

# **Developing Creativity and Innovation in Engineering and Science**

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# **TOPICS**

**Creativity and Innovation in Engineering and Science**

**Necessary Conditions for Creativity**

**How to Develop a Good Idea**

**Colleagues**

**The Art of Obsession**

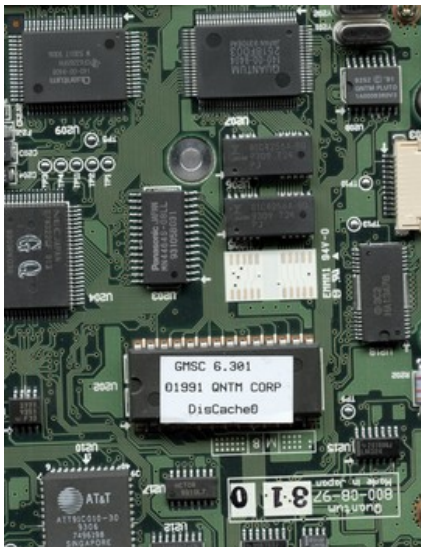
**The Technology You Use**

**Future Technology**

# **Creativity and Innovation in Engineering and Science**

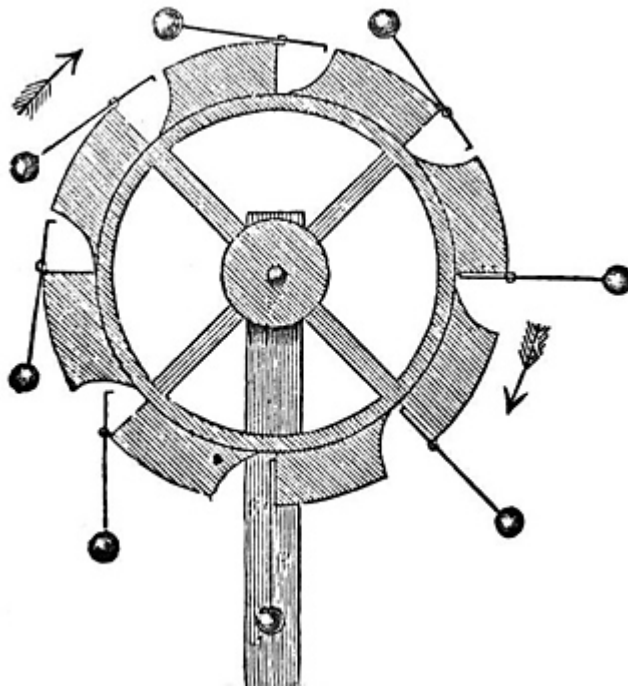
# Creativity

**Creativity is sought everywhere: in the arts, entertainment, business, mathematics, engineering, medicine, the social sciences, and the physical sciences. Common elements of creativity are originality and imagination. Creativity is intertwined with the freedom to design, to invent and to dream. In engineering and science,, however, creativity is useful only if it fits into the realities of the physical world.**



## Example of Constraints on Creativity and Innovation

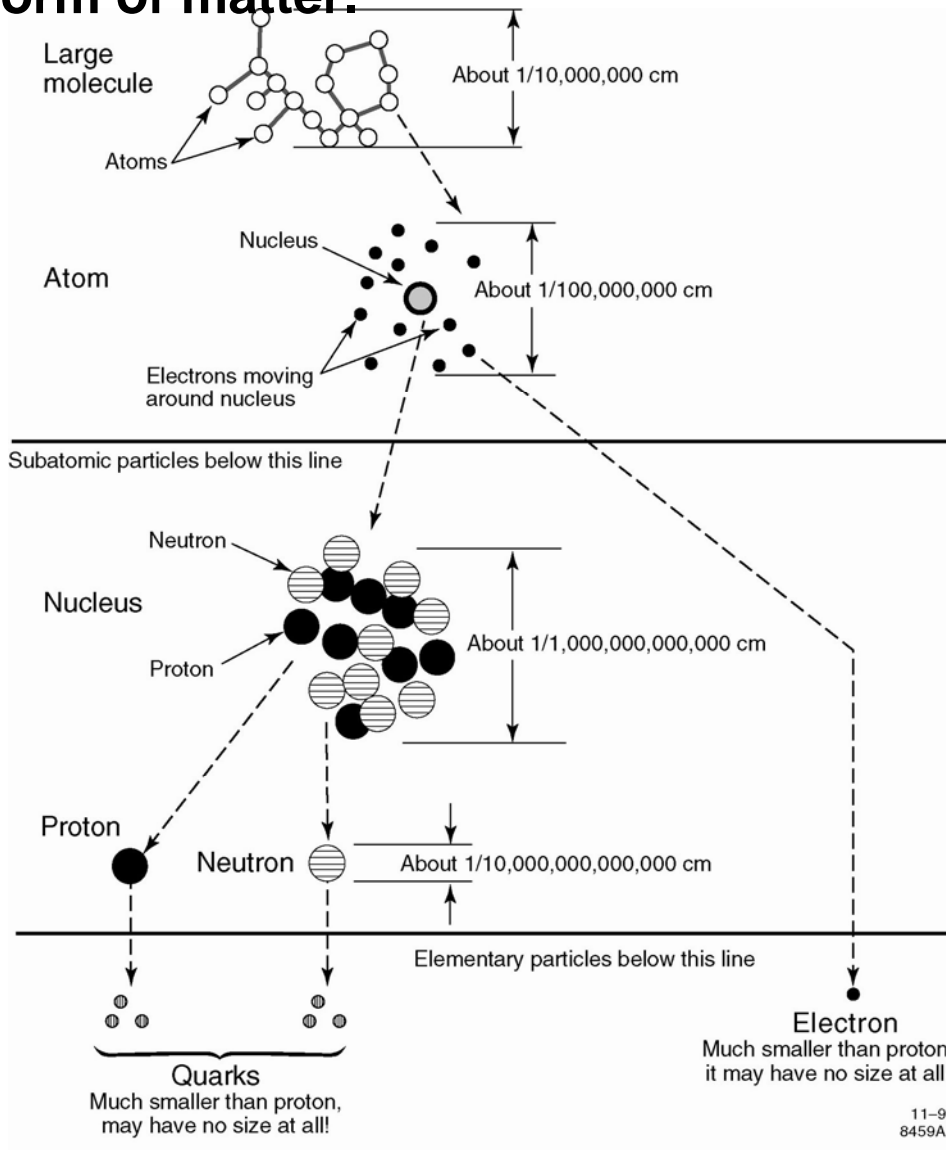
A creative idea in science or engineering must conform to the law of conservation of energy (including the mass energy  $mc^2$ ). An inventor that thinks that she or he knows how to violate the conservation of energy will have to disprove a vast amount of laboratory measurements and accepted theory.



