, simultaneously. Certainly it is now obsolete to stigmatize this unconscious side of human nature as sick rather than healthy. That's the way Freud thought of it originally but we are learning different now. We are learning that complete health means being available to yourself at all levels. We can no longer call this side "evil" rather than "good," lower rather than higher, selfish rather than unselfish, beastly rather than human. Throughout human history and especially the history of Western civilization, and more especially the history of Christianity, has there tended to be this dichotomy. No longer can we dichotomize ourselves into a cave man and a civilized man, into a devil and a saint. We can now see this as an illegitimate dichotomy, an illegitimate "either/or," in which by the very process of splitting and dichotomizing, we create a sick "either" and a sick "or," that is to say, a sick conscious and a sick unconscious, a sick rationality, and sick impulses. (Rationality can be quite sick, as you can see on the television very quickly these days with all the Quiz programs. I heard of one poor fellow, a specialist in ancient history, who was making an awful lot of money, who told somebody that he had gotten this way simply by memorizing the whole *Cambridge Ancient History*. He started with page one and went on right through and now he knows every date and name in it. The poor guy! There is a story by O. Henry about a man who decided that since the encyclopedia encompassed all knowledge, he wouldn't bother going to school, but would simply memorize the encyclopedia. He started with the A's, worked his way on through the B's, C's and so on. Now *that's* a sick rationality.)

Once we transcend and resolve this dichotomy, once we can put these together into the unity in which they are originally, for instance, in the healthy child, or in the healthy adult, or in especially creative people, then we can recognize that the dichotomizing or the splitting is itself a pathological process. And then it becomes possible for your civil way to end. This is precisely what happens in people that I call self-actualizing. The simplest way to describe them is as psychologically healthy people. It is *exactly* what we find in such people. When we pick out from the population the healthiest 1% or fraction of 1%, then these people have in the course of their lifetime, sometimes with the benefit of therapy, sometimes without, been able to put together these two worlds, and to live comfortably in both of them. I've described the healthy person as having a healthy childlikeness. It's hard to put it into words because the word "childlikeness" customarily means the opposite of maturity. I don't know what you'll make of it if I say that the most mature human beings living are also childlike. That sounds like a contradiction but actually it is not. Perhaps I could put it in terms of the party example I spoke of. The most mature people are the ones that can have the most fun. I think that's a more acceptable phrasing of it. These are also people who can regress at will, who can become childish and play with children and be close to them. I don't think it's any accident that children generally tend to like them and get along with them. They can regress to that level. Involuntary regression is course a very dangerous thing. Voluntary regression, however, apparently is characteristic of very healthy people.

Now as for practical suggestions about achieving this fusion, I don't quite know. The only really practicable one that I know in ordinary practice for making this fusion within the person is psychotherapy. And this is certainly not a practicable or even a welcome suggestion. There are possibilities, of course, of self-analysis and self-therapy. Any technique which will increase self-knowledge in depth should in principle increase one's creativity by making available to oneself these sources of fantasy, play with ideas, being able to sail right out of the world and off the earth, getting away from common sense. Common sense means living in the world as it is today; but creative people are people who don't want the world as it is today, but want to make another world. And in order to be able to do that, they have to be able to sail right off the surface of the earth, to imagine, to fantasy, and even to be crazy, and nutty, and so on. The suggestion that I have to make, the practical suggestion for you people who manage creative personnel, is simply to watch out for such people as they already exist and then to pluck them out and hang on to them.

I think I was able to be of service to one company by making this recommendation. I tried to describe to them what these primary-creative people are like. They are precisely the ones that make trouble in an organization, usually. I wrote down a list of some of their characteristics that would be guaranteed to make trouble. They tend to be unconventional; they tend to be a little bit queer; unrealistic; they are often called undisciplined, sometimes inexact, "unscientific," that is, by a specific definition of science. They tend to be called childish by their more compulsive colleagues, irresponsible, wild, crazy, speculative, uncritical, irregular, emotional, and so on. This sounds like a description of a bum or a Bohemian or an eccentric. And it should be stressed, I suppose, that in the early stages of creativeness, you've got to be a bum, and you've got to be a Bohemian; you've got to be crazy. I notice on your program that you are going to have a session on the "brainstorming" technique. And this may help us toward a recipe for being creative as you get this from people who have already successfully been creative; they let themselves be like this in the early stages of thinking. They let themselves be completely uncritical. They allow all sorts of wild ideas to come into their heads. And in great bursts of emotion and enthusiasm, they may scribble out the poem or the formula or the mathematical solution or work up the theory, or design the experiment. Then, and only then, do they become secondary, become more rational, more controlled and more critical. If you try to be rational and controlled and orderly in this first stage of the process, you'll never get to it. Now the brainstorming technique, as I remember it, consisted in just this—in not being critical—letting yourself play with ideas—free association—letting them come out on the table, in profusion, and then only later on, tossing away those ideas which are bad, or useless, and retaining the ones which are good. If you are afraid of making this kind of crazy mistake, then you'll never get any of the bright ideas either.

Of course, this kind of Bohemian business is not necessarily uniform or continued. I am talking about people who are able to be like that *when they want to be* (regression in the service of the ego; voluntary regression; voluntary craziness; voluntary going into the unconscious). These same people can afterwards put on their caps and gowns and become grown up, rational, sensible, orderly, and so on, and examine with a critical eye what they produced in a great burst of enthusiasm and creative fervor. Then they can say sometimes, "It felt wonderful while it was being born, but it's no good," and toss it away. A truly integrated person can be both secondary and primary; both childish and mature. He can regress and then come back to reality, becoming then more controlled and critical in his responses.

I mention that this was of use to one company or at least to this one person in the company who was in charge of creative personnel, because it was precisely this sort of person he'd been firing. He had laid very great stress on taking orders well and on being well adjusted to the organization.

I don't know how an organization manager is going to work these things out. I don't know what would happen to morale. This is not my problem. I don't know how it would be possible to use such characters in the middle of an organization which has to do the orderly work that ensues upon the ideas. An idea is just the beginning in a very complex process of working out. That's a problem that we'll be working out in this country more than any other place on the face of the earth, I guess, during the next decade or so. We've got to face it. Huge sums of money now are going into research and development. The management of creative personnel becomes a new problem.

However, I have no doubt that the standard of practice which has worked well in large organizations, absolutely needs modification and revision of some sort. We'll have to find some way of permitting people to be individualistic in an organization. I don't know how it will be done. I think it will have to be a practical kind of working out, just simply trying out this and trying out that and trying out the other, and finally coming to kind of an empirical conclusion. I would say that it would be a help to be able to spot these as characteristics, not only of craziness but also of creativeness. (By the way I don't want to put in a good recommendation for everybody who behaves like this. Some of them actually *are* crazy.) Now we've got to learn to distinguish. It's a question of learning to respect or at least to look with an open eye on people of this sort and trying somehow to fit them into society. Customarily today such people are lone wolves. You will find them, I think, more in the academic situation than you will in large organizations or large corporations. They tend to be more comfortable there because they're permitted to be as crazy as they like. Everybody expects professors to be crazy, anyhow, and it doesn't make much difference to anyone. They're not beholden to anyone else except for their teaching, perhaps. But the professor has time enough ordinarily to go off into his attic or his basement and dream up all sorts of things, whether they are practical or not. In an organization you've got to give out, ordinarily. I don't know how you can put these necessities together in your situation. That's your problem. It's like a story I heard recently. Two psychoanalysts met each other at a party. One analyst walked up to the other analyst and slapped him in the face without any warning. The analyst who was slapped looked startled for a moment and then shrugged his shoulders and said, "That's *his* problem."

Designing for the Whole Man

Presented by Robert H. McKim, Special Lecturer Stanford University

One of John Arnold's requisites for the comprehensive designer is that "He must understand man." Now this is, of course, a very large order. Psychologists, anthropologists, biologists, motivational researchers and, indeed, poets, artists, and novelists work full time at the job of attempting to understand man. The designer, who usually has his hands full keeping up with at least a portion of the rapid advances in modern technology, may well wonder when he is to find time to "understand the organism for which he is designing." But time limitations notwithstanding, a knowledge of and concern for human values and needs *is* of prime importance to the designer. Design is, after all, a response to human needs; needs which are all too often lost sight of in this age of intense technology.

Those of you who saw Jacque Tati's film, "My Uncle" will remember that the uncle's misadventures in his nephew's fantastically-equipped modern house were a satire on the utter lack of human value in much contemporary architecture and product design. The house itself, a collection of all the geometrical clichés of modernism, was the essence of cold impersonality. The automatic kitchen was a nightmare of whining motors and flashing lights. The automatic garage door clamped down on people and cars like the jaws of a hungry alligator. And finally, when the uncle tries to take a nap on his nephew's living room couch, he finds that the couch has been chosen more for its modern appearance than for comfort, and that a nap is possible only after the couch has been turned on its side. When the uncle returns to his own apartment in an ancient section of Paris, he is able to truly relax again, for here human values are still more important than those of the machine.

There is unquestionably a good deal of truth in Tati's satirical protest, a protest which is aimed directly at us, as designers. We often do forget that design is ultimately for the well-being and happiness of man. We often do allow technology to become an end in itself. Spurred on by Tati's protest, let's take a fresh look at this complex activity of design. First of all, let's establish a frame of reference with a definition of design in terms of human values.

