DESIGN PROCESS AND CREATIVITY

BY

Prof. B. Roth

of Stanford University

UNIVERSITY OF THE NEGEV
MECHANICAL ENGINEERING DEPARTMENT
BEER-SHEVA, ISRAEL

אוניברסיטת הנגב
המחלקה להנדסת מכונות
באר־שבע

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PREFACE

These notes comprise a series of lectures to be used with Engineering students interested in design process and creativity. They were prepared in the Spring of 1973 by Professor Bernard Roth who was visiting at the University of the Negev, Beer-sheva, Department of Mechanical Engineering. The notes rely on available materials in the Engineering School Library at Beer-sheva and materials developed over the years at Stanford University. As far as possible precise references are given to books available at the Library in Beer-sheva. The lecture notes are proceeded by a suggested programme of lectures and assignments.

The major point behind these notes, and the type of activity that they tend to promote is basically one of *process*. In this it differs from the more usual mode of education, whose major emphasis is on a "body of knowledge". Naturally both process and "body of knowledge" are important ingredients for an Engineer. Unfortunately, most education deals only with knowledge and completely ignores process. It is hoped that these notes will in some small way help those interested in dealing with process, to give it a stronger place in the curriculum. Closely related to the idea of process is the notion of "experiential" education. The basic idea here is to let the student go through a series of guided experiences as opposed to the passive educational mode of copying material from the blackboard. It is therefore, important to try and use these notes in conjunction with projects and assignments where a student must go out and do things for himself. It is also useful to have him draw from his everyday experience and bring it into the classroom, thereby integrating his life and learning as much as possible.

Bernard Roth
Professor of Mechanical Engineering
Beer Sheva, June 1973

PROPOSED SCHEDULE OF LECTURES AND ASSIGNMENTS ON

DESIGN PROCESS AND CREATIVITY

Lecture

First hour-From beginning up to (not including) feasibility study.

Reading Assignment

Read: Chapters on design process in one of the recommended books.

Problem Assignment

Give the need statements that would lead to the following solutions as the best possible ones.

Solutions: Edsel cars, Israel Steel Industry, V.W. cars and Uzi.

Give at least ten need statements for each of these and hand them in next time.

Lecture

Second hour - From feasibility study up to (not including) creativity

Reading Assignment

Read: Chapters on: Feasibility, Preliminary and detail design in one of the recommended books.

Problem Assignment

Give the student a complaint and require that he work on the problem and hand in next time:

1. Problem statement
2. Feasibility study
3. Preliminary design

An example of such a problem is the Astronaut-string problem given at the end of the preliminary design section of the notes.

The student is to hand in sketches and written material.

Lecture

Third hour. - From beginning up to (but not including) creative process.

Reading Assignment

Read: Chapter on creativity in one of the texts.

Problem Assignment

Hand in assignment on Bug List and Product List as described in notes under list making.

Lecture

Fourth hour - From creative process to end.

Reading Assignment

Read: Material on sexless connector design case.* (ECL 1A, 1B, 1C)

Problem Assignment

Hand in your designs.

Lecture

Fifth hour - Review creative process and discuss case.

Reading Assignment

Read: First part of case. Come into class with modified designs and be prepared to discuss case.

*This case is from Stanford design library. Other possible cases are in E pp. 230-4, D ch. 3, W pp. 17, 18, 34, AL p. 70-3.

DESIGN PROCESS

Definition

Engineering design is a specialized process of problem solving (although it has its own peculiarities because of technological patterns). It basically follows the process of problem solving in general.

[W ch. 1,2]

Characteristic

The nature of Engineering Design is that there is generally *no one right answer*. Normally many possible designs may be conceived and it is difficult to determine which will be most suitable. Even hindsight often does not answer the question: which design is best?

Examples

I. Problem in Space Travel: Land a man on the moon and return him safely to earth.

Possible Solutions:

1. Multistage rocket directly from earth to moon and return.
2. Create an earth-orbiting space station first, then launch to the moon and return to earth from this station.
3. Multistage rocket fired directly to lunar orbit. Launch a moon-vehicle from a lunar-orbiting satellite, return to lunar orbitor and thence to earth.
4. Variations of the above and others.

II. Problem in Automatic Washing Machine: Contain a spinning wash tub within a cabinet without unusual noise or vibration.

[AL pp. 3,4]

Possible Solutions:

1. Mount the tub on a "swing" of steel cables and restrain it with friction damping materials.
2. Support the tub from a fixed center point and restrain the motion with springs and friction damping.
3. Hang the tub on flexible steel rods and restrain it with damping.
4. Swing the tub from a mid-point and restrain the motion with springs and damping.

