ME349
Engineering Design Projects

Creative Problem Solving

Confront the Problem

Is it a real problem? Or is it one imposed through some ad-hoc agent, and that can, if treated appropriately, vanish.

For example, you are working on the design of a building's HVAC system, and you are told what flow rate of air is expected in a particular area of the building. Your preliminary calculations indicate that ductwork would need to be so massive as to require a redesign of the walls of the rooms. You trace the flow rate requirement back to a particular client representative who had ventured the value of the flow rate only as a guess, but somehow it became embedded as a hard requirement. After consultation, it is determined that the flow rate requirement can be relaxed.

Change the Source of the Problem

Sometimes the source of the problem can be altered to either eliminate the problem or direct it to another part of the product where it can more easily be treated.

For example, you are designing the structural elements of a forklift. The loads to the structure near the lifting motors are very high; designing for them will require large, heavy components that will raise the center of gravity (perhaps to a dangerous point), and interfere with the operation of the forklift. The problem is not that stresses are too high in your components, but that the load is being directed at your components. Can the geometry of the forklift be altered to give loads a path to the axles (they inevitably end up there, right?) and that avoids the components with which you are concerned?

Isolate the Problem

Can the effects of the problem be isolated to particular systems or subsystems of a product, thereby allowing designers to focus their attention on it and not having to involve every designer on the project?

You are designing a pumping facility for volatile chemicals. Electric motors are used as components, but are found to be generating too much heat and there is a risk of explosion as a result. The motors could be insulated thermally but this introduces two new problems.
First, the motors could overheat. Second, the design is more complex now, as a result of introducing the insulation, which leads to a (slightly) higher probability of failure.

Alternatively, can the design be changed so that the electric motors are kept distant from sources of volatile chemicals? This isolates the source of the heat without necessarily introducing greatly complexity, and still allows for simple venting of heat to the environment.

Invert the Problem

Inversion is a classic technique to solve design problems. There are many examples of this.

Two good ones are a butcher's meat saw, and a computer printer.

<u>Butcher's Meat Saw</u>

In attempting to cut meat, common problems exist which do not for many other cutting processes. Consider a simple handsaw for wood. In operation, the wood is held still, and the saw is moved across it to cut the wood. When cutting meat, the consistency of the meat can make holding it difficult and the motion of cutting less efficient.

In a butcher's meat saw, the meat is held on a tray and passed by a fast-spinning, but stationary, rotary saw. In comparison, the handsaw moves through the wood which remains stationary; whereas for the meat saw, the meat moves while the blade remains stationary.

We have inverted the problem in the meat saw by requiring the meat to move against the blade rather than having the blade move through it (as with the handsaw).

Why is this done? What are the problems that we are dealing with by inversion? The answer is the problems of quality, control, and productivity. They're all coupled in this and many other design problems.

<u>Computer Printer</u>

The original computer printer was a typewriter, with a mechanism attached to it that would strike keys on actuation by the computer. The problem was that the mechanism was working so fast to keep up with the output from the computer, that the inertia of the typewriter keys themselves made the hammers strike one-another and get stuck. Additionally, the carriage, which carried the paper, could not perform a ``carriage return'' quickly enough to match the speed with which the computer was operated.

In this case, inversion was applied by utilizing small, light print heads (a concept originated by the IBM Selectric Typewriter) that have little inertia, and that can be made to move across the paper very quickly. The carriage no longer does carriage returns; it's the print head that provides this function. The problem was inverted by making that which moved stationary, and that which was stationary move.

Heavy Vehicle Brakes

A long time ago, brakes for trucks and other heavy vehicles were normally released and pressing the brake pedal engaged them. This is obvious and intuitive and is how brakes function on automobiles and light duty trucks. However, there was a problem: when the brakes failed, the vehicles would lose control. For a very large heavy vehicle, this had potential for catastrophic results.

The solution was to invert the problem. In modern braking systems, the brakes are engaged unless the engine is running and all pressure sensors indicate nominal operation. In this case, when the vehicle is operating normally, the brakes are forced to release by a hydraulic or pneumatic mechanism. If there is a failure of the braking system, then the brakes will automatically engage, stopping the vehicle.

In this case, the inversion is functional. The function of the old braking system was to be released unless engaged by the driver; the function of the new braking system is to be engaged unless released by the driver (in combination with the brake sensors).

Divide the Problem

This is the classic ``divide and conquer'' technique. A problem that seems difficult can sometimes be handled by breaking it into a series of sub-problems, such that the solutions of those sub-problems can then be put together to solve the original, difficult problem.

Examples of this abound even in everyday life. The trick to this approach is that many people divide the problem badly. For example, a robotics company divides the design of a new robotic manipulator into segments based on the classical engineering disciplines: mechanical, electrical, controls, etc. This is not a good way to divide the problem since: in the final product all these segments are very strongly coupled, but the coupling will be difficult to manage because the engineers are divided along the lines of coupling rather than along the lines of operation/function.

Divide and conquer works best when the division is made in terms of the kinds of product function. For a robotic manipulator, three sub-teams could be developed: one for the end-effector, one for the base/mounting/shoulder areas, and one for the upper- and forearm sections of the manipulator. Each team would have a mechanical engineer, a controls person, a manufacturing specialist, etc. to make sure that at every point of the process, all the possible engineering issues are treated.