I have said that design is a response to human needs. But what kind of a response? Many of the lower forms of animal life *instinctively* respond to their needs in some form of design; beavers build dams, bees build hives and birds build nests. Is there something about man's design response itself which is distinctively human?

This early Neolithic Japanese pit house (Figure 1) looks very much like a nest which has been built on the ground by an enormous bird.[84] A closer examination of the house and its contents would reveal, however, that its occupant has a very unusual talent for making a great variety of *non-instinctual* design responses. A reasoned design response, for example, makes possible the combination of a sharpened rock fastened to the end of a stick to make a hatchet with which to build the house. The first distinctive quality of the human designer, then, is his ability to make *reasoned* responses to his *physical* needs. The primary human values in design in the early days of man were undoubtedly physical needs—the physical needs to stay alive, fed, and sheltered.

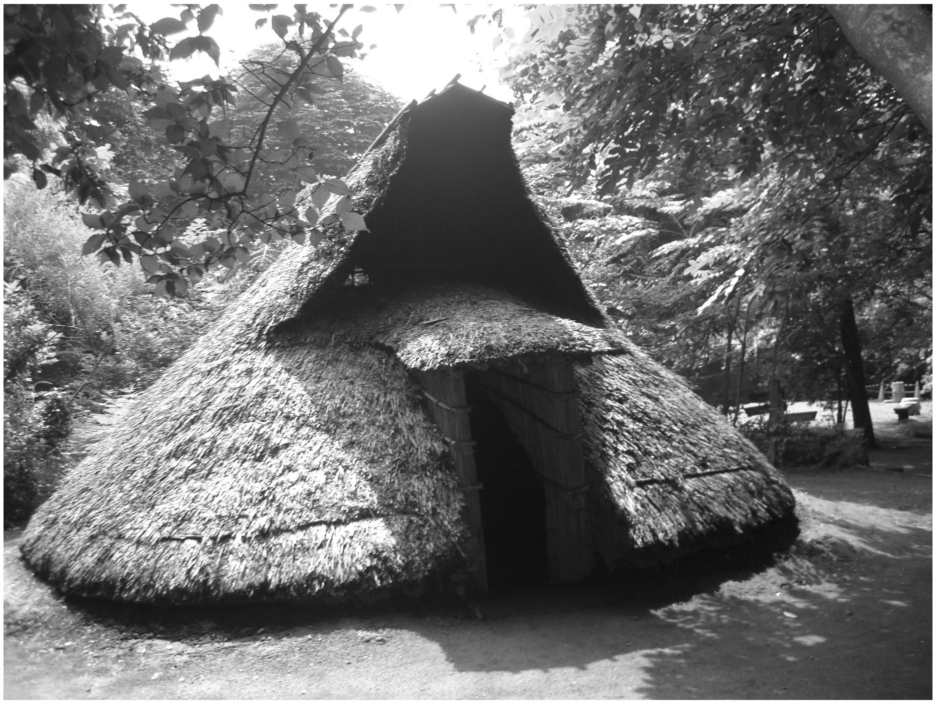

Figure 1. Early Neolithic Japanese pit house.

Even today the great majority of mankind spends most of its energy on responding to physical needs. But this caveman (Figure 2) had the time and desire to respond, by design, to needs other than the physical need to survive. These cave paintings are a response, partly a reasoned response and partly a *felt* response, to this artist's *intellectual* and *emotional* needs to understand the mysteries of nature and to record his feelings about the world in which he finds himself. These drawings reveal that man is a good deal more than a reasoning creature with a unique ability for satisfying his own physical needs. He is, as well, a feeling creature with the ability to respond, by design, to emotional needs of a very high order. The ability to respond to intellectual and emotional needs by means of reason and feeling is the ability to make art.

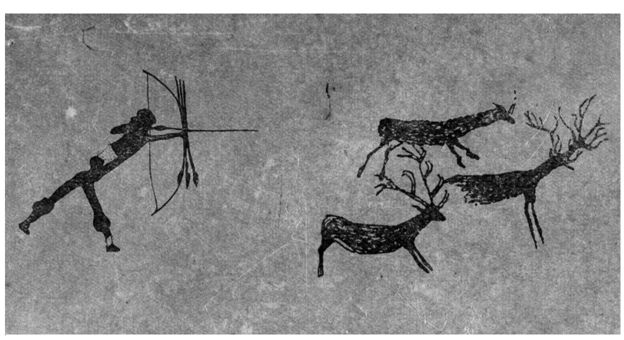

Figure 2. Cave art.

The human designer, as we have seen so far, is capable of manipulating materials in reasoned *and felt* responses to his physical, intellectual and emotional needs. In primitive forms of human life, these needs are most often caused by some condition in the *natural environment*. The sun, rain, wind, the sea, the forest, animals in the forest—all had an enormous formative effect upon man's early needs for design.

But as man began to develop into the communal sort of life, into tribes and kingdoms, he soon found that he had to respond, by design, to an unnatural environment, which I shall call the *cultural environment*. To illustrate the effect of the cultural environment upon human needs, and upon design, we may take as an example a recent design experience among many of the primitive tribes of Africa. For centuries, the warm natural environment of these tribes made the design response of clothing seem highly unnecessary. Their cultural environment was also quite untouched by the civilized values of the United States which require that men wear tight shirt collars, ties, and suits on a sweltering hot business day. But when Christian missionaries came upon the scene in Africa, a change in the cultural environment of many primitive tribes took place. The need for a design response— clothes—was experienced in very short order. Today, the native women are wearing calico dresses and the men are wearing dungarees, despite the hot weather.

In a modern society such as our own, the cultural environment probably has a more decisive effect upon human needs than does the natural environment. It often causes seemingly irrational needs for design which appear absurd to the people of other cultures. It causes fashions and styles in design. It sometimes frustrates the satisfaction of important human needs. But the design and art forms which constitute a good part of the cultural environment are the essential backbone of civilized values. It is a very stiff backbone, to be sure, but designers have, in the past, had remarkable success in bending it to their will. A cultural environment which frustrates the healthy satisfaction of human needs is, in my opinion, a culture which is in for a change.

To sum up the discussion, so far, into a definition of design, I say that: *Design is the unique capacity of the human species to manipulate materials and energy in a reasoned or a felt response to human physical, intellectual, and emotional needs—human needs which are partially formed and modified by the natural and cultural environment.*

Now, using this definition as a frame of reference, let's take a more detailed look at the physical, intellectual, and emotional needs of man and their influence upon design.

The human values in design which are the chief concern of modern technology are physical values. The engineer and scientist are primarily concerned with extending man's physical power over his environment. Utopia, to the engineer, would be a world in which the most strenuous physical task would be the pushing of a button. This Utopian vision, which presumably has the majority of the world's population sitting at home contemplating its navel, is perhaps not too far off.

The other day I had a talk with Mr. Kenneth Hoover, who is the Chief Engineer of the [San Francisco] Bay Area Rapid Transit District. Under Mr. Hoover's direction, a very advanced rapid transit system is currently being engineered for proposal to Bay Area voters in 1960. According to Mr. Hoover, "The aim of our engineering will be to eliminate human slavery." For example, the slavery involved in the monotonous activity of ticket selling and ticket taking will be replaced with an electronic system. Each commuter will have an IBM punched credit card which he will place in a turnstile in order to get aboard the train and once again in order to get off at his destination. The credit card number and the distance of the trip will be recorded in a central magnetic tape memory bank. The repetitive slavery of accounting will be eliminated by the electronically calculated bill which issues to the commuter from the memory bank once a month.

Mr. Hoover is not quite sure whether the public will be emotionally prepared for his idea that the trains should also be piloted automatically. He hopes that vertical rapid transit, in the form of the automatic elevator, will have paved the way for this, as well.

Slavery, in the form of monotonous, uncreative, production-line activity, is certainly the bane of the industrial revolution, and it is hopeful to see that steps are being taken to eliminate it.

A civilized existence depends upon leisure to cultivate the "pleasures of the mind." In the past, high levels of civilization, such as the Golden Age of Greece, have always resulted from the intellectual and artistic activities of a class privileged not to be slaves or serfs. If leisure is gradually being made available on a democratic basis by the electronic and mechanical slaves of modern technology, it is possible that the first truly democratic "golden age of civilization" is in the offing.