*A perpetual motion machine  
violates the conservation of energy.*

# Another Example of Constraints on Creativity and Innovation

A creative idea in science or engineering must conform to our present knowledge of the nature of matter, unless we invent or find a new form of matter.



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## Observations and Rules of Thumb

If your idea is in an area where the basic science or mathematics is not known, begin by paying attention to the known observations and rules of thumb in that area.

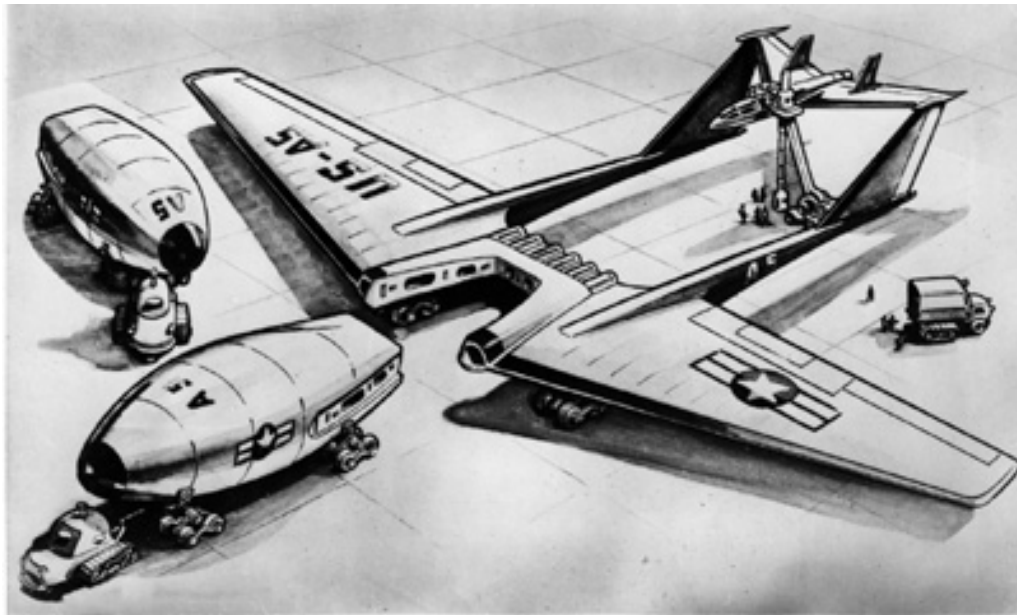
Keep in mind, however, that observations and rules of thumb may be wrong. Remember when doctors thought that ulcers were caused by spicy food and stress? Now we know that most ulcers are bacterial infections.



# Practicality and Feasibility Constraints

Creativity in science, engineering and computer science is constrained by feasibility and practicality.

Consider the work in the US on a nuclear reactor powered airplane in the 1950's.



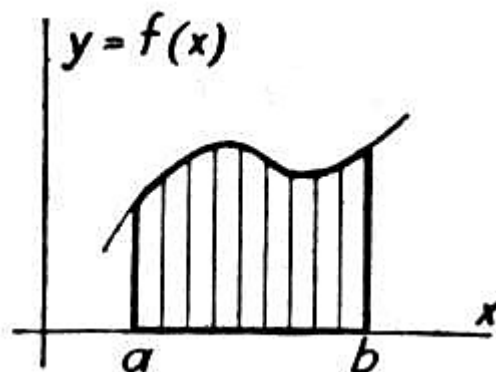
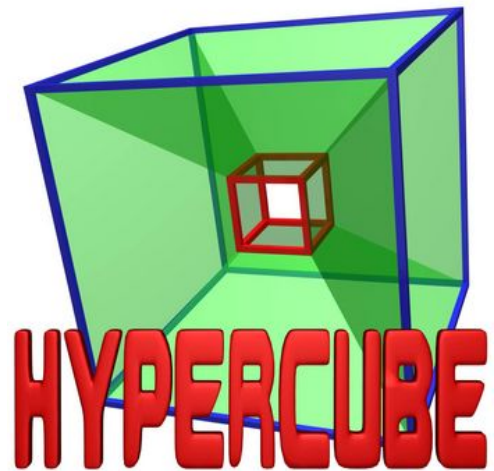
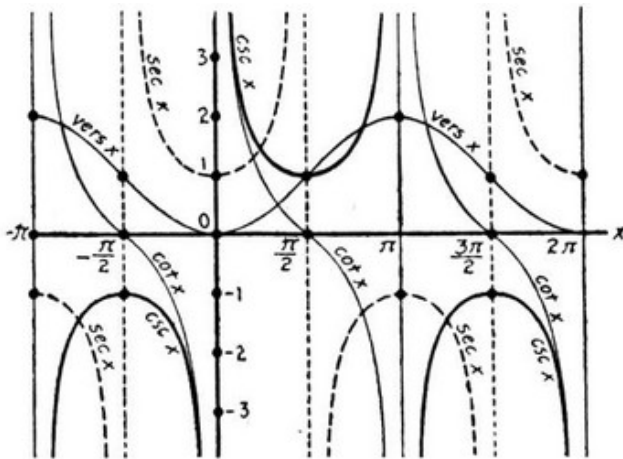
*The airplane was designed to have  
the reactor in the front and the crew in the rear.*



