# How do scientists really do science?

Presentation to the San Diego Middle School
Science Education Leadership Initiative (MSSELI)

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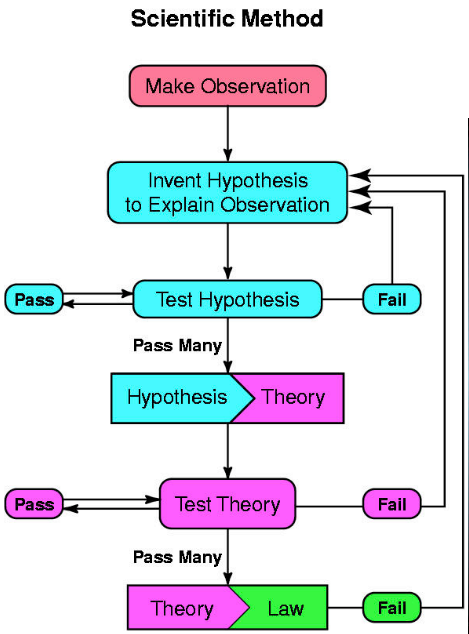
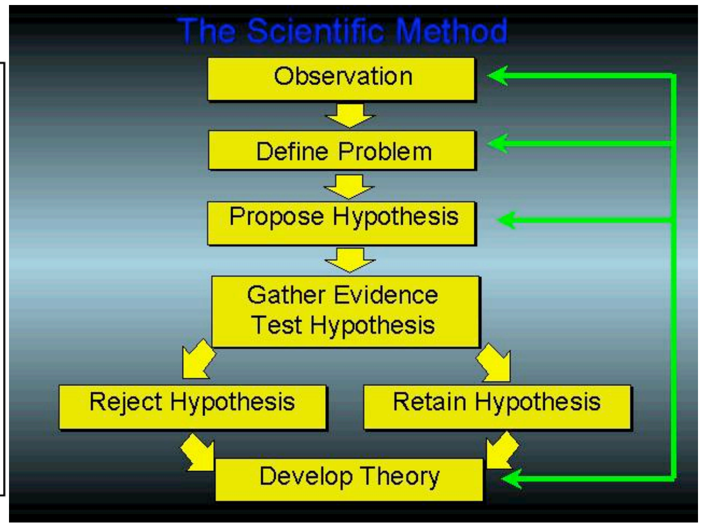
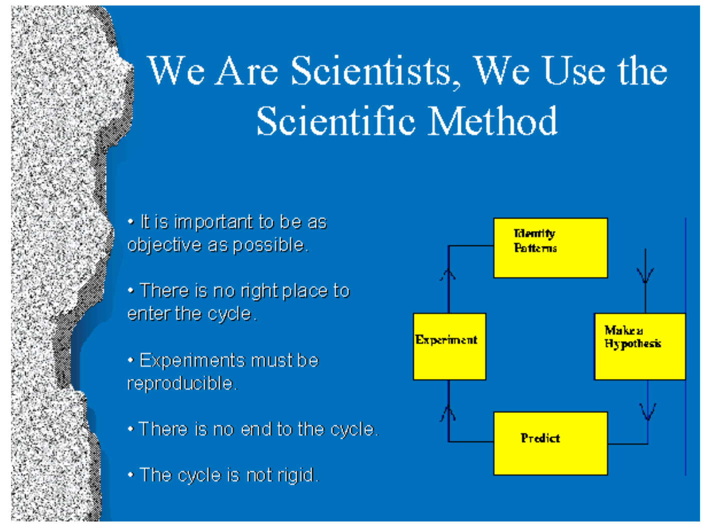
# Standard Mantra: "Scientists follow the scientific method"