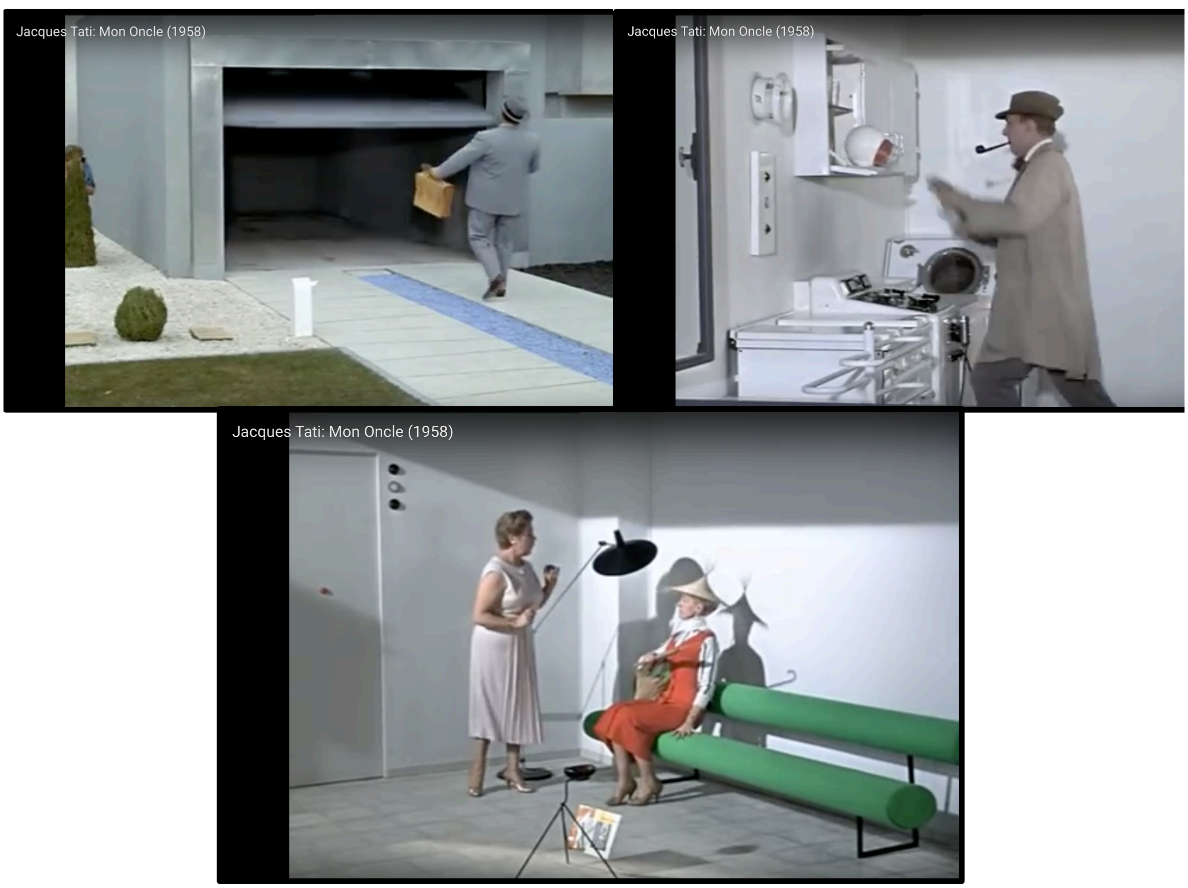

Figure 3. Motorized garage door, automated kitchen cabinet,
and living room sofa in the film *Mon Oncle*.

But going back to the protest of Jacque Tati, we see that there are physical aspects of design which we have not yet considered. Our technological slaves, as we saw in Tati's film, are often quite unfriendly (Figure 3). The noisy kitchen machinery was physically offensive to the ears, the living room sofa was physically uncomfortable, and human beings were physically incapable of moving fast enough to get out of the way of the motorized garage door. In other words, these designs were not accommodated to the limitations of man's physical nature.

Figure 4. Automobile designs from 1950s
(top: 1957 Edsel ad; left bottom: 1958 Rambler interior).

These pictures, including a recent automobile ad, graphically demonstrate lack of physical comfort in the design of recent Detroit automobiles (Figure 4). Jagged door openings, insufficient head, leg, and knee room, and uncomfortable sitting positions are but a few of the unpleasant physical features of the latest "advances" in automobile styling. Of course, automobile manufacturers know full well that they are offending the human anatomy with their design. They claim, and they have reams of market research statistics to back them up, that the public prefers the long, low, fast look to being comfortable. Comfort, in other words, is an insignificant need in comparison to the emotional needs which are satisfied by current modes in styling. Perhaps a more accurate appraisal would be that the public is emotionally attracted by the sleek, low look until the physical discomfort aspect of the car reveals itself after purchase. Once it does, however, you have often a grumbling customer who will be looking for a more sensible car for his next purchase. In my opinion, the fixed equation of good looks with lowness is a mental block in the Detroit creative process. It is certainly possible to have a good-looking car with a more comfortable, higher silhouette. And it is regrettably short-sighted policy to consciously deny a product the fulfillment of so basic a human need as physical comfort. I feel a bit guilty about picking on Detroit this way— it does seem like everyone is trying to make a monkey of them these days.

Figure 5. Frank Walsh with Elmer Average.
Source: Department of Special Collections, Stanford University Libraries:
Ampex collection, M1230, Box 53, folder 7439.

Figure 5 shows Frank Walsh, Manager of the Ampex Instrumentation Industrial Design Department, using a human engineering manikin, which he calls “Elmer Average,” with the mockup of an Ampex instrument. By introducing the human factor into the design at an early date, using manikins, mockups, and the vast amount of anatomical data that is available to every designer, Frank will have little trouble in accommodating his design to the fixed physical nature of man. In addition to anatomical dimensions, Frank also has at his disposal extensive data on body motion and strength limitations.

Another aspect of physical needs in design is the task of accommodating design to the senses. This is largely a matter of getting illumination levels high enough and sound levels low enough. Like Jacque Tati, I am especially concerned with some of the appliances in my own home which are extremely noisy and offensive to the ear. A good deal of adrenalin is lost in our house every week, for example, when the solenoid valve in our dishwasher shuts with the sound of a pistol shot.

We human beings seem to have a vast adaptability which permits us to live with the sensory annoyances of our manufactured environment without much conscious protest. But as Jacque Tati has pointed out, much of the noise and general physical abrasion of modern existence is anti-human in character and takes a terrific toll in the ragged nerves which are so characteristic of our age.

If our human values are such that we consider the machine to be an extension of man, with man the boss and the machine the servant, then early consideration of man's physical relationship to the machine becomes of obvious importance. By early inclusion of man into the design hypothesis as a non-variable, it is usually possible to accommodate the other design variables to man's physical nature. Once the design is partially "set," however, the designer will often begin to consider man the variable. Man, unfortunately, is not a variable—he has already been designed. Only early inclusion of man into the design process can bring man into his proper relationship with the machine.

We have discussed the importance of *accommodating* design to the senses; without proper illumination or adequate sound conditioning, the senses may very well be abused by design. *Clarifying* design to the senses is also an important design task in *designing for intellectual needs*. The intellectual purposes of design clarification are: (1) Minimizing needless intellectual effort required in the use of a product. (2) Satisfying the intellectual appetite for knowledge and order.

We have all had the frustrating experience of not being able to understand how to turn a simple product on or off. Clairvoyance is certainly required to divine that the rotating knob on several popular appliances must be *pulled out* to turn the appliance on. Every evening thousands of Americans climb into their automobiles, reach for the headlight knob, turn instead its identical twin, the windshield wiper knob, or perhaps its triplet, the cigarette lighter. It is not difficult to find examples of "Chinese puzzles" in our everyday design world. Unfortunately these puzzles are not fun; they are frustrating.

Many methods are available for minimizing intellectual effort in design; human engineering guides are quite helpful in this area. The headlight—windshield wiper—puzzler of this car (Figure 6) could easily be minimized in several ways.

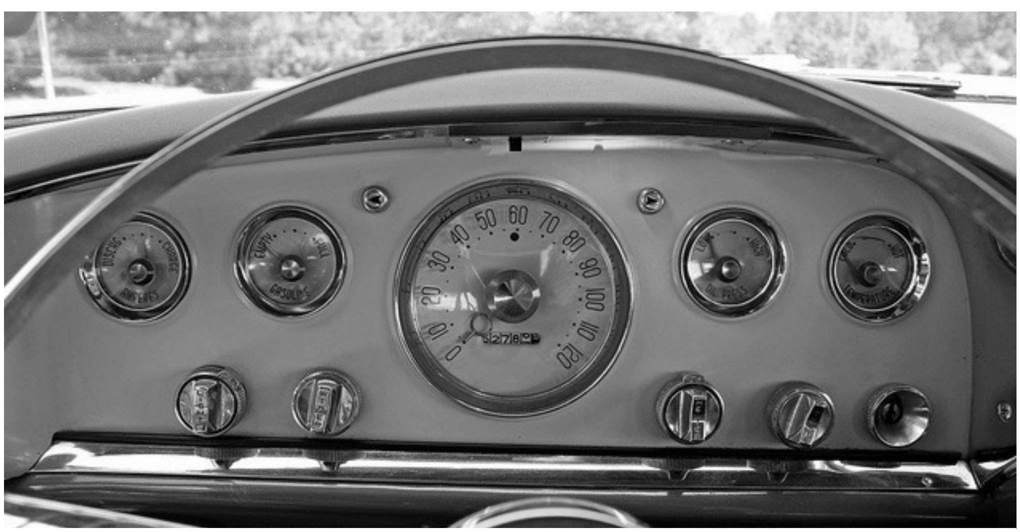

Figure 6. 1956 DeSoto Firedome Sedan dashboard.

(1) *Coding* the knobs by shape or texture so that their differences would be tactually clear—day or right. The confusion that arises with these controls usually takes place when it is dark.

(2) *Positioning* the knobs according to their respective functions—the windshield wiper knob near the wipers, the headlight knob near the ignition key for handy use when starting up at night.