# **Necessary Conditions for Creativity in Engineering and Science**

## *Be Competent in Mathematics*

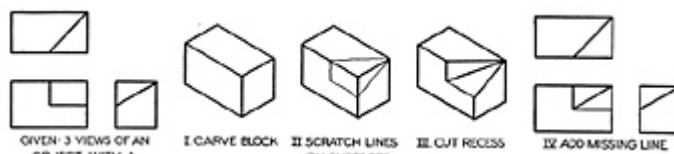
You don't have to be a mathematical genius. There are a lot of fields where mathematics is secondary. Nonetheless, you should be competent in mathematics.



## *Visualization*

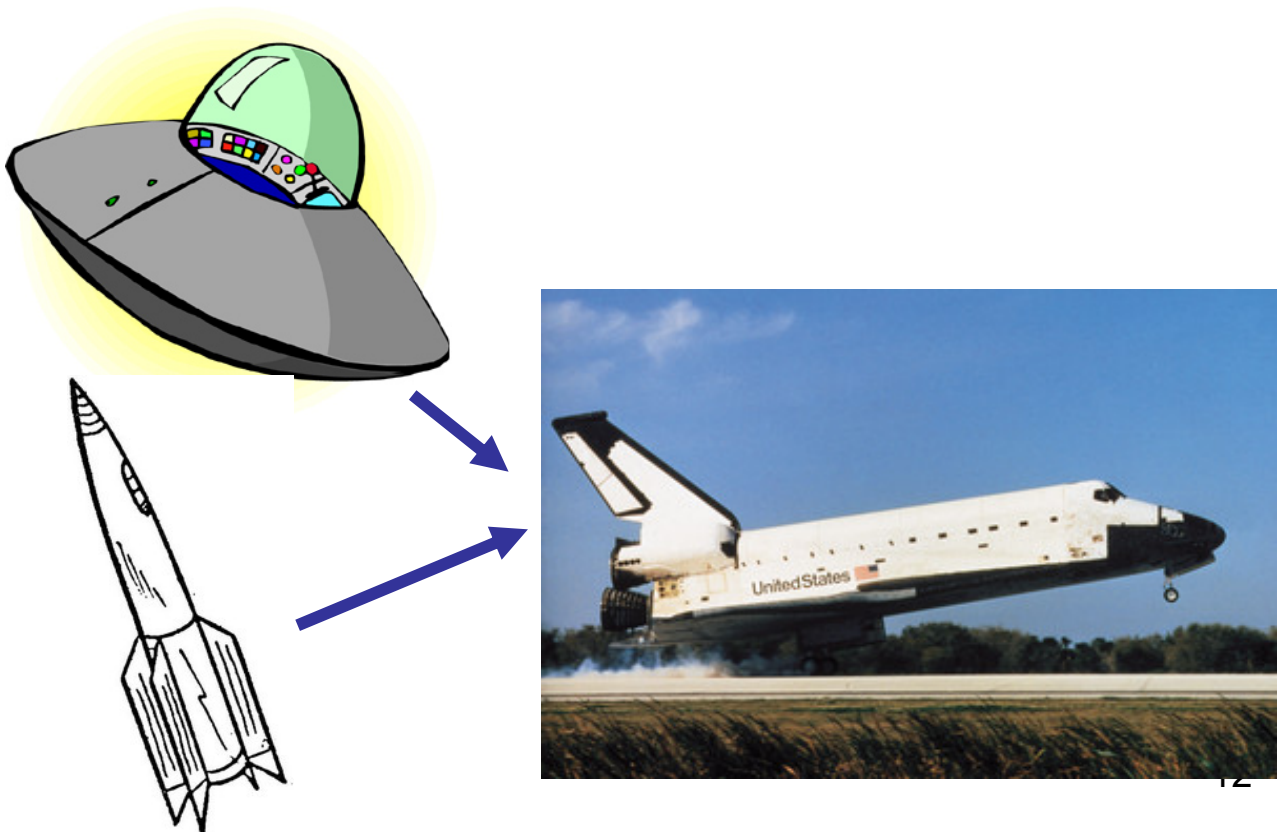
In engineering and scientific work it is crucial to be able to visualize how the work can be accomplished. The intended work might be the invention of a mechanical or electronic device, the synthesis of a complicated molecule, the design of an experiment to evaluate the efficacy of a new drug, or the full modeling of how proteins fold and unfold.

Different kinds of work require different kinds of visualization. Spread sheets or flow charts may work best in some cases. Drawings might be more suitable in others. Whatever the project, the value of visualization is in finding the best way to proceed while avoiding mistakes and perhaps even finding alternative solutions or great related ideas. Do not go into engineering or science if you do not have a basic ability to visualize. Visualization is crucial for creativity in engineering and science!