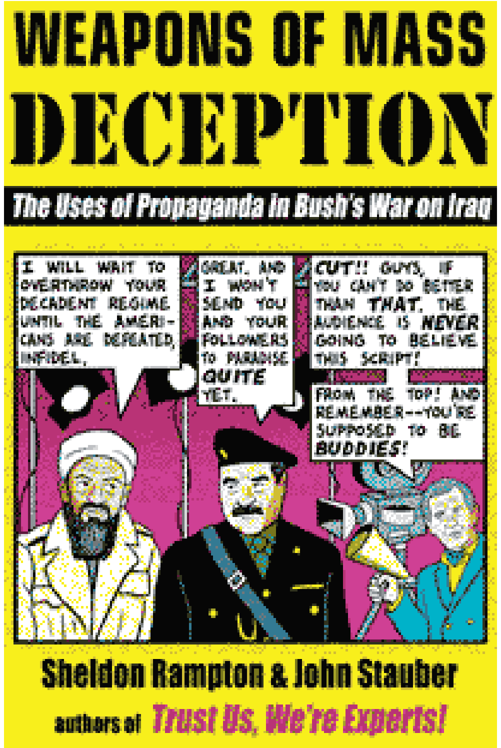




***The only problem with teaching this is that there is no single simple "scientific method"***

***There are a wide variety of ways to do science***

# “Hypotheses” should be banned: they are not part of science

- Scientists don’t make hypotheses (here I mean hypotheses as promoted by science fairs: a guess as to what your experiment will demonstrate)
- They don’t appear in scientific papers
- They are not desirable because they will tend to bias experimental design and analysis (much as the CIA’s bias that Iraq had WMD led to faulty conclusions that Iraq did have WMD)



# NSTA Position Statement

"Although no single universal step-by-step scientific method captures the complexity of doing science, a number of shared values and perspectives characterize a scientific approach to understanding nature. Among these are a demand for naturalistic explanations supported by empirical evidence that are, at least in principle, testable against the natural world. Other shared elements include observations, rational argument, inference, skepticism, peer review and replicability of work."

<http://www.nsta.org/positionstatement&psid=22>

# Similarity between scientists and teachers

| | |
|---|---|
| How do scientists solve problems? Many ways. | How do teachers teach students? Many ways. |
| Scientists have different styles and strengths | Teachers have different styles and strengths |
| May spend entire career in one area or may branch into new areas | May spend entire career teaching one subject or may teach new subjects |
| Constrained by current knowledge, resources | Constrained by standards, district policy, resources, knowledge |
| Common goal: Improved understanding of nature or technology development | Common goal: Improved student learning |

"What appears to [the working scientist] as the essence of the situation is that he is not consciously following any prescribed course of action, but feels complete freedom to utilize any method or device whatever which in the particular situation before him seems likely to yield the correct answer. In his attack on his specific problem ***he suffers no inhibitions of precedent*** or authority, but is completely free to adopt any course that his ingenuity is capable of suggesting to him. No one standing on the outside can predict what the individual scientist will do or what method he will follow. In short, science is what scientists do, and there are as many scientific methods as there are individual scientists."

Percy W. Bridgman – "On Scientific Method"
From: *Reflections of a Physicist, 1955*

<http://hackensackhigh.org/~nelsonb/bridgman.html>

"Feynman was always the inquisitive type; he had to have the facts. To find out what happened to the shuttle, he went straight to the people who put the shuttle together."