Many puzzlers could be solved with greater ease if less reliance were placed on instruction manuals and more thought given to "building in" the instruction by means of design clarification. Modern kitchen stoves, for example, are often partially inoperable without complex instructions from a manual. Many of these instructions could be built into the design in the form of the logical arrangement of the controls into flow patterns which visually indicate operating procedure. Human engineers have made extensive contributions to this sort of design clarification, especially in the cockpit controls of jet aircraft where the minimizing of intellectual effort is essential to pilot safety.

Figure 7. 1950s automobile bumper and exhaust designs.

In addition to eliminating needless problem solving activity, the designer should also try to satisfy man's intellectual appetite for knowledge and order. The "thinking man," for example, is pleased when a design *looks* like it does what it does. A pleasing visual quality of some of our current automobiles is the fact they look like they are capable of going in a forward direction at a rapid rate of speed. But some models have been the butt of many jokes because they do not have this visual clarity of function; they look like they could go either direction with equal ease.

Automobiles have many other functions which call for visual clarity. For example, does the air intake to the radiator visually satisfy the intellect by looking like it scoops air in an effective manner? Do the bumpers visually express their protective function? Figure 8 shows various degrees of success with visual clarity in automobile bumper and exhaust treatments.

Or do the wheels visually express their rotative function? This solid disk wheel does not visually express the rotation of the wheel when the car is rolling. The radial lines on this disk and the spokes of wire wheels more clearly express, by their motion, the rotative function of wheels and therefore they more dramatically explain to the intellect the "truth" about wheels.

Figure 8. "Moon" wheel, radial lines, wire spokes in vintage automobiles.

Another aspect of visual clarity is visual clarity of structure. The rational man is not only interested in seeing "how it works," he is interested in seeing "how it is constructed." We can see structural clarity most dramatically in many new commercial structures (Figure 9) where the steel skeleton is exposed and the non-load-bearing curtain walls look non-load-bearing (in many cases, glass). One look at these modern buildings and we can experience how they were made and what holds them together.

Many modern designers also try to give visual clarity to the processes and materials which form the structure. For example, a characteristic of injection plastics is a fluid state which can be successfully molded into virtually any form, except perhaps rectilinear forms which tend to "dish in" on the flat surfaces. To give expression to the nature of the materials and processes in this case, the designer might use an organic form which would visually portray the fluid nature of the molding processes, avoiding rectilinear forms which are more naturally formed by other processes.

The use of concrete to imitate rough-hewn stone in the Stanford Post Office (Figure 10) offends the intellect, whereas the fluidity and moldability of the ferroconcrete technique is clearly expressed to the intellect in the Michigan State Medical Society building (Figure 11) by the architect, Yamasaki.[85]

Figure 9. Lever House curtain wall design (1952).

Figure 10. Stanford University Post Office (constructed 1959).

Figure 11. Michigan State Medical Society Headquarters by Yamasaki (1959).

Clarity of design infers order—visual order and functional order. Bringing order to a number of elements in a design requires value judgments regarding their relative importance in terms of human use—a "functional hierarchy" of values. Establishing a "functional hierarchy" is of prime importance to establishing the "visual hierarchy" as we shall see in the following example:

A "functional hierarchy" for a low-priced TV set might be established, in terms of a broad "human use factor," as: 1. Picture tube. 2. Channel selector. 3. On-off volume control. 4. Case. 5. Hold and contrast controls. 6. Speaker. I have placed the speaker last because in terms of human use, I feel that the user would rather be unaware of the speaker, maintaining the illusion that the voice emanates from the picture image. To arbitrarily reverse this hierarchy in the visual ordering of these components would normally be quite undesirable. For example, to satisfy an "aesthetic impulse," the designer might make the volume control overly prominent in terms of its color, size or position—thereby distracting the eye from No. 1 of the functional hierarchy—the picture tube.

The concept of relating the visual and functional hierarchies can also aid in visually clarifying structure because structure is, after all, functional. A functionally-oriented visual hierarchy gives design intellectual meaning and avoids the visual anarchy of styling. It is design for "the thinking man."

This painting by Mondrian has no utilitarian function (Figure 12). Nevertheless it does seem to have a strong intellectual quality. It reminds us, perhaps, of the beauty that is experienced, by other means, in mathematics or science. And, like science, it rejects the human emotional and subjective values which we find in this romantic painting by Chagall (Figure 13).

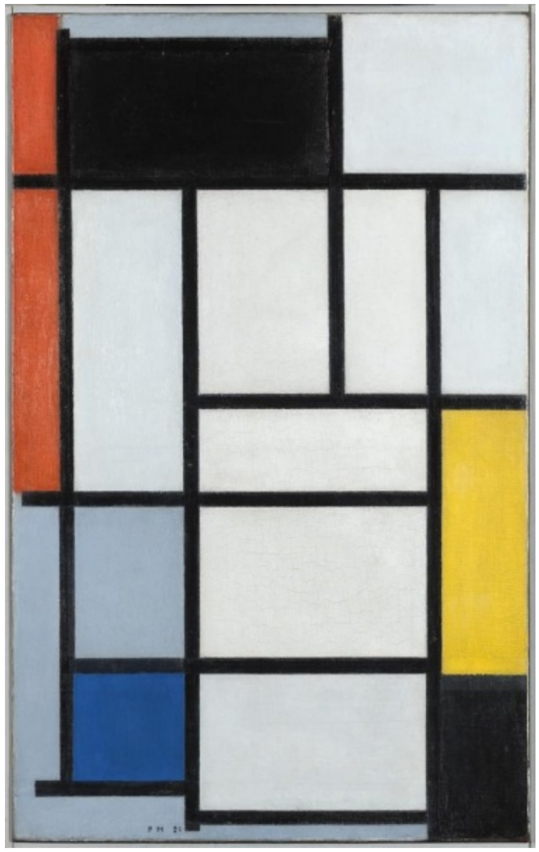

Figure 12. Mondrian's "Composition with Red, Black, Yellow, Blue, and Gray" (1921); Gemeentemuseum Den Haag.

Figure 13. Chagall's "Big Sun" (1958); courtesy www.marcchagallart.net.

Mondrian’s painting visually satisfies the intellectual appetites for unity, balance, and proportion. (I might add, at this point, that *purely* intellectual appetites do not exist. To desire or to have an appetite for the “joys of the intellect” implies an urge which is motivated by emotion.)

Unity is the same for Mondrian as it is for the scientist; in the words of Leonardo da Vinci, “Every part is disposed to unite the whole, that it may thereby escape from its own incompleteness.”

Balance is the human appetite for equilibrium, whether it be the equilibrium of visual forces, physical forces or the forces of daily living which act upon us all.

Proportion is the relation of one part to another; it is a matter of ratios whether in art or geometry.

Mondrian’s theory of art is that art is an “oasis” where we can experience the unity, balance, and proportion which is so badly lacking in our everyday life. According to Mondrian, if a perfectly ordered Utopian existence were possible, art would no longer be necessary. Presumably in Mondrian’s Utopia, mathematics, science, engineering, and invention would also be outmoded.

Mondrian’s art parallels the new age of science in its rejection of subjective values, in its denial of human emotions. Perhaps this is what makes it seem so modern. But man is a thinking and feeling creature. The modern artist, architect, and product designer often seem to want to revolutionize man’s emotional nature out of existence. Jacque Tati’s protest about the cold and impersonal quality of the geometrical modern house is directed precisely at this one-sided value so prevalent in the current cultural environment.

The overemphasis, in modern design, upon intellectual needs has been the result of a cultural revolution. And because the cultural environment does have a large formative effect upon design, I believe it would pay us to briefly trace the historical development of contemporary modes of design.

The 19th Century was an all-time low period in the history of western art. Architecture consisted of copying details of past periods and combining them in bastard styles such as Greco-Romanesque-Gothic (with a touch of Early Halloween). Painting had become a sentimental and formless art which flourished under the patronage of the newly-moneyed class of marketers and merchandisers of the machine age.

By the turn of the 20th Century there was a significant portion of the European intelligentsia which was fed up with the moneyed class and all that the moneyed class stood for—including its decadent art. A revolution, in art as well as in politics, ensued.

In painting, “Les Fauves” (The Wild Beasts), and the “Cubists,” including Picasso, Braque and Matisse, introduced the visual revolution of cubism, Dadaism, and surrealism. In architecture a similar revolution took place and undecorated buildings with their structures exposed were soon seen in many European cities. It was a violent revolution and there was much bitterness between the entrenched academic artists and architects and the modern “upstarts.” As in all revolutions, the “upstarts” were forced to become extremists in order to fulfill their mission of overthrowing the decadent art they so much despised.

The revolutionary modern architects proclaimed “Form Follows Function.” Decoration (the bread and butter of the academic architect) had no function—so off it came. The skeletal structure of the building (which the academic architect disguised with decoration) *was* functional—so the form of the skeleton was exposed.

The slogan, “Form Follows Function,” was like a fresh breath of air after over a century of stale copyism. Product designers, especially in the German Bauhaus School, were inspired by this new architecture and soon followed suit.

But the pendulum of history often swings rapidly from one extreme point of view to the extreme of an opposite point of view. In their effort to throw over the irrational, sentimental, tradition-oriented patterns of the old regime, modern architects insisted upon “modernity” and “rationality” at all costs.