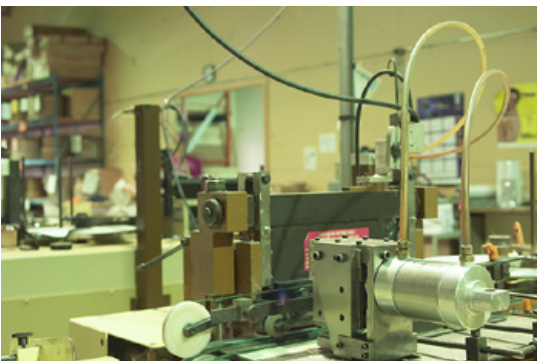
## *Imagination*

**Imagination is another crucial ability required to be creative in engineering and science - imagination with respect for the constraints I have talked about: known physical laws, correct observation and experimentation, feasibility, practicality. Begin with the far reaches of your imagination at the science fiction level, then gradually apply these constraints.**



## ***Evaluate Your Laboratory Skills***

**Evaluate the extent of your hands-on skills and laboratory skills. Are you good at working with tools, at building equipment, at running equipment – electronics, microscopes, telescopes...? This is my strength. I am an experimenter in physics because I like to work on equipment, am mechanically handy and get great pleasure when an experiment works. But hands-on skills do not have to be your strength. Isadore Rabi, my doctoral research supervisor at Columbia University in the 1950's, had no laboratory skills. Yet Rabi won a Nobel Prize for advancing experimental atomic physics. When choosing what to work on in engineering and science, honestly evaluate the extent of your hands-on and laboratory skills.**



# **Getting A Good Idea in Engineering and Science**

# Personality and Temperament

You must take into account your personality and temperament when choosing a technical field, or particular field of science. Be yourself.

Creative scientists and engineers have many different types of personalities



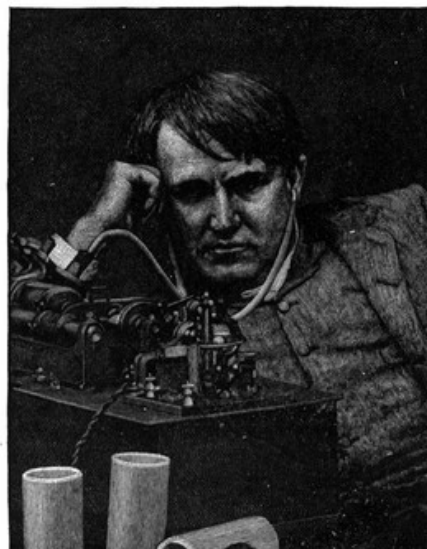
Yang



Yau



Hopper (compiler inventor)



Edison



**Curie**



**Turing**



**Perelman**



**Yalow**



# The Truth about Creativity and Innovation:

For every good idea, expect to have five or ten bad, wrong or useless ideas.



*Phlogiston model of combustion*

*Astrology*

*Lamarckian evolution*

*Homeopathic medicine*

*magnetic ether*

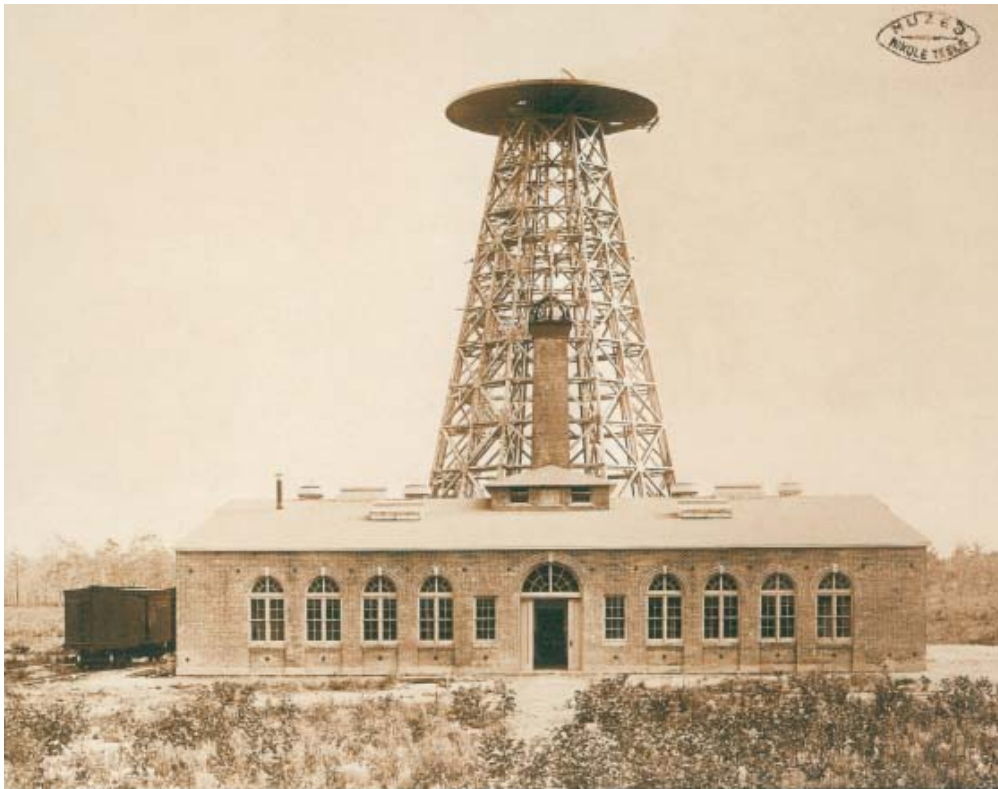
*Electromagnetic ether*

*Steam powered flying automobile*

*Everyone wired automobiles*

*Cold fusion*

# Great Engineers and Scientists Have Bad Ideas As Well As Good Ideas.



**Nikola Tesla was a pioneer in long distance Wireless - a great idea! - but he also thought he could use the same tower to transmit large amounts of low frequency power.**

# Can Creativity and Innovation Skills in Engineering and Science be Taught in the Classroom?

- [J. L. Adams *Conceptual Blockbusters*]

I believe the pressure of reality is important - a product *must* be improved or an experiment *must* work or a more efficient computer algorithm is *needed*.