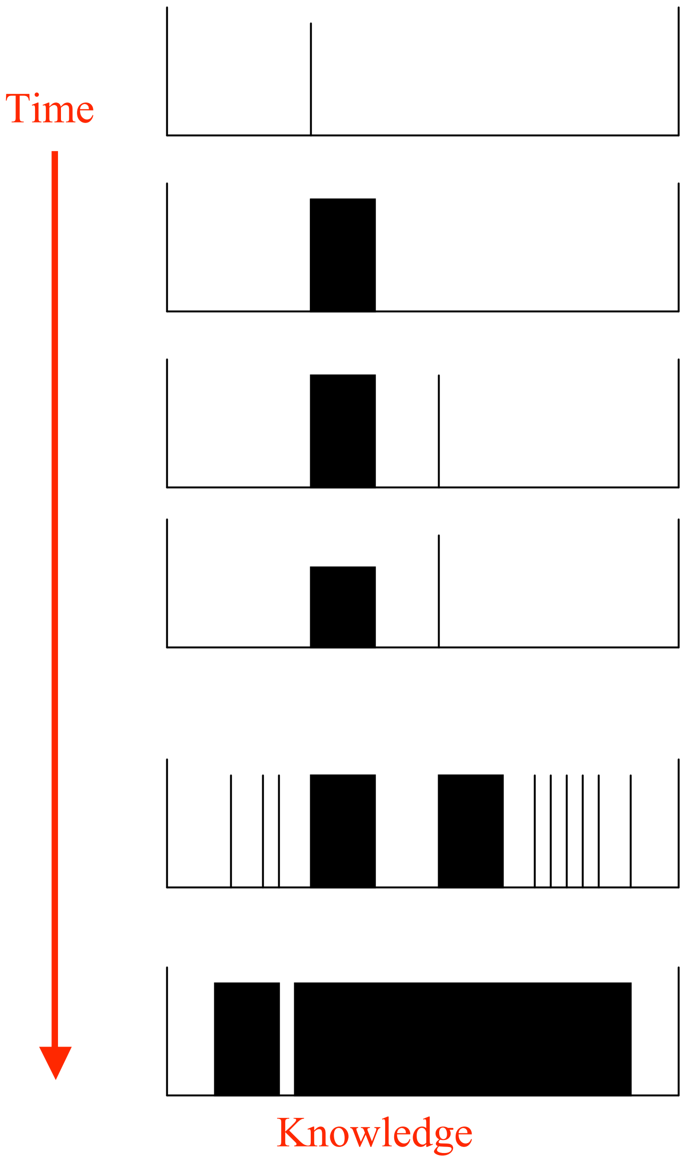
<http://www.fotuva.org/online/frameload.htm?/online/challenger.htm>

Is the statement in bold italics above true? Isn't the scientist often biased by how things have been done?

# Constraints on solving problems

- Funding
  - Even if you have funding, you are constrained to do your proposed work
- Research team
  - Number, expertise, background
- Equipment
- Competitors
- Research that is “in”
- It’s hard to get funding for research that is “out”
- Current modes of thinking – the “box”
- If you have been in the field your entire life, you know the standard ways of solving problems but you may be less likely to use a novel approach
- If you are new, you don’t know the standard ways, but may be more likely to use a novel approach

# Time line of development of knowledge in a scientific area: The March of Science




Initial discovery

Further investigations of initial discovery

A related discovery

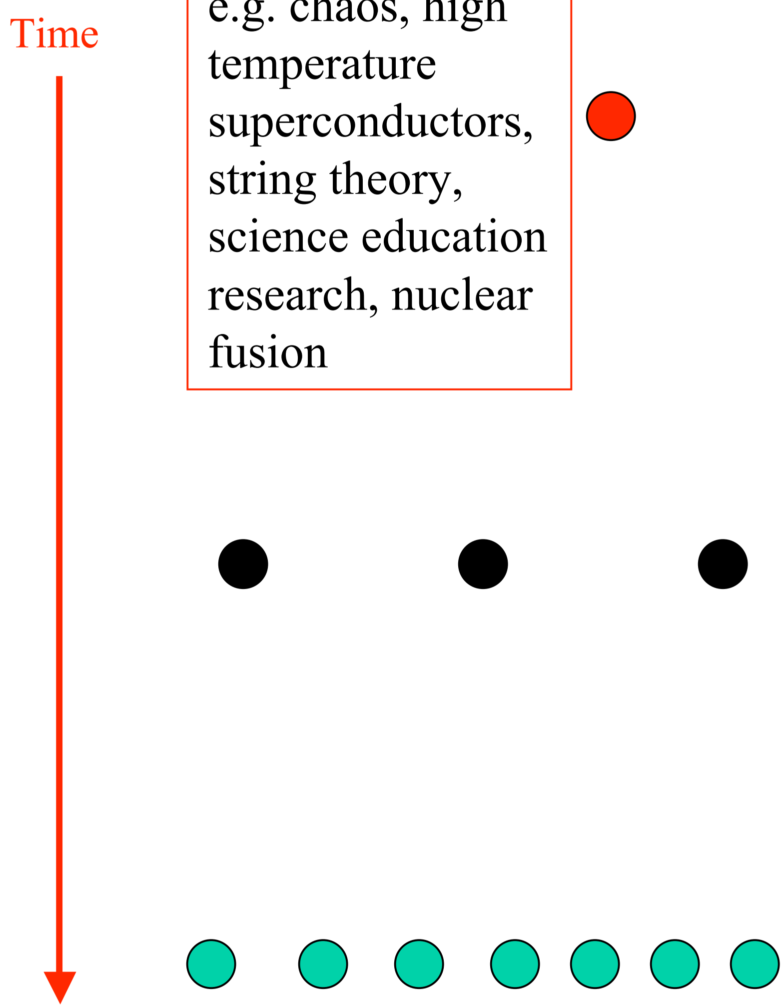
Original understanding of initial discovery is shown to be partially false