This is, however, not a hazard-free solution either. Consider the design of the Sikorsky S-92 Helibus. Sikorsky is a world leader in helicopter engineering. The S-92 is the result of a global collaborative engineering effort. While such international efforts are the way of the future (for various reasons), there is also danger of making the kinds of mistakes that would have never happened if a single co-located company had engineered it.

The S-92 cockpit, fuselage, and tail sections are each made by different engineering companies. There is wiring that runs from the cockpit all the way to the tail (through the fuselage). The designers of the cockpit and the tail spent a lot of time making sure that the wiring that started at one end would reach the other. But they forgot to mention this to the fuselage designers, who quite naturally omitted the passageways, ducts, trays, and conduits to let the wiring get from the cockpit to the tail. This resulted in cost overruns as the fuselage section had to be re-designed once the error was caught.

The engineers involved were so concerned about the ends of the wiring (which are arguably the most important parts of it) that they forgot all about the middle: the wiring itself. Wiring, after all, serves the very important function of transmitting signals from one point to another. The connectors at the ends of the wires might seem important to engineers concerned with the behavior of the wire (its response to stimuli from the operating environment), but they forgot to consider its function (how it achieves the behavior).

This is a good example of how function modeling could have been useful. Had a computer model of the wiring (including a model of the functions of wiring) been available to the engineers, then we can imagine that some AI-based consistency checker would have been able to determine that the fuselage did not provide the passages needed to let the wiring reach both ends of the helicopter.

Designing by Analogy

Reasoning by analogy is a powerful tool to stimulate creativity in design.

An analogy is defined in the Merriam-Webster online dictionary as:

1) inference that if two or more things agree with one another in some respects they will probably agree in others.
2) resemblance in some particulars between things otherwise unlike; b: comparison based on such resemblance.
3) correspondence between the members of pairs or sets of linguistic forms that serves as a basis for the creation of another form.
4) correspondence in function between anatomical parts of different structure and origin.

Two important points are that:

- the correspondence may be functional, structural, or otherwise
- one can reason by inductive inference about predicted similarities between entities, based on observed similarities.

Here are some examples of famous discoveries/inventions that resulted from analogical reasoning.

Lord Kelvin developed the mirror galvanometer from noticing sunlight reflecting from his monocle.
The engineer Sir Marc Isambard Brunel invented the caisson from observing ships worms tunneling through wood.
Benjamin Franklin invented the lightning rod from observing that pointed rods discharged Leyden jars when in proximity to them.
An anonymous naval officer who invented the take-off ramp on early aircraft carriers after seeing a water-ski jumper (these ramps are still in use for ships supporting the Harrier "jump jets.")
The inventor of Velcro developed his idea from a direct analogy to plant burrs.

Successfully reasoning by analogy requires two kinds of knowledge: a deep knowledge of the design problem, and a deep knowledge of many other kinds of engineered artifacts from/to which one may analogize.

This implies that it is very important to take the time to study and reason about a design problem before starting to think about solutions. Also, it's very important to have as broad an experience base as possible.

The best designers will constantly revisit the problem as they attempt to solve it, not only for verification purposes, but to reinforce their understanding of the problem to promote analogical thinking. The best designers also tend to be well traveled and well read, having worked in many different areas; this broadens their experience base and facilitates analogical reasoning.

The general principle of reasoning by analogy is to study a problem with the goal of looking for similarities between it and other problems you already know how to solve. Don't limit yourself to thinking only about structure, but think also about function (especially), shape, manufacturability, materials, etc.

As you start to think of analogies to the problem, list the solutions to the problems that you've identified. Once you have a few of these, revisit each solution and try to borrow concepts that may apply to the problem you have to solve.

There is a branch of philosophy concerned with this kind of reasoning, called synectics; a fair amount of information on this topic is available online. (try Google find out more).

Designing with Product Attributes

As a design begins to take shape, functionally if not structurally, it begins to acquire attributes, or characteristics that make the design unique. Sometimes, by reasoning about the attributes, one can make headway towards a complete design. Each attribute of a design usually implies certain properties or behaviors of the product. Think about the properties that the attributes imply, and try to find ways to use those properties to improve the design.

For example, the dollies used to deliver beverages to passengers on European trains used to have a large coffee maker built into them. The tank for hot water was near the top of the dolly. This made the dolly unstable, difficult to steer, difficult to see around, and dangerous. But by observing that the water tank is large and heavy (when full, at least), we can immediately suggest an improved design, wherein the tank is placed low in the dolly. In this case, the attribute of the product is the ability to make coffee, and the properties involved are the size and weight of the water tank.

By placing the tank lower, the center of gravity of the dolly is lowered. This makes the dolly more stable and easy to steer. Also, by eliminating the large-sized tank from the upper part of the dolly, visibility is improved so the dolly operator can see where the dolly is going.

Certain properties of objects are obvious targets for this kind of reasoning. Some of these include:

shape
: If something is square or flat, can it be used as a base for something else? If it's round, can it be rotated for some useful purpose?

weight
: Is something heavy? Can this be used to stabilize the product? How should the weight be distributed to achieve this?

density
: Low density materials make things light. What are the advantages of very light (or very heavy) things?

surface finish
: Roughly finished things tend to have high coefficients of friction. Is that useful?

conduction
: Is electric conduction an advantage or a disadvantage? Can something that is conductive be used safely as a ground?