The Machine—rational, unsentimental, and modern—became a visual symbol of the artistic revolution. Painters painted people in the form of machines (Leger) and architects proclaimed, “A house is a machine to live in.” (Le Corbusier) The structural clarity and the clean geometric shapes of the machine became the artistic ideal.

But what did the designers mean, when they proclaimed “Form Follows Function”? Structural clarity and undecorated geometric forms were refreshing to the eye—but if function means “the satisfaction of physical needs,” the modern architects did not seem to be practicing what they preached. Floor plans and window-patterns too often made the human users of modern design into the guinea pigs of some diabolical experimenter. And if the function of design can be further defined as “the satisfaction of emotional needs,” modern design again seemed to be amiss, because even the people sympathetic to the artistic revolution were complaining of the “cold antiseptic feeling” of the new work. If modern designers were not practicing “Form satisfies human physical and emotional needs,” what were they practicing?

In my opinion, “good design” and the slogan “Form Follows Function” has come to mean an almost exclusive emphasis on the intellectual values of visual clarity of function, structure, and materials plus the visual application of the intellectual principles of unity, balance, and proportion.

It is certainly all to the good for design to satisfy the thinking man. But what of the function of design, in terms of other human values? Man also has emotional needs. Man has shown an irrational appetite for decoration, for example, since his earliest utilitarian art—can modern design revolutionize this human need for decoration out of existence? Man has also a great irrational need for being enclosed, cozy, secure (perhaps to satisfy atavistic or pre-natal unconscious needs)—can modern design with its gold-fish-bowl expanses of glass, liquidate this human need for security?

Perhaps the pendulum has swung too far toward intellectualism and is even in danger of sticking for a while in this position, producing an academy of pseudo-intellectualism. We need to take a look at man’s emotional needs, for they are being starved in some respects and surprisingly overfed in others.

Harry C. Meserve, in his excellent book, *No Peace of Mind* [1958, p. 118] wrote:

> For purposes of analysis, there may be such a thing as “pure reason,” but in all life reason is tinged with emotion, and all emotion, at least among the sane, is in some measure disciplined and directed by reason and thought.... Feeling is the force which enables us to act upon thought, to bring ideas over into the field of action. In the long run, it is what we care for, what we love, what feels right that enables us to act creatively.

As in a well-balanced life, good design must balance the requirements of physical, intellectual and emotional needs. But, obviously, not all emotional needs are good ones. The bloody history of the weapons of war is but one example of man fulfilling the wrong emotional needs through design. When we consider designing for the emotional needs of man, therefore, we come quickly to the question of morality in design.

Today it is considered immoral (and illegal) to use a switchblade knife; but you may design one without restraint. It is moral to design a thermonuclear weapon; fortunately, it is currently considered immoral to use one. The emotional values of many of our most popular products, if translated to human behaviour patterns, would certainly seem, if not immoral, at least overbearingly arrogant and power-happy.

Morality in design certainly has not been aided by the contributions of the psychologist-in-industry, the motivational researcher. The motivational researcher, motivated himself by a newly found gold mine, doesn't hold the classic view of man as a rational creature, motivated by dignified and noble emotions. To the Freudian merchandiser, the noble aspect of man is but the visible portion of an iceberg whose submerged portion, the unconscious mind, contains enormous emotional needs of a decidedly ignoble nature—needs which are just waiting to be satisfied by a design which will sell like hotcakes. These Freudian insights into the basic emotional needs of man are now orienting many large-scale design efforts.

An example of motivational research at work is revealed in Vance Packard's *Hidden Persuaders* [1957, p. 67]:

> After psychiatric probing a Midwestern ad agency concluded that a major appeal of buying a shiny new and more powerful car every couple of years is that "it gives him (the buyer) a renewed sense of power and reassures him of his own masculinity, an emotional need which his old car fails to deliver."
>
> One complication of the power appeal of a powerful new car, the Institute for Motivational Research found, was that the man buying it often feels guilty about indulging himself with power that might be regarded as needless. The buyer needs some rational reassurance for indulging his deep-seated desires. A good solution, the institute decided, was to give the power appeals but stress that all that wonderful surging power would provide "the extra margin of safety in an emergency." This, an institute official explains, provides "the illusion of rationality" that the buyer needs.

With 33,000 dead and 5,000,000 injured as a result of last year's automobile accidents, this design response to emotional needs for "power" and "masculinity" seems to me to be decidedly immoral. Our morality of behaviour certainly does not sanction everyone to go around carrying a loaded gun so that they can be "reassured of their masculinity." It seems to me that designers should have similar standards for design morality, standards which would be applied at the inception of every new design.

Now I would like to get to a more pleasant subject: the delight which sensory stimuli such as color, shapes, rhythmic patterns, and textures can bring to the emotions.

Perhaps the most emotional visual element is *color*. Color, ranging from light to dark and from pale to bright, defines our visual world. It defines the boundaries of shape and distinguishes one shape from another. Color, much like sound, can be a physical experience—even a painful one. For example, imagine a room painted in this fluorescent red (Figure 14) now used in flashy advertising and as a safety color on airplanes.

Figure 14. Fluorescent red neon sign (1927, Palo Alto, CA).

A good deal has been written and said about the emotional values of color. In fact, color has become a part of our language to express emotional states of being; for example, "to see red" or "to feel blue." The color red is generally recognized to be passionate, stimulating, and exciting; blue is often described as relaxing and sad.

Many attempts have been made to systematize the selection of harmonious color—just as many attempts have been made to apply mathematics to art. These "scientific" methods always ignore such human factors as the expressive, emotional effects of color, and result in the harmony that one finds in mush.

The scientific approaches to color harmony also overlook the problems of color associations. For example, "Butter yellow" is an appropriate and appetizing color for butter and its substitutes. Not many years ago housewives were going to the messy trouble of kneading yellow coloring into margarine in order to change it from white to the more appetizing associations of yellow. "Butter yellow," however, looks quite unpleasant when painted on an automobile—the association with butter no longer being such a favorable idea.

Color can also fulfill intellectual functions such as the forceful communication of a simple idea; red for stop, green for go. But the true role of color is an emotional one; it makes us gay at a carnival, spiritually exalted in a stained glass cathedral, and totally contented in the somber green of a forest.

Color is undeniably a powerful means to satisfying emotional needs through design. Rhythm, however, is an aspect of design which is capable of satisfying a larger appetite, partly instinctual, partly physical, intellectual, and emotional. John Dewey, in *Art as Experience* [1934, pp. 152–153], writes:

> The larger rhythms of nature [are so bound up with the conditions of even elementary human subsistence, that they] cannot have escaped the notice of man as soon as he became conscious of his occupations and the conditions that rendered them effective. Dawn and sunset, day and night, rain and sunshine, are in their alternation factors that directly concern human beings….
>
> Man's own life is affected by the rhythm of waking and sleeping, hungering and satiety, work and rest…. With the working of wood, metal, fibers, clay, the change of raw

> material into consummated result…. there are the recurrent beats of patting, chipping, molding, cutting, pounding, that mark off the work into measures. But more significant were those times of preparation for war and planting, those times of celebrating victory and harvest, when movements and speech took on cadenced form.
>
> Thus, sooner or later, the participation of man in nature's rhythms, a partnership much more intimate than is any observation of them for purposes of knowledge, induced him to impose rhythm on changes where they did not appear…. The mysterious movements of serpent, elk, boar, fell into rhythms that brought the very essence of the lives of these animals to realization as they were enacted in dance, chiseled in stone, wrought in silver, or limned on the walls of caves. The formative arts that shaped things of use were wedded to the rhythms of voice and the self-contained movements of the body, and out of the union technical arts gained the quality of fine art.

An example of rhythm in design can be seen (Figure 15) in the structure of this modern bank building in San Francisco. The exciting "beat" of its radiating beams satisfies, perhaps, the most primitive and basic of man's visual needs for design.

Figure 15. Zellerbach Building with original American Trust Company Pavilion (1959).

Shape is another visual element which can have an important stimulating effect upon the emotions. The energetic effect of the starburst shape in the foreground building as compared to the serene effect of the rectangular Zellerbach building in the background is a case in point.

Shape has strong associative values. Organic shapes are associated with the natural environment, the world of plant and animal life; organic shapes remind us of the appeal that we find in the human form. Geometric shapes are associated with a manufactured environment where straight lines and round circles are possible; geometric shapes also remind us of an ideal which is purely intellectual and, therefore, not entirely human.

Every design, of course, has shape—is up to the designer to control the dynamics of that shape to evoke emotions which are appropriate to the product.

I said earlier that an ancient need of man is to decorate. It is interesting to find that modern architecture is returning to the use of decoration in [Edward Durell] Stone's [design for the original] Stanford Medical Center (Figure 16). It is regrettable, however, that the decoration is geometrical and, therefore, a bit anti-human. And as Eliel Saarinen pointed out in his book, *The Search for Form in Art and Architecture* [1948, p. 238]: "When (Nature) produces decorative pattern—as happens constantly and everywhere—there is always functional thought and expressiveness behind it." Stone's decoration is applied decoration, applied wholesale without regard to meaning.

Figure 16. Stanford Medical Center by Durell (1959).