Many related discoveries by many scientists and initial discovery is now well understood

Mature field is well understood – many scientists have abandoned it

These diagrams are true on many scales of fields, subfields, etc.

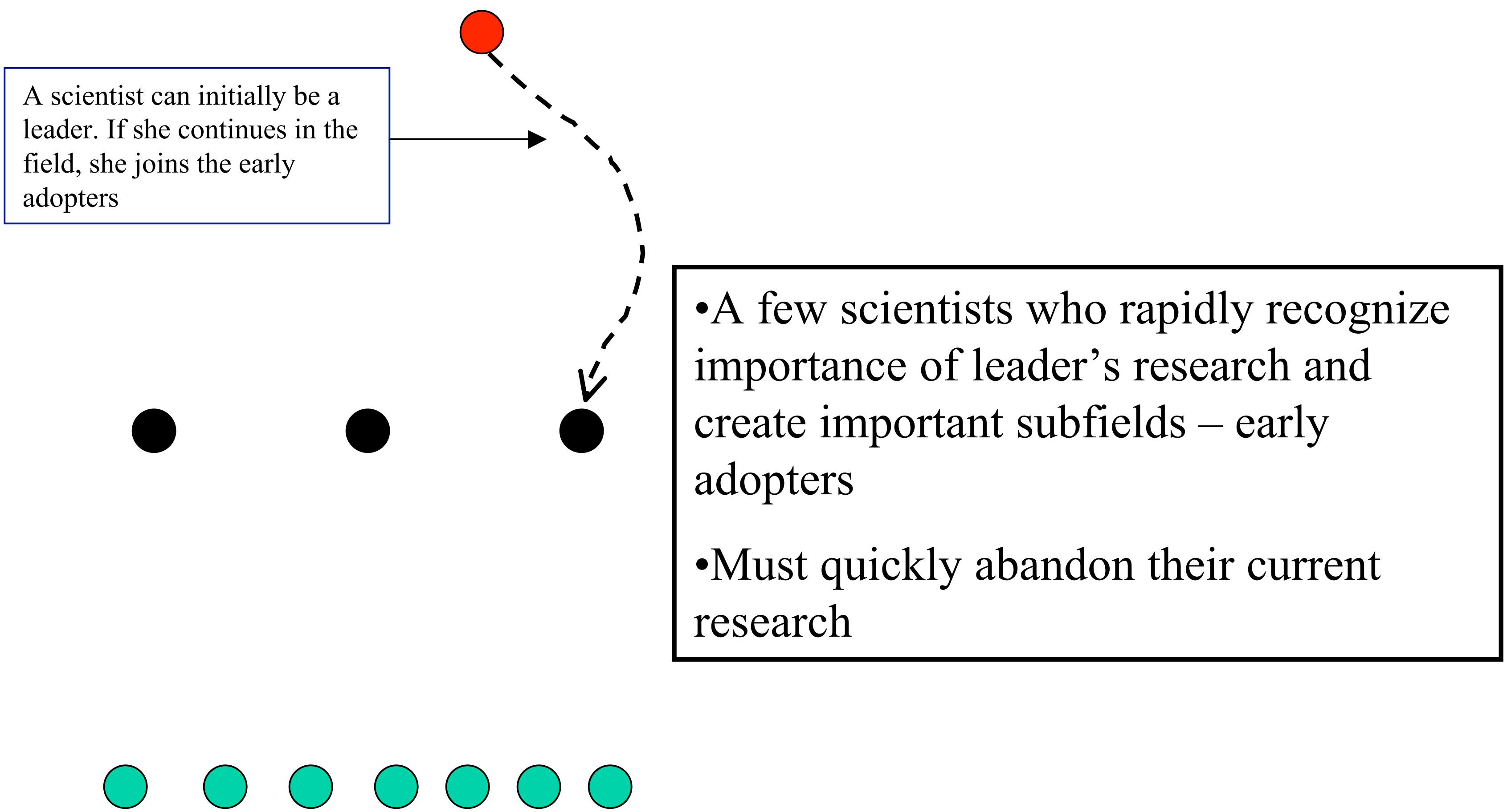
# The March of Science: Number of participating scientists