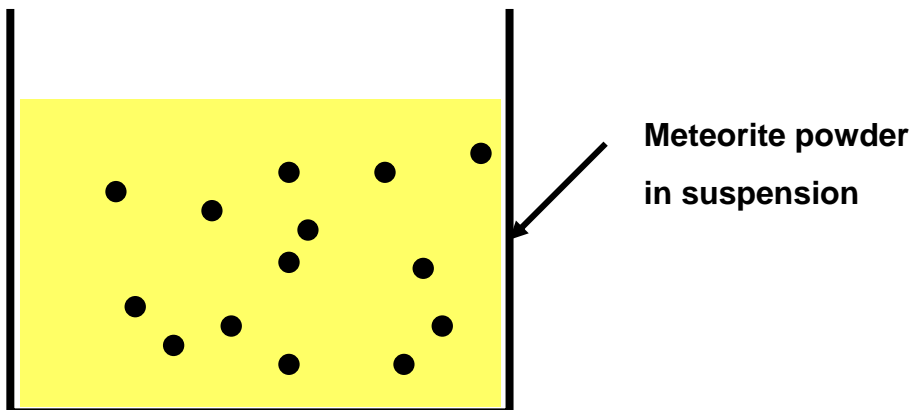


## Helpful Hints:

- Keep Your Eyes and Ears Open.
- Avoid the “not invented here” prejudice.
- Remember, you can learn from many different people.

### My Experience:

Five years ago we wanted to make a colloidal solution of powdered meteorite, My academic friends in colloid science were of little help – we learned how to do it from a lubrication engineer.



## Reduce the Frequency of Bad Ideas:

- Make sure that you understand the physical laws and the neighboring technology relevant to your new idea.
- Colleagues, the literature, and the Web can be of help.
- Sometimes you have to keep going until *you* are the expert on the idea and *you* discover the show-stopper!

For example, be sure Maxwell's Equations are obeyed:

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \quad \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \cdot \mathbf{B} = 0 \quad \nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

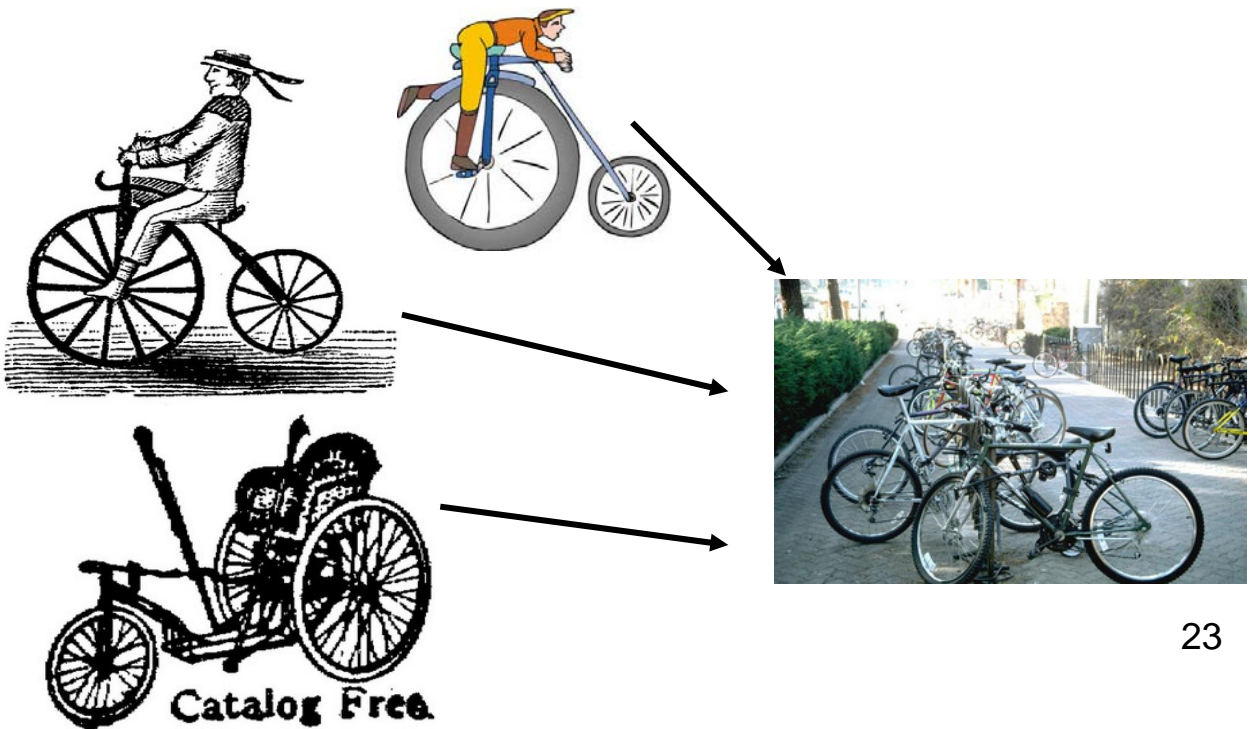
## The Development Process:

**It is rare for the complete development of a good idea to occur quickly. Be prepared for a winding road of research, development and prototyping or for a maze with many wrong turns.**



## Sorting Out Good & Bad Ideas:

You may turn a bad idea into a good idea - don't kill the bad idea prematurely. A bad idea can evolve into a good idea. This evolution into a good idea can be a short process, like turning a bug into a feature, to quote my colleague Eric Lee. Or the evolution from bad to good can be long with many intermediary steps.