All of these are presently being used. Which one most economically restrains a spinning tub while taking up the smallest space and not causing unusual noise and vibration? No one seems to know.

Premature Closure

Too often engineers move rapidly from the problem statement to a specific solution; too late they find a better solution. However, most successful engineers spend a considerable portion of time developing understanding of the problem and generating alternative approaches. It is important to avoid what we term "premature closure"; this is best accomplished by using a plan for carrying out design work. This plan is called *the design process*. It is a series of steps through which the design passes before it is completed. *By making this a conscious process, the engineer can greatly improve his chances of arriving at a better solution.*
[AL p.4]

Morphology of Design

The basic steps in the design process are:

- Need Analysis and Problem Statement
- Preliminary Design
- Detailed Design
- Production
- Distribution
- Consumption
- Retirement

The general flow is from top to bottom of this list. However design is an iterative process and ideas developed at a "lower" stage may reflect backup causing a change in the results of a previous step, which in turn causes changes up and down the ladder. All steps affect all other steps, and each mostly in some degree enter at all stages.

The first four of the above steps will now be described in detail. It is with these elements that this course will be most directly concerned.
[B pp. 4-49, AS ch. 3, E pp. 22-9]

Need Analysis and Problem Statement

The starting point of a design project is a hypothetical need which has been, or is imagined to be, observed currently on the socio-economic scene. "Needs" come in various forms. Some examples of how needs are identified are:

1. Hunches or untested observations
2. Market and consumer studies
3. Customer requests

No matter how a need is identified, its economic reality must be such that individuals, institutions or society will recognize the need and be willing to pay the price for its satisfaction.
The importance of establishing a need is that otherwise a technical success can be achieved while the project itself is a financial failure.
[W ch. 3, AS ch. 2,8]

Examples of technical successes:

with no need: "White Elephants" e.g. Edsel cars
Israel Steel Industry

with need : V.W.
Uzi
University of the Negev in Beer Sheva

Problem for Students

Consider each of the above examples and write down what the problem statement was that led to this particular solution. It is important to note that there are many different problem statements possible for each item. See if you can understand that *too specific a problem statement can limit the possible solutions to too great a degree.*

For example, the problem statement which led to the solution 'University of the Negev in Beer Sheva'may have been:

-Israel needs more trained engineers
(How many solutions can you think of for this problem statement? Is the University of the Negev the "best" solution?)

-The Negev needs an institution of higher learning
(as above; how about its location?)

- The city of Beer Sheva wishes to grow quickly
(as above)

-The professors at Haifa need second jobs in order to make ends meet
(as above)

-etc.

Notice that all of the above lead to the solution'University of the Negev at Beer Sheva'. But they all also have many other solutions. It is important to keep a needs statement as broad as possible and in that way not to unnecessarily limit your possible solutions. Note that some of the above are much more limiting than others.

Example :

I need to get married has as a preliminary design solution some of the opposite sex. But if the real need is *I need to be taken care of,* the following additional solutions are possible: mother, army, "friend" of either sex, housekeeper, patron, navy, prison, hospital, and so on.

Problem statements are extremely useful in Engineering Design (as well as in life). It is important when they are given to you by others (such as supervisors) to make sure you are *getting the need in its most general form and not in a form which in fact already specifies a solution which has been quickly served upon. It is most important to prevent the consideration (consciously or subconsciously) of possible solutions from taking place before the problem statement is formulated and well understood.*

[E p. 24]

5005

Feasibility Study

After the problem has been studied and formulated to an extent that the engineer believes the problem is defined, the feasibility study begins. (Because of the iterative nature of the design process, the engineer may return many times to the problem statement and modify it and his subsequent feasibility study.) This study consists of:

The synthesis of possible solutions and the checking in a preliminary way to determine if the solutions are 1) physically reliable 2) economically worthwhile 3) financially feasible.

Synthesis of solutions is the step which most characterizes the project as a design undertaking. This is the step that most of all requires creative, inventive effort. It is called synthesis because it almost always involves combinations of known principles, materials or components. The most widely accepted approaches for generating solutions will be discussed later under the heading of Creativity. You will learn then that in general it is best to first generate as many solutions as possible and then later to evaluate them.

Let us assume that we have generated a set of logically plausible solutions. It is then necessary to review each of these for:

physical realizability Could the major elements of the concept be combined as visualized to effect the solution? Is it in accordance with natural principles? Does the existing technology contain all the elements of the solution?

economic worth - Is it of sufficient value to repay the effort and investment?

financial feasibility - Are there enough resources available to carry out this project?