Texture is both a visual and tactile element which offers delight to both senses at once. Light and shadow upon an object or the space that surrounds or pierces through it are other elements which can delight the eye and the emotions.

I am very much impressed by the recent statements of the architect, [Minoru] Yamasaki, regarding his desire for delight in architecture. His assessment of the problem applies to the problems of product design as well. Mr. Yamasaki said:

> I am for delight in architecture. I believe in this delight for certain positive reasons which I will list here; reasons which go beyond restlessness with the prevailing technique.
>
> Within the limited palette available in the dogma of rectangles to which we have committed ourselves, we cannot solve the complex architectural needs of our society. There is physical evidence at hand that a total environment of rectangular modules will be overwhelmingly dreary. I can picture it as monotonous as the Arabian desert, which I

> experienced recently. The problem is that we cannot leave our cities as easily as I was able to leave the desert.
>
> Midtown New York, for instance, is rapidly losing the little character it possessed. The plastering of facades of whole blocks with regimented patterns of glass and porcelain-enamel rectangles has made so many New York blocks look exactly alike. Our life gives promise of being spent in look-alike houses, look-alike automobiles, look-alike buildings....
>
> We Americans who pride ourselves in our democracy, who hope to win the cold war by spreading our beliefs of cooperation and warmth in humanity, gentleness in mankind instead of brutality, must have a vocabulary of architecture which is consistent with our ideals. By building an intelligent and inspiring environment in which it is delightful to be, which shows the best of our knowledge of beauty and gentility, we will express in physical terms our most hopeful aspirations….
>
> Four years ago, [continued Yamasaki,] I took a trip around the world. It was on this trip that I first awoke to the need for delight in our architecture. Fortunately, I spent most of these few short weeks in Italy and Japan. In Italy, I was struck with the joyful quality of its historical architecture. The rushing fountains, the exuberant buildings, brought an excitement to that architecture that I knew was missing in ours. The delight of a Bernini fountain or a Venetian skyline bright in the sun is pure enjoyment. The background of colorful buildings in the Piazza San Marco or in the Market Square in Siena provides unending pleasure to thousands in their leisure.
>
> In Japan, I found delight in the combination of buildings and gardens conceived with the primary thought of giving inner security and pleasure to man. This utter lack of ostentation in Japanese architecture is in curious but impressive contrast to the ideals of many architects today to show strength and power in their buildings. I wonder if the latter isn't just another form of muscle-flexing. Though neither exuberant delight of Italian buildings nor serene delight of Japanese architecture should be swallowed whole, there is obviously much to be learned from both.

Mr. Yamasaki is, of course, plugging for design which better satisfies the emotional needs of man. But as Clive Bell writes in his book, *Art* [1914, p. 50]:

> To make the spectator feel, it seems that the creator must feel, too. What is this that imitated forms lack and created forms possess? What is this mysterious thing that dominates the artist in the creation of forms? What is it that lurks behind forms and seems to be conveyed by them to us? What is it that distinguishes the creator from the copyist? What can it be but emotion? Is it not because the artist's forms express a particular kind of emotion that they are significant?—because they fit and envelop it, that they are coherent?—because they communicate it, that they exalt us to ecstasy?

In conclusion, I would like to ask the question, "Who designs for the whole man?" The engineer designs primarily for man's physical need for power over his environment. The artist designs exclusively for man's intellectual and emotional needs. Modern architects and product designers have often succeeded in satisfying intellectual man, while abusing him physically and starving him of the emotion of delight. Motivational researchers have spurred designers on to satisfy emotional needs that would perhaps be better left unsatisfied.

Clearly we badly need the designer who understands and is capable of responding to the needs of the whole man. This designer should be capable of reasoned as well as felt design responses. He must understand man's physical needs, needs not only for power over his environment but needs for physical comfort and sensory well-being. He must understand man's intellectual needs, needs for minimizing needless problem solving in design as well as visual needs for knowledge and order. The designer who designs for the whole man will also understand man's emotional needs for designs which satisfy civilized motivations and which delight the emotions through the senses. This designer must have the fortitude to exert his influence on the current cultural environment which is depriving us all of basic human needs.

We badly need the designer who truly "understands the organism for which he is designing." I predict a brilliant future for the comprehensive designer, who promises to be such a man.

STANFORD ENGINEERING DESIGN COURSES 1957–1963

This is a compilation of the design courses that were introduced by John E. Arnold or Robert McKim 1957–1963. The courses are listed once in the year they were first offered to show the evolution of the curriculum. The year headings indicate the Stanford University Bulletin, "Courses and Degrees," in which the course first appears.

— 1957–58 —

Arnold joined Stanford University as a professor in the Schools of Business and Mechanical Engineering and taught one course (114a) in Autumn 1957; the continuation courses (114b, c) were taught by Frank Robert Arnold. In 1958–1959 John Arnold taught the entire series, 114a, b, and c. Subsequently, these courses were taught by Peter Z. Bulkeley, Robert E. Keller, Bernard Roth, or staff.

114a. Mechanical Engineering Design—Design of machine elements, stressing a rational approach; their incorporation in mechanical, electromechanical devices arising from synthesis problems primarily of kinematic character where stress analysis is of secondary importance. Introduction to electro-mechanical computer elements. Enrollment limited. Prerequisites: 3, 50, and C.E. 114. *4 units, autumn, (J. Arnold), TTh 10; lab. TTh 1-4*

— 1958–59 —

Arnold introduced the following graduate courses, which he taught from 1958–1962; they are the only courses he taught in 1959–1960.

Adams and others continued teaching Philosophy of Design (214a); it is still offered today as "History and Philosophy of Design."

Comprehensive Design (214c) had been taught by Robert H. Eustis as ME150 in 1957–1958, which he described as: "Treatment of comprehensive mechanical engineering problems involving consideration of factors necessary for preliminary design." Eustis, George Leppert, and Stephen Jay Kline constituted an internal ME committee that brought Arnold to Stanford.

214a. Philosophy of Design—An introduction to the philosophy of comprehensive design. A discussion of the attitudes and viewpoints of the designer and a thorough investigation of the techniques of analysis, synthesis and evaluation that he uses. Emphasis will be placed on understanding of the creative process and the factors that influence it. Limited registration. Prerequisite: Permission of Instructor. *3 units, autumn, (J. Arnold), W 1-4*

214b. Human Factors in Design—A study of Man's strength and weaknesses in opposition to and/or in cooperation with machines. The problems associated with the transfer of information, energy, and matter between man and machine will be investigated. Limited registration. Prerequisite: M.E. 214a. *3 units, winter, (J. Arnold), W1-4*

214c. Comprehensive Design—Seminar discussions and actual design practice in the solving of complex and comprehensive engineering problems. Imagination tempered with sound engineering analysis and judgment will be stressed. Limited registration. Prerequisite: M.E. 214b. *3 units, spring, (J. Arnold), W 1-4*

— 1960–61 —

Arnold taught the following Senior Colloquium in 1961, 1962, and in spring 1963. All candidates for A.B. degree were required to enroll in a senior colloquium: "They are designed to stimulate serious thought rather than to impart information for its own sake. Thus the emphasis is on discussion and analysis, not lectures. In most cases students are not admitted to a Colloquium being taught by a staff member of their major department."

SC49. How to Ask a Question—Knowing what questions to ask and how to ask them is sometimes more important than the eventual answers. Each of man's advances was started by a question. *2 units, winter, (J. Arnold, Mechanical Engineering), T 2-4*

— 1961–62 —

Robert McKim first taught these courses in 1961. They, along with 214b, were offered through 1964–1965 and gradually reformulated thereafter.

112a. Rapid visualization — Freehand perspective and shading techniques for rapidly visualizing design concepts. Emphasis is upon two-dimensional visual communication which is lucid and quickly executed. Prerequisite: Engr. 9 or consent of the instructor. *3 units, autumn, (McKim), MW1-4*

112b. Introduction to Product Design—A study, through lecture and laboratory exercises, of the human values in product design, including functional, human engineering, psychological, and esthetic factors. Laboratory exercises consist of developing simple product concepts three-dimensionally, with rapid model making techniques. Prerequisite: 112a. *3 units, winter, (McKim), MW 1-4*

112c. Product Design and Presentation—A continuation of 112b, with emphasis shifted to the influence of mass production methods and materials upon design. Presentation techniques for communicating design concepts to others, especially to non-designers, will also be considered. Prerequisite: 112b. *3 units, spring, (McKim), MW 1-4*

116a. Advanced Product Design—Invention and development of new product concepts with emphasis upon methods for determining: unfulfilled human needs. Each design concept is developed into a working model. Prerequisites: 112a, b, c. *3 units, autumn, (McKim). TTh 1-4*

116b. Advanced Product Design—Continuation of 116a, with emphasis upon the influence of technology, especially "technological breakthrough," upon the formulation of new product concepts. Prerequisite: 116a. *3 units, winter. (McKim). TTh 1-4*

116c. Advanced Product Design—Continuation of 116a, b, with emphasis upon developing a large, complex design to solve a "big" need, i.e., mass transportation or city planning. Prerequisite: 116b. *3 units, spring, (McKim), TTh 1-4*

— 1962–63 —

Arnold added the following course in 1962–1963, listed under general Engineering. He was on sabbatical in the fall of 1963 and so might have taught it in the spring. This is his only course listed in the 1963–64 catalog.