# Limit Your Working Hours

**In China and the U.S. there is pressure in engineering and science to work very long hours, a '24/7' work-week. But creativity and innovation require relaxation time and non-technical activities.**





**“The importance of Good Luck  
is overrated in engineering and  
science discovery and  
innovation.”**

- [J.H. Austin, *Chase, Chance, & Creativity*]



***Good Luck***

## It Is Important to Reduce Exposure to Bad Luck

The basic avoidance principle is the same as being careful when crossing a freeway. In engineering and science most bad luck is caused by mistakes in calculation, design, measurements, or in experiments. I have had bad luck -perhaps you have too- by going into a project that didn't smell quite right to me, but I kept hoping for the best...



# Colleagues

# In the Modern World the Highly Productive Lone Engineer, Inventor, or Scientist is Very Rare.



# Find Colleagues Who are Smarter Than You and Know More

I always look for colleagues who are smarter than I am, and who know more than I do. The obvious Advantage is that she or he may be able to solve the problem that has produced a dead end in your work. But more importantly, smart and knowledgeable colleagues can save you a lot of time!



**You Don't Have to be a Fast Thinker or a Fast Talker.**

**In fact, it is Best to Avoid Having Such People as Colleagues.**



# **The Art of Obsession In Computing, Engineering and Science**

# Obsession is Important When You Have a Good Computing, Engineering, or Scientific Idea

When you are imagining and visualizing an idea that you expect to be fruitful it is important to be obsessed with the idea. Think about the idea as much as possible - perhaps even to the extent of neglecting boyfriends, girlfriends, children or spouses. Obsession, or immersing yourself in the problem, will enable you to focus and thoroughly explore all the aspects of the idea: what has been done on related ideas, compatibility with physical laws and mathematics and logic, feasibility, practicality, extensions, variations.





**But, if the course of the work you find that you run out of money, someone else has a better idea, or your idea has a serious flaw - give up the obsession...**