The set of potentially useful solutions are those which meet all three of these tests to within a sufficient level of confidence. These and only these are the feasible solutions!

[W ch. 4,6, 7; AS ch. 4]

Preliminary Design

The purpose of the preliminary design phase is to determine which of the feasible solutions is the best. In this phase, an evaluation of each idea is carried far enough to give a basis on which to judge which idea is the best to carry onto the next phase.

This is perhaps the most difficult phase because there may be little information to base judgements upon. It is often in this step that much engineering analysis is first applied. Also inexpensive mockups and tests are not uncommon.

[W ch. 9, AS ch. 5, B pp. 450-2]

Example

Problem statement: Some means is needed to move small aircraft around (on the ground) by airport personnel.

Feasibility:

Synthesis of possible solutions gives a list:

Push
Pull
Lift
Hands
Machines
Animals
People
Cables
Bars
Wheels and jacks
Air films
Cushions
Hooks
Cranes

etc.

After combining all these and elaborating the following three, we judged feasible (i.e. they passed the physical, economical and financial test):

1. Tow bars by hand
2. A motor driven hand cart with a wheel driving the nose wheel of the plane by friction
3. An inflatable air cushion on a dolly which is pulled by hand

Preliminary Design

Can use "rough" calculations to determine if in:

1. is man strong enough?
2. is cart capable of pushing plane; if so what hp. is required?
3. what air pressure would the "bag" need? How long would it take to fill?

What other questions should we ask ourselves before we decide on one of these?

Student Problem

Astronauts reported that using strings to restrain binoculars, light meters, and cameras cause serious tangles. One astronaut reported, "I accidentally bumped an untied small container of film and it floated out of sight behind the instrument panel." Carry this problem through the Problem Statement, Feasibility Study, and Preliminary Design steps. Do not forget to consider lift-off and re-entry. (The student can be given copies of the photos on pp. 384-6 of Engineering Design by Woodson. In which case they should be told the spacecraft is a two-man Gemini.)

[W p. 17 (prob. A)]

Detailed Design

At this step, the engineer starts to develop the chosen solution in detail. It is important to keep in mind that any change in problem definition uncovered at this stage should also be accompanied by a reevaluation of the entire design process to be sure the present solution is still the best.

It is usually at this stage that large amounts of resources are committed. The actual work entails *the design first of the main subsystems and the analysis of their cumulative effects.* Then the design of all component parts is carried out. It is in this part that all outstanding detailed questions must be answered. All materials, dimensions and tolerances must be selected. All purchased parts must be specified, and the manufacturing process must be decided upon. The final phase of this step involves checking every detail, every component and every subsystem. Testing may be necessary to verify calculations or discover unsuspected consequences.

Although the remaining steps of the design process are equally important as those we have discussed, we will, because of the press of time and the emphasis of this course, stop at this point. Our next topic will be the subject of creativity.

Creativity, like the problem solving process, enters into many aspects of our daily lives. In the following lectures, we will try to give you several of the so-called creativity techniques which are considered generally useful in the design process. These techniques can be applied at every step of the design process. They are especially invaluable for the generation of alternative solutions as needed in the Feasibility Study part of the process.

[AS ch. 6, B pp. 453-6]

CREATIVITY

Definition

There are many definitions of creativity. For our purposes, we will define it to be a mental process that can aid in the recognition of a problem, and can motivate the person to formulate an imaginative solution, which is both valuable and innovative.

[B pp. 391-400]

Who is Creative ?

Creativity is usually associated with genius or at least some "spark of genius". This is not the actual situation. *All persons of normal intelligence possess some ability to think creatively and to engage themselves in imaginative and innovative efforts.* Unfortunately, the average person's creative ability has been steadily diminished since childhood; this is a result of social pressures against individuality and lack of exercise of the creative faculties in daily life. There are standard techniques and basic principles for stimulating innovative and creative thinking. Many industrial firms in the United States and elsewhere use these techniques for improving the creative abilities of their engineers. (It is interesting to note that studies have shown that over 70% of the most creative people , in a group of students, do not rank in the upper 20% of their class on traditional I.Q. measures.)

Now let us outline some of the factors that influence creative behavior. This will be followed by an outline of certain creativity expanding exercises.

Motivation

The engineer must be motivated to use imaginative and innovative thought. Most creative people derive a feeling of pleasure, exhilaration, satisfaction and pride from completing a creative task. Motivations, however, usually consist of the need for: food and preservation, faith, love, aspiration for fame or freedom, competition, pride and loyalty.

Conditions that Stimulate Creativity

The following are generally considered attributes associated with creative individuals. Developing them will enhance the likelihood of creative expression.