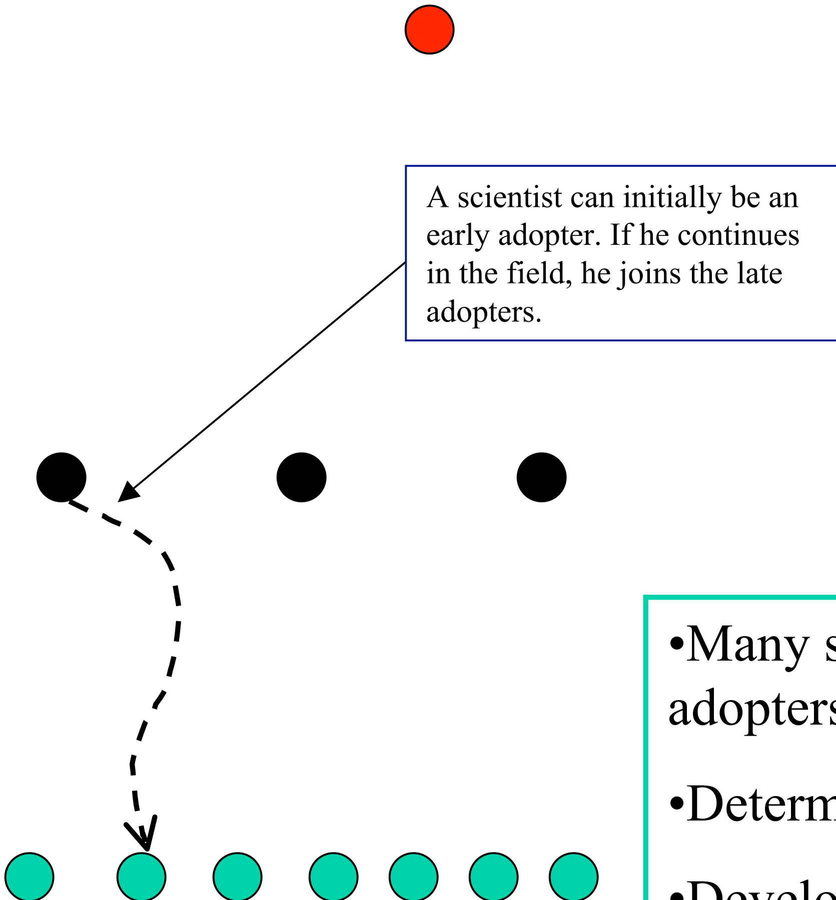

e.g. chaos, high temperature superconductors, string theory, science education research, nuclear fusion

- Leaders/risk takers; one or a small number of people; create new fields
- Good instincts; able to sense new productive fields
- Could lead to Nobel Prize or completely useless/career killing