**and move on!**

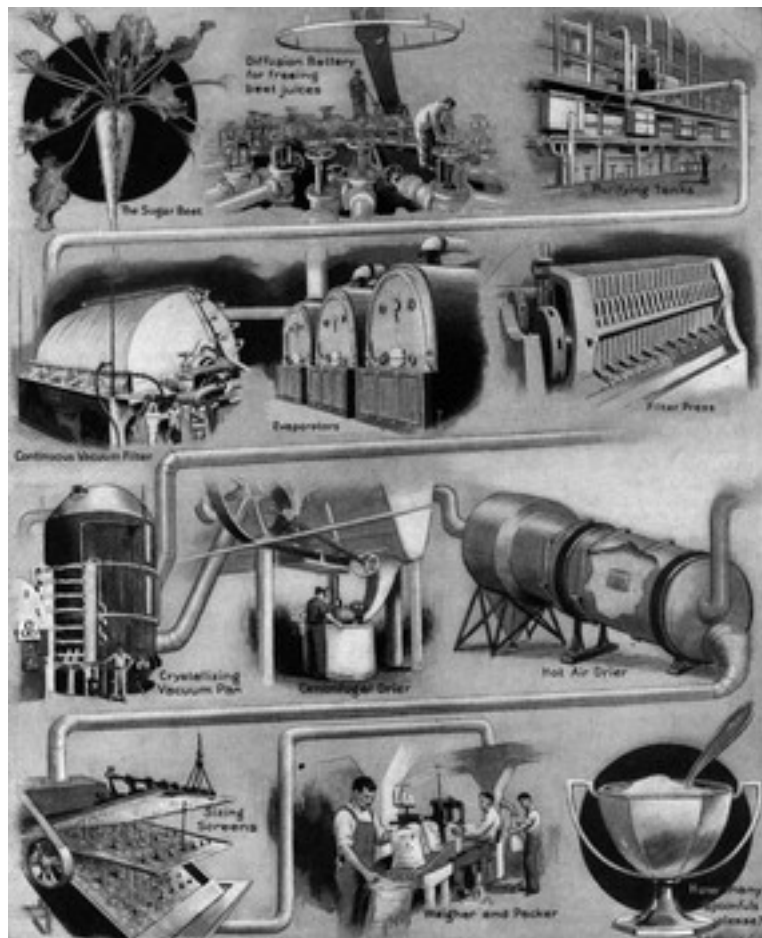


# The Technology You Use

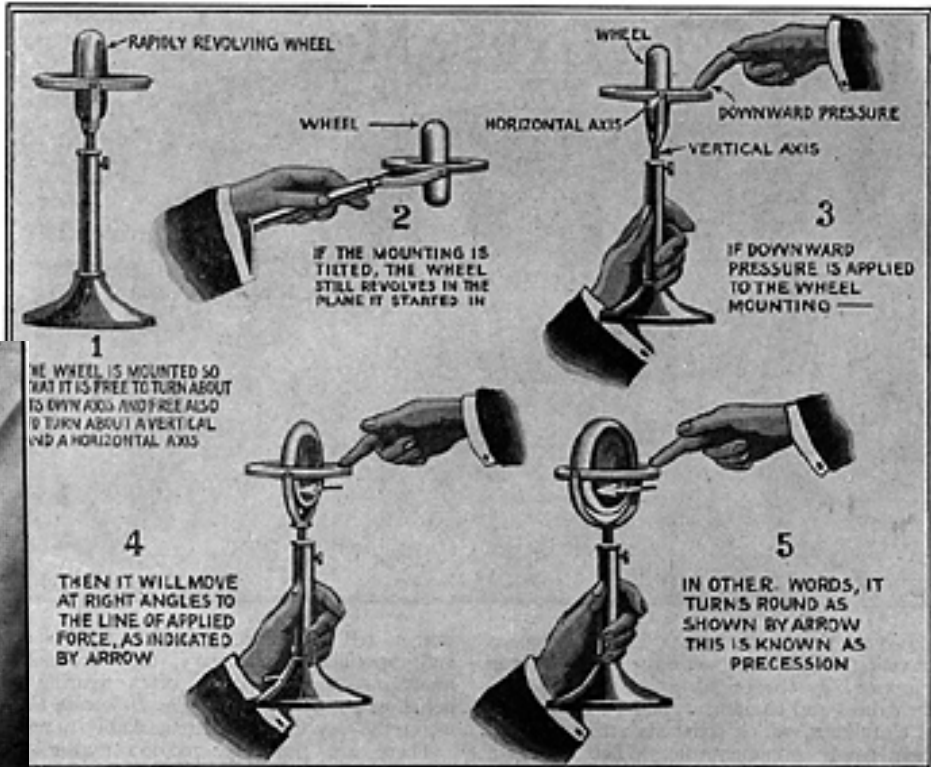
# Technology & You

You must be interested in - perhaps even enchanted by - some of the technology, software, or mathematics you use.

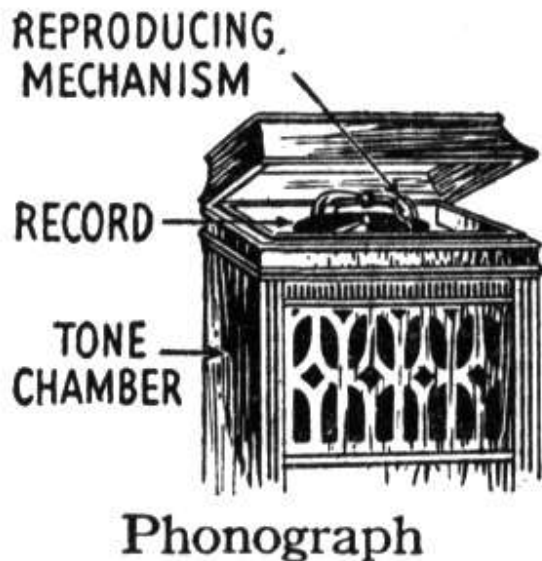
Then the bad days are not so bad.



Another advantage of being enchanted by the technology, programming, or mathematics that you work with is that you will be more likely to think of improvements and variations.