Intellectual curiosity
Sensitivity to recognize that a problem exists
Acute powers of observation
Directed imagination
Initiative
Ability to think in analogies and images
Originality
Intuition
Memory
Verbally articulate
Ability to analyze and synthesize
Patience, determination and persistence
Intellectual integrity
Understanding the creative process

[B ,pp. 400-1]

Conditions that Depress Creative Thinking

Many people are not creative because of so-called "road blocks" to creative behaviour. If these are recognized in time, they can be counter-acted and continually guarded against. Later we will give some techniques useful in this activity of *conceptual blockbusting*.

In this discussion, we are concerned primarily with conceptualizing *new ideas* (i.e., problem-solving). A conceptual block is a "mental wall" that blocks the problem-solver from correctly perceiving a problem or conceiving its solution. Although the primary cause of conceptual blocking is *mental inflexibility*, many specific kinds of blockage have been identified. Here is a list of conceptual blocks; it is by no means exhaustive:

1. PERCEPTUAL BLOCKS occur when problem is first perceived. Examples are:
   a. Difficulty in isolating the problem
   b. Tendency to delimit the problem area too closely
   c. Inability to view problem from various viewpoints
   d. Seeing what you expect to see; stereotyped seeing; premature labelling
   e. Saturation
   f. Failure to utilize all sensory inputs

2. EMOTIONAL BLOCKS color and limit how we see, and how we think about a problem. Examples are:
   a. Lack of challenge; problem fails to engage our interest
   b. Excessive zeal; overmotivation to succeed quickly; can only see one direction to go (ours)
   c. Fear of making a mistake, of failing, of risking
   d. Inability to tolerate ambiguity; overriding desire for security, order; "no appetite for chaos"
   e. Prefer to judge ideas rather than to generate them
   f. Cannot relax, incubate, "sleep on it"

3. CULTURAL BLOCKS are acquired by exposure to a given set of cultural patterns. Examples in this culure are:

   a. Fantasy and reflection are waste of time, lazy --even crazy
   b. Playfulness is for children only
   c. Reason, logic, numbers, utility, practicality are good ; feeling, intuition, qualitative judgments, pleasure are bad
   d. Tradition is preferable to change
   e. Any problem can be solved by scientific thinking and lots of money
   f. Taboos

4. IMAGINATION BLOCKS interfere with the freedom with which we explore and manipulate ideas. Examples are:

   a. Fear of unconscious
   b. Lack of access to areas of imagination (inhibitive block)
   c. Lack of imaginative control (compulsive block -- e.g., incessant worrying)
   d. Inability to distinguish reality from fantasy

5. ENVIRONMENTAL BLOCKS are imposed by our immediate social and physical environment. Examples are:

   a. Lack of cooperation and trust amongst colleagues
   b. Autocratic boss who only values his own ideas; does not reward others
   c. Insecurity in job
   d. Distractions -- phone, easy intrusions
   e. Lack of support to bring ideas into action

6. INTELLECTUAL BLOCKS occur when information is incorrectly collected, formulated or processed. Examples are:

   a. Lack of information, incorrect information
   b. Inflexible or inadequate use of intellectual problem-solving strategies
   c. Formulating problem in incorrect language (e.g., verbal, math, visual)

7. EXPRESSIVE BLOCKS restrict conceptualization at the final stage of idea-expression. Examples are:

   a. Inadequate language skill to express idea (verbally, visually, musically, etc.)
   b. Slowness in expression; can't record ideas quickly enough

[B pp. 401-6]

We will now expand upon and illustrate some aspects of this list.

Perceptual blocks inhibit the creative process because they deprive one of information that should be available.

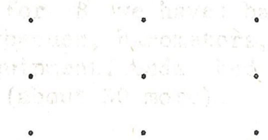
a. Difficulty in isolating the "real" problem

Example: A recent snow storm closed the roads to Jerusalem. To avoid this, more snow removal equipment will be purchased. Many people believe that the *problem was not the snow but the driver training*. Foreigners report driving in much worse conditions without such difficulty. *It is possible that even if all the snow were removed the slush left on the wet roads would still cause them to be closed.*

[B p. 401]

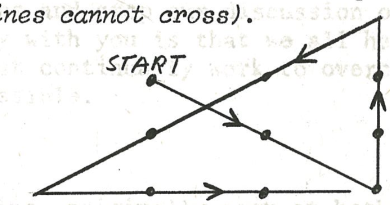
b. Tendency to delimit problem too closely

Example: Draw four continuous straight line segments so that they pass through each of the nine dots of the square matrix. You must not pass through any dot more than once, nor retrace any line, nor lift pencil from paper.