9. Engineering Drawing—(Formerly M.E. 9.) Study and application of the language of vision as it applies to the engineer and scientist. Main emphasis is placed on machine drawing, orthographic and isometric projection; free-hand sketching and pictorial representation; and descriptive geometry. *4 units, autumn, winter, or spring, (J. Arnold, Staff), MW 1; lab. MW 2-5*

The following staff course is also listed in the 1962–63 catalog:

215a, b, c. Design Seminar—Round-table discussions with visiting professionals from areas of design, advertising, art, marketing, and business. Three critical papers per quarter required. *2 units, autumn, winter, spring, (Staff), by arrangement*

— 1963–64 —

The design seminar series (215a, b, c) was relisted under Directed Study in the 1963–64 catalog:

215. Seminar in Design—Problems touching on all aspects of design. For all graduate students in both Product Design and Engineering Design. Speakers from industry and Stanford illustrating the cross-discipline responsibilities of the designer will be featured. Registration for one unit of credit with + or —grade, is optional; a letter grade is given for students presenting talks. *1 unit, autumn, winter, and spring, (Staff), W 4*

McKim also added a design project Directed Study course in association with the Product Design program, with three parts (a, b, c) in autumn, winter, and spring:

299. Design Project—Consists of a minor and a major project. Ten-week minor project emphasizes economic and marketing determinants. Three-quarter major project requires student to identify an unexplored problem area which will exercise all design determinants. In the first quarter, student submits statement of intent and performs research. In the second and third quarters he performs analysis, experimentation, and synthesis, culminating project with a working prototype of his design concept. For Product Design students only. 5 *units, (McKim), by arrangement*

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INDEX

NOTES

[1] *Stanford University Bulletin* (1960, p. 423), "Senior Colloquium 49. How to Ask a Question." All candidates for the Stanford A.B. degree were required to enroll in one of the senior colloquia. Quite fitting Arnold's intent, the Bulletin states, "The Senior Colloquia are limited to 15 students each and are built around subjects or issues of continuing importance, or a basic document of enduring significance. They are designed to stimulate serious thought rather than to impart information for its own sake. Thus, the emphasis is on discussion and analysis, not lectures. In most cases students are not admitted to a Colloquium being taught by a staff member of their major department" (p. 422).

[2] For example, see Westbrook (1991), Menand (1992), and Sandel (1996).

[3] Robert McKim, personal communication, 16 September 2016.

[4] Arnold's concept of "creative problems" was possibly influenced by Guilford's (1950) paper that "pointed out that almost all the tests and achievement examinations used by American psychologists and educationists… [had] one predetermined correct answer." In contrast "creative thought is more likely to issue in a variety of new answers, in other words to be divergent" (Vernon, 1970, p. 11).

[5] In his essay on "the myth of industrial design" Fuller (1959) referred to industrial designers as being "showmen" and "decorators." Indeed, Dreyfuss began his career as a stage set and costume designer, and he emphasized appearances with a marketing perspective that seems at odds with the concept of a comprehensive designer: "If a tractor appears well put together outwardly, it is logical to assume that the internal mechanism is equally sturdy" (1955, p. 146). Nevertheless, Dreyfuss was a pioneer in orienting designers to how a product fit people physically and perceptually, to the extent of studying the context of their activities (such as how climate affected clothing worn while riding a bicycle). It is not clear that Fuller appreciated these methods and contributions. For example, Fuller wrote, "I assure you that no aircraft company will let an industrial designer through its engineering front door" (1959, p. 77), yet Dreyfuss's firm was engaged by Lockheed Aircraft Corporation to design the interiors of the Super Constellation (Dreyfuss 1955, p. 130–135). Fuller claimed that industrial designers are called in only after a ship is built; yet Dreyfuss describes "a close co-operation with the engineers. Our offices become as one" (p. 46)—engineers were hired or borrowed to work with designers (p. 229). Furthermore, Dreyfuss (1955, p. 18) blames the disconnection between engineering and human factors on manufacturers who "considered the industrial designer merely a decorator, to be called in when the product was finished." Winograd (2008) provides a wholly positive account of Dreyfuss's contributions, including contextual design, interface metaphors, iterative prototyping, and emotional design. Practices and projects in the 1950s no doubt varied, and this blended and sometimes problematic relation between "designer" and "engineer" may be an important reason why Arnold sought to relate the perspectives of engineering and industrial design in one person.

[6] Arnold (1959b); cited by Kizilos-Clift (2009, p. 531).

[7] Strictly speaking the objective is “actualization (or realization) of the self,” rather than the bootstrapping that the term “self-actualization” might imply.

[8] For an exclusively systemic (symbolic) model of thinking, see Newell and Simon (1972); Schön (1987) provides a contrary analysis.

[9] Herbert Dreyfus’s (1972) well-known philosophical critique emphasized the nature of unconscious processes constituting skills that could not be reduced to descriptive formalisms. See Clancey (1997) for a detailed account of related analyses and the later synthesis of psychology and the social sciences called “situated cognition.”

[10] From Cringley (1995).

[11] As we see in Dreyfuss (1955), the notion of “human-centered” design has a long history, considering different aspects of people and using different methods. Norman (1988) used the term “user-centered design” focusing on tasks, constraints, affordances, etc., with aesthetics secondary. “Human-centered computing” sought to relate people and automation (e.g., see Shafto and Hoffmann, 2002; Hoffman et al., 2012). Under the rubric of “work systems design” (Sachs, 1995), Sierhuis and Clancey (2002) began with activities and socio-cognitive practices, designing for the “total system” interaction of people, facilities, tools, and procedures.

[12] From an Internet site promoting Alexander (2003), “Summary of Book Four: The Luminous Ground,” http://www.natureoforder.com/summarybk4.htm.

[13] The star Arcturus is mentioned on the first page of Asimov’s (1951) *Foundation*, which he presented at the MIT Science Fiction Society (1951). The minutes of the meeting record that “Arnold, speaking informally after Asimov, told members of the Society of a new phase in Tech’s Product Design Course. Under the projected set-up, students will design products for use in alien environments, specifically other planets. He invited members of the Society to contribute ideas on possible environments.” Notably, The Tech (1954) announcement for a subsequent meeting gave top-billing to Arnold’s presentation on Arcturus IV and mentioned that Asimov would attend.

[14] Arnold rewrote the lectures between 1954 and 1959; none of Pittman’s quoted passages appear literally in 1959. For example, the 1954 statement “I don’t believe one has to be an amatuer [sic] to innovate, but it may be true that he has to think like one” (Pittman, 1955, p. 58) now appears in 1959 as “I am certain that innovation is not limited to amateurs, but it may be limited to only those who think like amateurs; who are as fearless, as uninhibited, as sensitive and observant as a newcomer to a field of activity” (p. 62). However, the list of blocks quoted by Pittman (pp. 47–50) appears word for word in the 1959 version (p. 91 and following), which is the source for this book.

[15] The 1956 passage quoted by Kizilos-Clift (2009, pp. 216–217) about “the art of asking good questions” appears word for word in the 1959 version, Chapter “Factors Influencing Creativity,” p. 84. The remark about daydreaming in children (Kizilos-Clift, 2009, p. 216) is similar to what Arnold said in a speech in September 1956 (Arnold, 1957), but it does not appear in the 1959 version. Kizilos-Clift also states that the 1956 version quoted from Solomon Asch (p. 269, which appears in Asch’s “Opinions and

Social Pressure," 1955). However, Arnold doesn't cite Asch in 1959 or other articles, though he does mention several times the cultural pressure to conform.

[16] For a list of Arnold's business affiliations see Smith (1959, p. 34).

[17] Wissinger (1964) here cites Simberg (1957, p. i).

[18] A more curious point is why Arnold does not mention McKim, Maslow, or Hartman by name in his lectures. As co-presenters at the seminar they are hardly being slighted—their work is obviously being promoted, and Arnold might have deferred to them to present their own ideas. We know also that McKim's presentation was prepared for the seminar, and the dates of subsequent publications by the others suggest that they were also largely presenting new material, which Arnold would not be expected to discuss. On the other hand, we might have expected some aspect of Hartman's and Maslow's work to be integrated in the discussion of creativity. Hartman had presented to Arnold's MIT students, and in 1956 Arnold was considering working with Maslow at Brandeis to get a Ph.D. in psychology (Kizilos-Clift 2009, p. 515).

Perhaps inviting someone to speak was a step towards incorporating their work in the main discussion of creativity factors and methods. Fuller and Gordon had spoken in 1956 (Pulos 1990, pp. 185–186) and their ideas are prominently mentioned in the 1958–1959 notes. Possibly Maslow and Hartman were invited to further develop their analytic approaches and connect them to the creative process, so Arnold could assimilate their theories into practical methods for creative engineering. Indeed, Maslow comments in his introduction about the strangeness of relating to a business audience, and Hartman introduces his "moral science" of creativity as addressing a shortcoming of psychological and aesthetic perspectives, that is, what everyone else at the seminar has presented.

[19] Austin R. Baer, personal communication, 26 February 2015.

[20] American Society for Engineering Education, Engineering Case Library. Available: https://archive.org/details/engineeringcaselibraryasee&tab=about. See also: Stanford University. Engineering Case Program (1948-1972). Case Files. Stanford Digital Repository. Available: http://purl.stanford.edu/rz867bs3905.