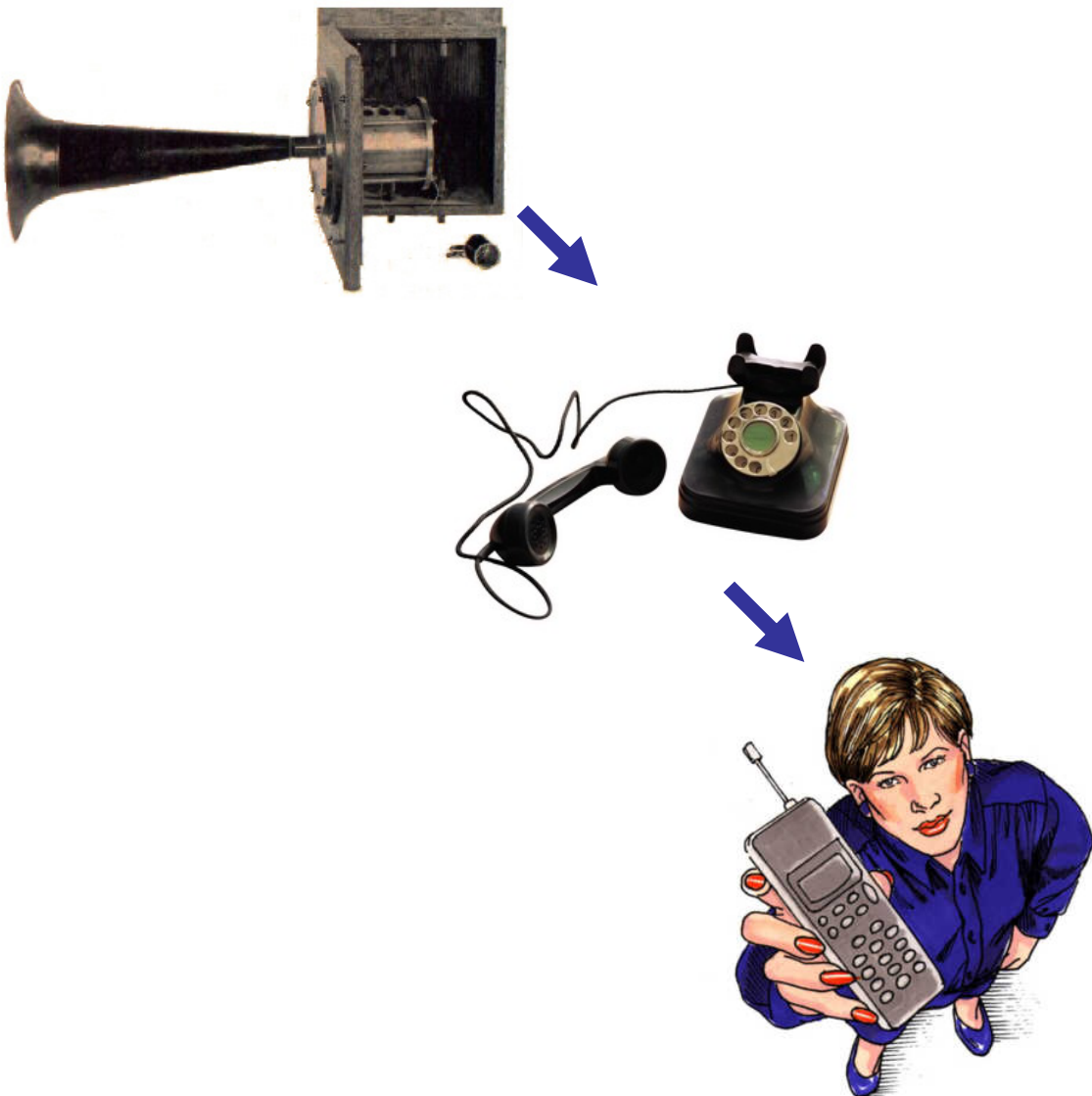


**You should be fond of the technology, mathematics, or programs that you use, but not so much in love that you are blind to the possibility that there may be a better way.**

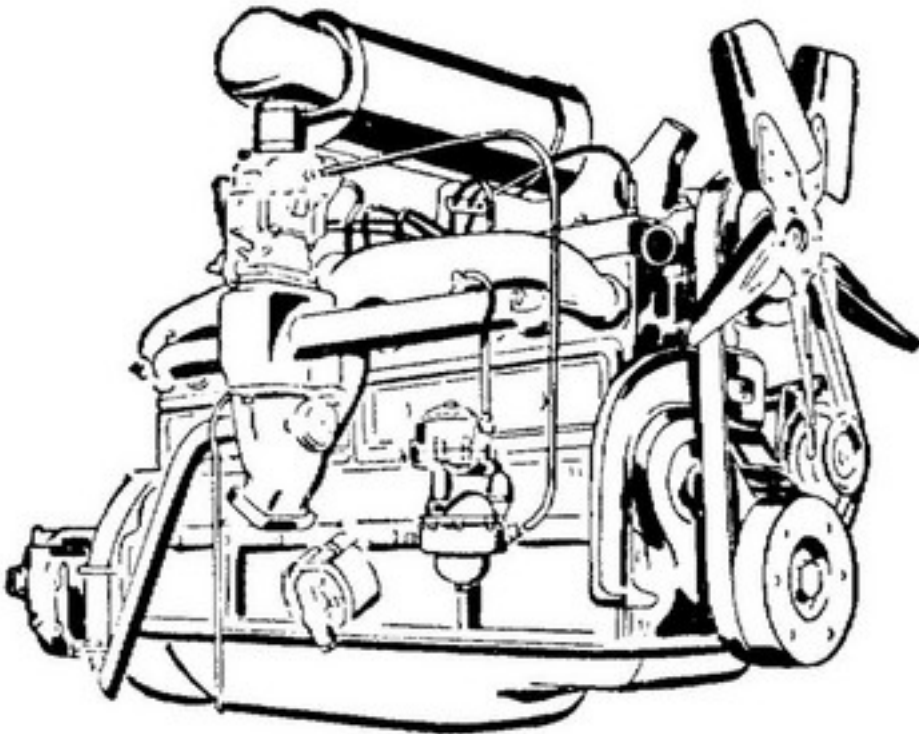


# The Technology of the Future

**It is often impossible to predict the future of a technology. Some technologies are replaced again and again by new technologies serving the same function.**



# Some Technologies Persist through Incremental Improvements.

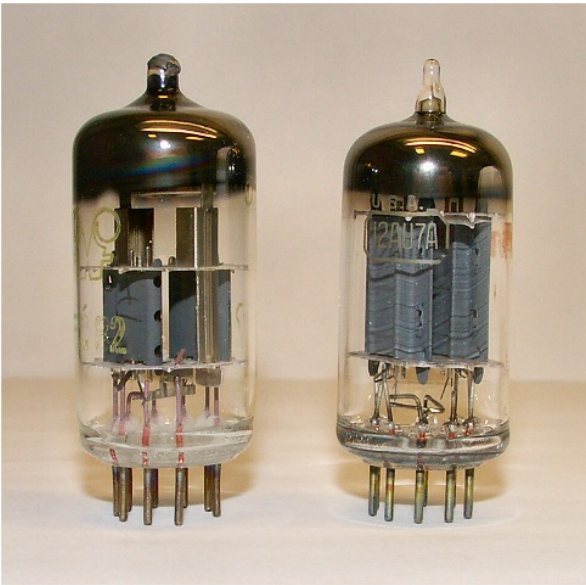


*The reciprocating gasoline engine  
Is 140 years old.*



# Some Promising Technologies Go Nowhere.

For example, my experience in 1950  
with the miniature vacuum tube and  
the transistor...



***Transistor inventors: William Shockley  
(seated), John Bardeen, and Walter  
Brattain, 1948.***

**I am not able to predict future  
technologies.**



Hubble Space Telescope