(Pause here for about 5 minutes and let students try it.)

The solution is "simple" if one realizes that there is no restriction that the lines must stay within the physical bounds of the matrix *(some people wrongly assume that the lines cannot cross).*



c. Stereotyped seeing and premature labelling

Example: Describe yourself with a single label (I am a professor.) How many additional labels can you collect? (father, bad tennis player, lover of buses, ...) This should bring home to you the limits of premature labelling. *A tragic example of stereotyped seeing and premature labelling is given by the Lybian Airliner incident. The French and Lybians saw MIG's because they "knew" they were over Egypt. The Israelis saw "spying" because it was Lybian.*

d. Saturation

Example: Draw a phone dial showing all details including position of numbers, holes and other parts. (Do this without looking at one.)
The inability to do this correctly indicates saturation.

e. Failure to utilize all sensory inputs

Example: If we turn out all the lights in a windowless lecture hall, do we become aware of new things? Try it and see.

List Making

One good technique for *overcoming perceptual blocks is list making.* By striving for a long list which lists attributes and has great diversity, it is possible to ensure a wealth of information to work from.

Example:

Many people have at one time or another thought it would be nice to invent a product and become a millionaire. It is very unusual for a simple and elegant idea to follow such a vague desire. There are two ways to begin that have been used extensively by successful inventors. They are the formation of the *Bug List* and the *Products List*. Assuming you have the desire to invent something, write lists as follows:

Assignment

1. Write down a large number of specific things (at least 100) that "bug" you, i.e., things that could be improved or should or should not be. "The world" is too general. "My neighbor's child crying" is just right.

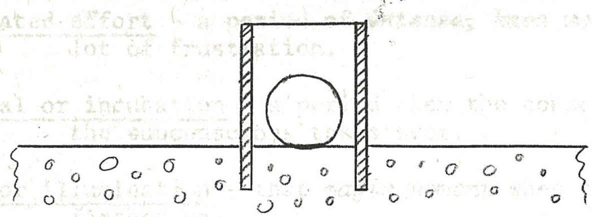
2. Write down all the products you can think of that begin with C. As an example for B we have: baby carriages, bags, baker's equipment, barbecues, barometers, bathroom accessories, bathtubs, beauty shop equipment, beds, bed pans, beverage dispensors and vendors, etc. (about 50 more).

The idea is to write everything that comes to mind on the list without filtering or making value judgments.

The other blocks on this long list can similarly be illustrated by simple experiments. In order not to belabor the point, let us just try two short questions and stop our discussion of blocks after that. The point to take away with you is that we all have blocks of one type or another and we must continually work to overcome them if we wish to be as creative as possible.

Example 1:

A steel pipe, originally open at both ends, is imbedded in the concrete floor of a bare room. The inside diameter of the pipe is 0.06 inches larger than the diameter (1.50") of the ping-pong ball resting gently on the floor at the bottom of the pipe. You are one of six people in the bare room; among you you have the following objects: 100 feet of clothesline, a carpenter's hammer, a chisel, a box of cornflakes, a file, a wire coat hanger, a monkey wrench, a lightbulb. List all the ways you can think of to get the ball out of the pipe. Please do not ask me any questions about this - just work with the given information and problem statement. Here is a diagram of the actual situation:



(after 5 minutes) Okay, let us see what we have come up with. Let us put the complete list on the blackboard. Someone please give me one method, etc...... Okay, are there any more? ......

Now that we have a "complete" list, do any of these trigger new ideas in you? Most important is the realization that probably the reason you did not think of one or the other idea is because of some block, not any lack of intelligence. For example, those who did not list urinating into the pipe might have done so because of the cultural block we listed under 3F, i.e. Taboos. This taboo may have prevented you from either listing it and/or saying it - one thing is for sure, it would not be due to 7a, inadequate language skills.

Example 2:

You have a supply of white bricks of standard size. List all of the uses you can think of for these bricks. (Please do not ask me any questions, just work with the given statement.) (after 5 minutes) Same as above.

Here the cultural taboos may again have entered if you did not think of using these bricks to break windows, or knock people out with. If you had fewer ideas than most, you should increase your fluency - it is good to have as many ideas as possible. The unworkable or silly ones can always be disregarded. Get loose!

Creative Process

So far, we have tried to make two major points:

1. Everyone can be creative.
2. Everyone has some blocks that limit him.

In creative work, as in design, there is a process which is generally followed, consciously by some, unconsciously by most. We will list this process and explain the steps briefly.