[21] The Box Car Design Project is attributed to Arnold in the Engineering Case Library, but the report itself states, "Prepared under the direction of John E. Arnold." Possibly this was a student term project and the detailed design problems reflect the student's conception of case studies and not Arnold's preference.

[22] One must be careful not to equate all constraints in the dependent hierarchy schema with "goals." In particular, goals for a design project operate at that level of complexity within the design activity; they do not control our values, etc. by which goals were formulated and framed.

[23] "Human and Robots in Exploration," workshop sponsored by the Search for Extraterrestrial Intelligence (SETI) and the Planetary Society, Stanford University, February 12–13, 2008.

[24] Mindell (2015) surveys how the "myth of autonomy" as existing apart from the dependent social system of human interests and control has confused the design and use of automated systems in the air, undersea, and on land (e.g., "self-driving cars").

[25] "Astronauts and Robots: Partners in Space Science and Exploration," conference sponsored by the American Astronautical Society, Jet Propulsion Laboratory, Pasadena, California, May 12–13, 2015.

[26] For a basic introduction and application to classroom examples see Clancey (2011). For a related discussion with respect to creativity see Taylor (1969).

[27] For an introduction to the ideas presented in this list see Lave (1988), Clancey (1991, 1997, 2002), and Wenger (1998).

[28] Arnold cites Whyte's later book, *Organization Man*, though doesn't mention this article or the term "groupthink."

[29] Marin's (1979) analysis of spiritual needs and ethics draws similar conclusions about "full participation in a vital polis or in a vivid communal or social world" (p. 52), consistent with Dewey's (1899) perspective on the collective and self-actualization.

[30] Anderson's (1997) encyclopedic article "Work, Ethnography and System Design" provides a superb historical review, comparing social scientists' interests, theories, and methodological development in different countries.

[31] David Kelley, personal communication, 24 September 2016.

[32] Austin Baer, personal communication, 25 February 2015.

[33] This essay is condensed from the editor's original Wikipedia article on John E. Arnold, available at https://en.wikipedia.org/wiki/John_E._Arnold.

[34] See Strong (1954, p. 40) and Hunt (1955).

[35] See Smith (1959, pp. 33-34); *The Times (San Mateo),* 1963, p. 21; and Tudor (1999, p. 321).

[36] [Did Arnold misspell "foreword" or is this a pun, to provoke the reader? Misspelling seems unlikely given that the manuscript was revised and distributed over several years. In particular, the 1959 seminar manuscript at one point states, "here at Tech" (p. 113), which would have been written no later than the summer of 1957. Also, the foreword of a book is usually written by someone other than the author. NB: Endnotes from this point are in the original seminar manuscript except those appearing in square brackets, like this.]

[37] "How Can We Develop Inventors," Charles F. Kettering, presented at Annual Meeting of ASME, November 29 to December 3, 1943, published in Pamphlet "Creative Engineering".

[38] Innovation, *The Basis of Cultural Change*, H. G. Barnett, Page 181.

[39] [The seminar manuscript refers to "David Koestler."]

[40] Koestler, Arthur, *Insight and Outlook*, Page 37.

[41] Ashby, W. Ross, The Design for an Intelligence Amplifier, contained in *Automata Studies*, Princeton University Press, 1956, Page 217. [The Stanford Archives version distributed with *Creative Engineering* course materials in 1959 is missing a page of text starting about here (page 12 in the original). The Business School Library, Stanford University has a complete copy.]

[42] [See Steinbeck (1952, Chapter 13). Corrected from "This in our time was the danger."]

[43] Greenewalt, Crawford H., "Key to Progress - The Uncommon Man," Speech given April 26, 1956 before 43rd Anniversary Dinner, Bureau of Advertising, American Newspaper Publishers Association: New York City.

[44] [ONR is the Office of Naval Research]

[45] [See Mooney (1954, 1963).]

[46] [AMA is Automobile Manufacturers Association?]

[47] [Pittman (1955, p. 17) cites an identical paragraph in Arnold (1954, pp. 27–28).]

[48] [Rogers (1961, pp. 353–354) calls these three factors the "inner conditions of constructive creativity" in the essay, "Toward a theory of creativity," presented at the Ohio State University "Conference on Creativity," December 1952; also published in Barkan & Mooney (1953, pp. 73–82) and Anderson (1959, pp. 69–82).]

[49] [The diagram is missing in the original text.]

[50] [Possibly this is a reference to Charles Erwin Wilson, an American engineer who was president of General Motors during WWII and served as United States Secretary of Defense under President Eisenhower.]

[51] [Pittman (1955, p. 52) says Arnold has condensed Osborn's checklist from *Applied Imagination*. However, the list Pittman provides, attributed to Arnold's 1955 Summer Seminar lectures, is Osborn's original; it is not condensed. Arnold's 1959 version given here is indeed condensed. Arnold has labeled Osborn's "Magnify" sub-list to be "Modify" and deleted the original: "MODIFY? New Twist? Change meaning, color, motion, sound, order, form, shape? Other changes?"]

[52] [The Stanford Archives copy distributed with *Creative Engineering* course materials in 1959 is missing a page of text starting about here (page 17 in the original). The Business School Library, Stanford University has a complete copy.]

[53] From *Imagination, Undeveloped Resource*, Copyright 1955, Cambridge, Mass.

[54] Ibid.

[55] Ibid.

[56] [Rogers (1953) calls these the two "conditions fostering constructive creativity."]

[57] Ibid.

[58] [See Hix, 1954.]

[59] [The original text indicates "(photo)" here; a photograph is not included in the manuscript.]

[60] [See Cros, 1955.]

[61] *Machine Design*, Jan. 26, 1956, Pages 56-60.

[62] *Bulletin, Société Industrielle de Mulhouse*, vol. 94, 1923, pp. 214-235, translated by A. R. Stevenson, Jr., for A.S.M.E., 1944.

[63] Talk given before the Faculty Club of the Massachusetts Institute of Technology, January 19, 1950.

[64] "The Dymaxion World of Buckminster Fuller," *American Fabrics*, Spring, 1953, Gentry, Spring, 1953.

[65] [This description of the comprehensive designer's qualities is adapted from Arnold (1955b).]

[66] Talk given before the Faculty Club of the Massachusetts Institute of Technology, January 19, 1950.

[67] [Richard Neutra was a modernist architect, famous for understanding client needs and designs relating art, landscape, and practicality.]

[68] A lecture presented June 23, 1959 at Stanford University, in a course on creative thinking under the supervision of Professor John E. Arnold. All rights reserved.

[69] [In Guilford's subsequent publications "figural" content is replaced by "visual" and "auditory."]

[70] [The diagram in the original text is missing labels for Content and Operations. The Content dimension is labeled "Figural, Symbolic, Semantic, and Behavioral" in Guilford's subsequent publications. Thus behavioral content is "social intelligence."]

[71] [The structure of intellect diagram has a top face, a left face, and a right face. The "cognitive" layer is the right face (i.e., "front layer"). Guilford's description in the text doesn't mention "behavioral" content, the right-most column. Thus the "cognitive" operation is associated with 6 rows (products) and 3 columns (content) constituting a layer of 18 cells.]

[72] [The memory layer is behind the right face and excluding the behavioral column has 18 cells.]

[73] This statement and others of similar nature in this paper should not be taken to mean that success in problem solving and in other creative endeavor is fully accounted for by intellectual abilities. Motivation and temperament also make their contributions.

[74] [The study is by Sprecher (1959), which was cited in Guilford's bibliography.]

[75] In collaboration with Dr. Myron S. Allen of the Department of Physics of Long Beach College.

[76] [These rules were subsequently published; see Schuster (1963).]

[77] [Zwicky's name is spelled "Swicky" in the original text, as it also appeared in the *Atlantic Monthly*, 1979, p. 74. Zwicky is particularly known for applying this method to discovery in astronomy, his specialty.]

[78] [Reprinted with permission; property of the Robert S. Hartman Institute.]

[79] [From Husserl (1913, paragraph 41). Hartman's source is the translation by W. R. Boyce Gibson, 1931; republished in 2012, New York: Routledge Classics, pp. 76-77. Text omissions are indicated; original emphasis is in italics, Hartman's emphasis underlined. For a more recent translation, see Fred Kersten, 1983, The Hague: Martinus Nijhoff.]

[80] [From Heidegger (1935).]

[81] [Originally published as Maslow (1958). The Stanford Archives version distributed with *Creative Engineering* course materials in 1959 indicates "Presented as a lecture at

the Creative Engineering Seminar, U.S. Army Engineer School, Fort Belvoir, VA, on April 24, 1958" and is missing some phrases. The text and formatting here correspond to the reprint in Parnes and Harding (1962, pp. 93–103).]

[82] [Original text here and elsewhere: "specially."]

[83] [Original text: "anesthesized."]

[84] [The slides presented by McKim during his lecture are not included in the distributed course materials. With McKim's approval, the editor selected illustrations that fit the text and would have been available in 1959.]

[85] [The original text referred to the Squibb building, but that building doesn't fit the description and is not by Yamasaki. McKim's slide almost certainly showed the Michigan State Medical Society Headquarters.]