[B pp. 319-26]

Preparation
Concentrated effort ("perspiration")
Withdrawal (incubation)
Insight (illumination)
Follow-through

[E p. 99, D p. 26]

As in the the design process, this is not a unidirectional, top-to-bottom type of process. Iteration is again a characteristic.

Preparation- formulating the problem and *gathering the information* and skills needed to work on a solution.

Concentrated effort - a period of *intense, hard work*, usually with a lot of frustration.

Withdrawal or incubation - a period when the conscious *work stops* and the subconscious takes over.

Insight or illumination - that *magic moment* when the "lightbulb" flashes on.

Follow-through - the creative process is nothing if one does not *follow through* on the idea.

It follows then that the creative process requires knowledge, hard work, relaxation, luck and motivation.

There are many famous stories of the magic moment of insight coming during moments of idle thought. However, this illumination *always* has been preceeded by preparation and concentrated effort.

We will now discuss several techniques that are recommended for use in the concentrated effort phase. These all have names and are referred to individually although combinations are in fact desireable.

Set-Breaking
Brainstorming
Inversion
Analogy
Empathy
Fantasy
Synectics
Check lists
Attribute listings
Morphological list (systematic search matrix)

[B pp. 408-16, AL ch. 3, E pp. 103-10, D pp.29-36]

Set-Breaking

Set is a word used by psychologists to mean a predisposition to a particular method or way of thought in solving a problem. "Being in a rut" connotes set. To become aware of set it is good to put yourself through a set-breaking experience on each problem. Basically, this means forcing yourself to let go of conventional patterns. One way to do this is to imagine that you are in some new environment - say another planet - in which the physical laws are altered. For example, if you have to design a new vacuum cleaner, the set-breaking approach might be to first assume you are designing such a device for a planet with no gravity , populated by a blind, armless population. In this way, conventional solutions and truisms could not be used. When you return to the real world problem, you may have lost some of your set.

[D pp. 28-9]

Brainstorming

This technique helps remove obstacles to creativity caused by fear of criticism or fear of appearing foolish or dumb. It can be done by an individual or in a group. The basic goal is to generate as many ideas as possible and to avoid any judgment as to good, bad, practical, silly, far-out, ridiculous, fantastic, excellent, etc. The rules of the game are:

1. Someone keeps a record of *all* the ideas (for all to see)
2. NO CRITICISM OR JUDGMENT (good or bad) is allowed.
3. Generate as many ideas as possible - SAY THE FIRST THING THAT COMES INTO YOUR HEAD.
4. THINK WILD - far-out ideas are wanted.

After an extensive list has been generated with one idea giving rise to another, the brainstorming session is over. If properly done, everyone is exhausted. Evaluation and further elaboration takes place at some later date. (For sample brainstorming sessions, see B ch. 3 and AL pp. 44-9.)

[B pp. 30-1, E p. 103, AL pp. 43-8, B pp. 412-4]

Inversion

This is another set-breaking technique. Basically, it calls for looking at the problem from a new angle. An example of this is the engineer who found the solution for getting the walnut meat out of the shell by drilling a hole in the shell and using air pressure. This solution was found by inversion. All the original ideas of getting the meat out of the shell had failed; so he inverted and got the shell out of the meat. [D pp. 31-2]

One way to consciously break a set is by a check list. The following has been proposed by the psychologist, A.F. Osborn:

1.	Put to other uses?	New ways to use as is? Other uses if modified?
2.	Adapt?	What else is like this? What other ideas does this suggest? Does past offer parallel? What could I copy? Whom could I emulate?
3.	Modify?	New twist? Change meaning, color motion, sound, odor, form, shape? Other changes?
4.	Magnify?	What to add? More time? Greater frequency? Stronger? Higher? Longer? Extra value? Plus ingredient? Duplicate? Multiply? Exaggerate?
5.	Minify?	What to subtract? Smaller? Condensed? Miniature? Lower? Shorter? Lighter? Omit? Streamline? Split-up? Understate?
6.	Substitute?	Who else instead? What else instead? Other ingredient? Other material? Other process? Other power? Other place? Other approach? Other tone of voice?
7.	Rearrange?	Interchange components? Other pattern? Other layout? Other sequence? Transpose cause and effect? Change pace? Change schedule?
8.	Reverse?	Transpose positive and negative? How about opposites? Turn it backwards? Turn it upside down? Reverse roles? Change shoes? Turn tables? Turn other cheek?
9.	Combine?	How about a blend, an alloy, an assortment, an ensemble? Combine units? Combine purposes? Combine appeal? Combine ideas?

[E p. 106]

Analogy

This method uses analogous situations in other problems to stimulate new ideas. Analogies may come from other engineering solutions, or from nature, or even from literature or other non-technical areas.

Examples: Tunnel digging machines use the same principle as worms.
The heart with its valves gives the idea for a pump.
The first automobiles were built like horse-drawn carriages without the horse.

This can be done individually or in groups. (See D ch. 3 for more involved examples.)

[D pp. 32-3, AL p. 42]

Empathy

The idea here is to identify personally with the thing, part, or process being devised. The object is to "become" the part, to see from its position what it might do. It is a very useful technique, but requires some willingness to do playacting (and for some, the overcoming of inhibitions).

Examples: In the walnut-meat-removal design problem, empathy would involve considering yourself the meat and wanting to somehow rid yourself of the shell, or considering yourself the shell.

In the design of an airplane shock absorber, it might involve imagining yourself first the wheel, then the airplane body, then the shock absorber system, and so on.

This technique can be done individually or in groups.

[D pp. 33-4]

Fantasy

This is closely related to empathy, but here you just let yourself go into a sort of directed daydream. You forget about the rules of nature and just let your mind go in any direction your imagination takes you. This can be done individually or in groups.

Example: A four man design team assigned the problem of designing an instrument to remove tissue samples from a human liver, used a group fantasy to generate design solutions. One man imagined he was the liver, another the vein leading to the liver, the third a cutting tool and the fourth the catheder which was put into the vein and carried the cutting tool. They closed themselves off in a dark environment and closed their eyes, each playing his part and telling what he imagined was happening. (Clearly this is an example of combining empathy and fantasy.) Other examples can be found in D. ch. 3.

[D p. 34]

Synectics (W.J.J. Gordon, Synectics, Harper and Row, New York, 1961)

This is a name given to a guided group type of creativity session using six or seven carefully selected experts. A typical group would involve a physicist, an electromechanical engineer, an anthropologist, a graphic artist, and a sculptor. The group is usually led by an expert on problem solving.

The method goes something like this. Suppose the problem is to find a new way to park automobiles in a crowded city. Only the chairman knows this. He suggests that the group discuss "storing things". The discussion would probably start with what storing means. This would lead to desireable features for storing. Next, the discussion might move to how things are stored in the home, nature, or industry. Next, someone might mention how bees store their honey. (This might be a solution to the problem.) Slowly, the chairman adds more constraints until he reaches the point at which he feels the group is close to the best solution. At this stage, he reveals the exact nature of the problem. Sessions last about three hours.

[E pp. 104-5, B pp. 414-5]

Check Lists

General listings are useful during early development phases to avoid the ommission of important features and to suggest possible improvements. One type of check list relates to the particular product development, and new ideas are added as they occur for later use. A typical check list contains the following information:

1. Significant physical conditions such as size, weight, shape, state, color, finish, pressure, temperature, vibration, shock acceleration, noise, radiation, etc.
2. Variations in functional aspects, materials, production processes, applications, packaging, etc.
3. Attributes and unusual characteristics of shape, finish details, package, energy sources, appearance, feel, fashions, maintenance features, assembly methods, etc.
4. Important social aspects, such as timing, human compatability, degree of complexity, service ability, cost, production potential, effect on living conditions, etc.
5. Also, possible rearrangements, recombinations, modifications, and elimination of excessive details and features.

There are many other types of check lists, including the one given under the section on Inversion (Osborn's), and the bugs list and product lists you developed as a homework assignment. The basic idea is to list everything you can possibly think of and find out, and then to check your work against the list to make sure that you have taken "everything" into account, and to let your mind be inspired by new associations.

[E pp. 105-7, B p. 409]

Attribute Listings

This involves the listing of attributes of various objects, or the specifications or limitations of certain need areas. By then changing, or modifying one or more of the attributes or specifications, originally unrelated objects can be brought together to form a new combination that better satisfies the need.

Example: Consider the old-fashioned wooden-handled screw driver. Its attributes 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

All these attributes have been changed in recent times to improve the screw driver:

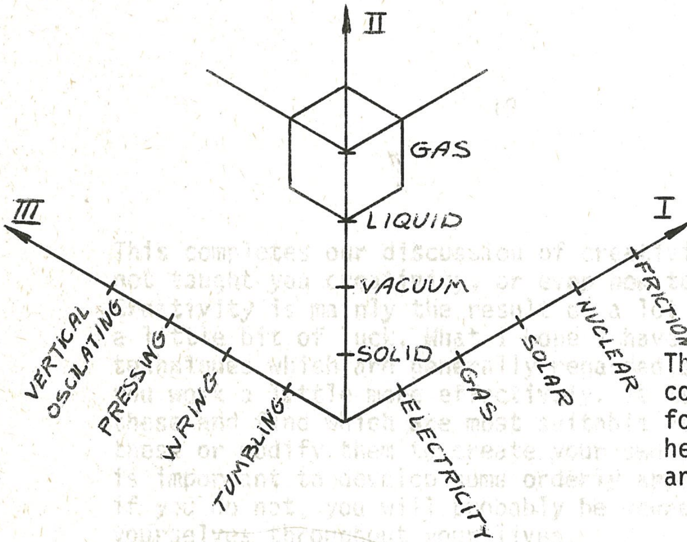
round shank - hex shank (wrench can be used to increase torque)
wooden handle- molded plastic handle (decreasing chances of breakage and of electric shock)
wedge shape - various shapes (for different types of heads)
manual power - electric and pneumatic
twisting action - pushing action with "Yankee" type driver

Morphological Analysis

Morphological analysis is a generalization of attribute listings and check lists. The method is one of: a) breaking the problem into two or more important dimensions based on the required functions of the system or component to be designed; b) "brainstorming" each dimension to compile as long a list as possible of ways of meeting this dimension; c) placing the lists in a kind of matrix with each dimension orthogonal; d) forming every combination possible and evaluating feasibility.

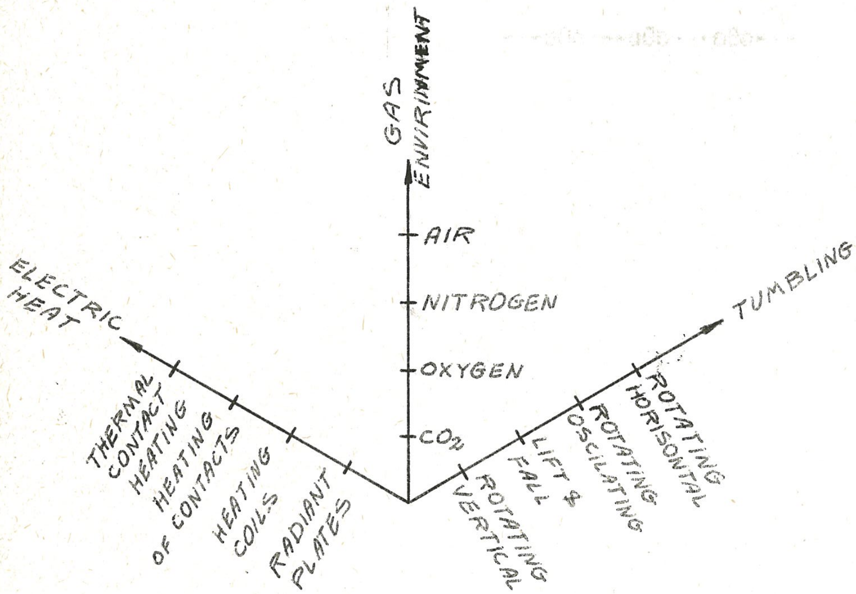
Example: Develop an improved means for drying clothes. We chose as bases:

I. Source of heat
II. Environment around clothes
III. Drying mechanism



This gives us many combinations, for example using nuclear heatsource in a vacuum and pressing.

The more feasible combinations can then be further expanded. For example the electric tumbler drying in a gas environment gives us :



Hence morphological analysis is a method for providing a large variety of design concepts starting from a few basic ideas for major functions. This is a highly recommended technique.

[AL pp. 39-41, D pp.34-4, B pp.409-12]

This completes our discussion of creativity. Certainly I have not taught you creativity, or even how to be creative. Creativity is mainly the result of a lot of very hard work and a little bit of luck. What I hope I have given you are some techniques which are generally regarded as useful and which can help you work a little more effectively. It is best to practice these and to find which are most suitable for you. You can adapt these or modify them to create your own variant. However, it is important to develop some orderly approach to problem solving. If you do not, you will probably be unnecessarily handicapping yourselves throughout your lives.

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REFERENCES

References for lecture notes are based on books on the Design Process and Creativity found in the Engineering Library at Beer Sheva.

Symbol	Title and Author	Library Call Number
AL	Creative Synthesis in Design J.R.M. Alger and C.V. Hays	620 ALG
AS	Introduction to Design M. Asimow	620 ASI
B	Engineering Beakley and Leach	620 BEA
D	Design Engineering J.R. Dixon	620 DIX
E	Introduction to Creative Design D.H. Edel, Jr.	620.04 EDE
W	Introduction to Engineering Design T.T. Woodson	620.04 WOO