# The March of Science: Number of participating scientists



# The March of Science: Number of participating scientists

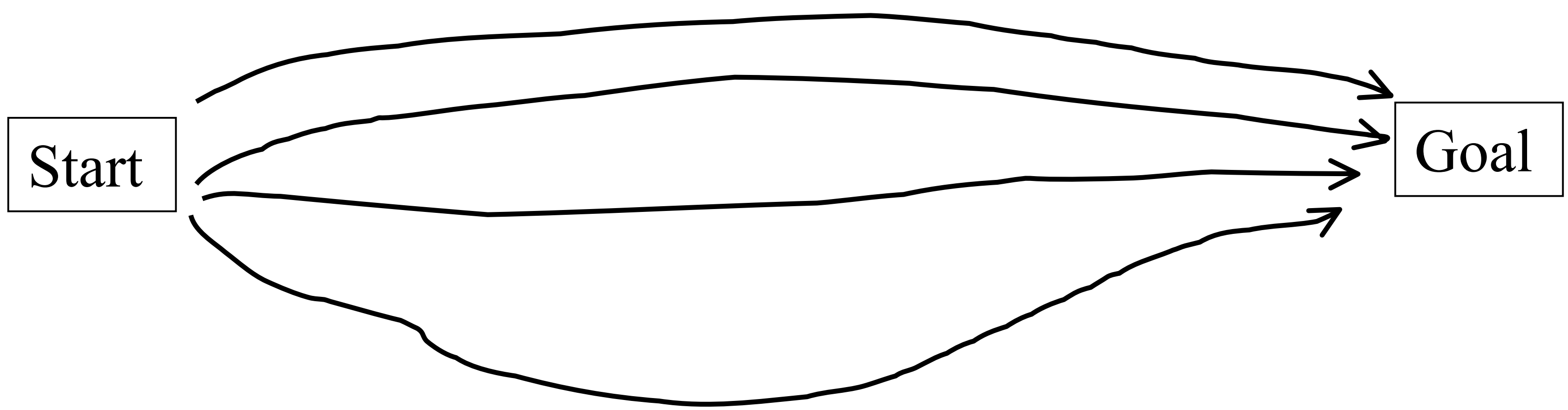



- Many scientists now in the field – late adopters
- Determine details/mechanisms of new science
- Develop well structured experiments to refute or support or refine theories
- Applied research, product development

Scientists have a vital role to play at each level – all are important to the growth of scientific knowledge

# How to approach problems

- Develop multiple approaches since you aren’t sure which one will work

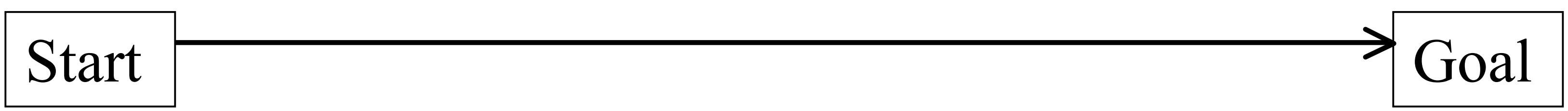


# How to approach problems

- Develop an initial approach that gets you closer to your goal

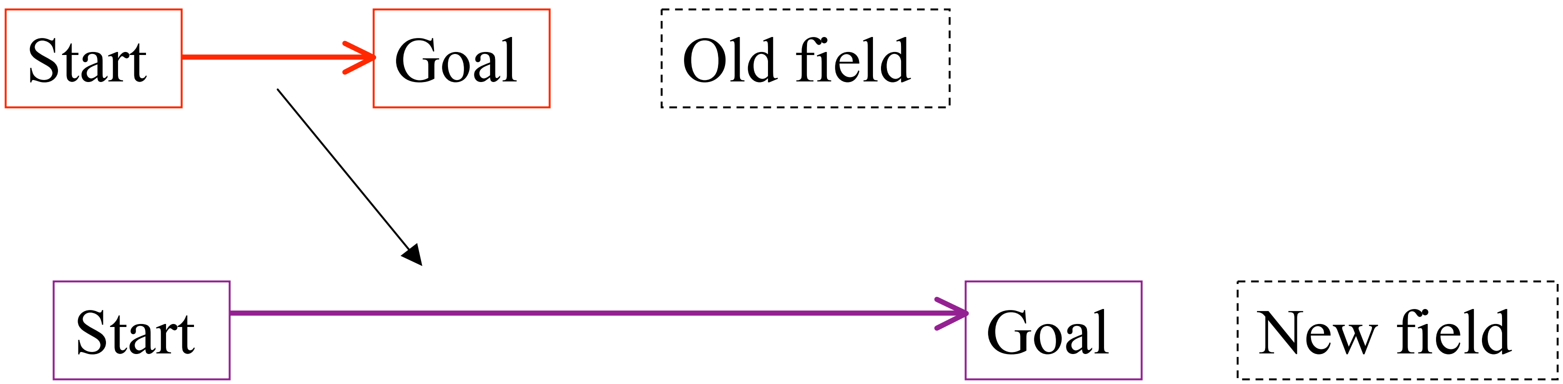

# Solving problems

- If problem and solution are well defined, then just "turn the crank"



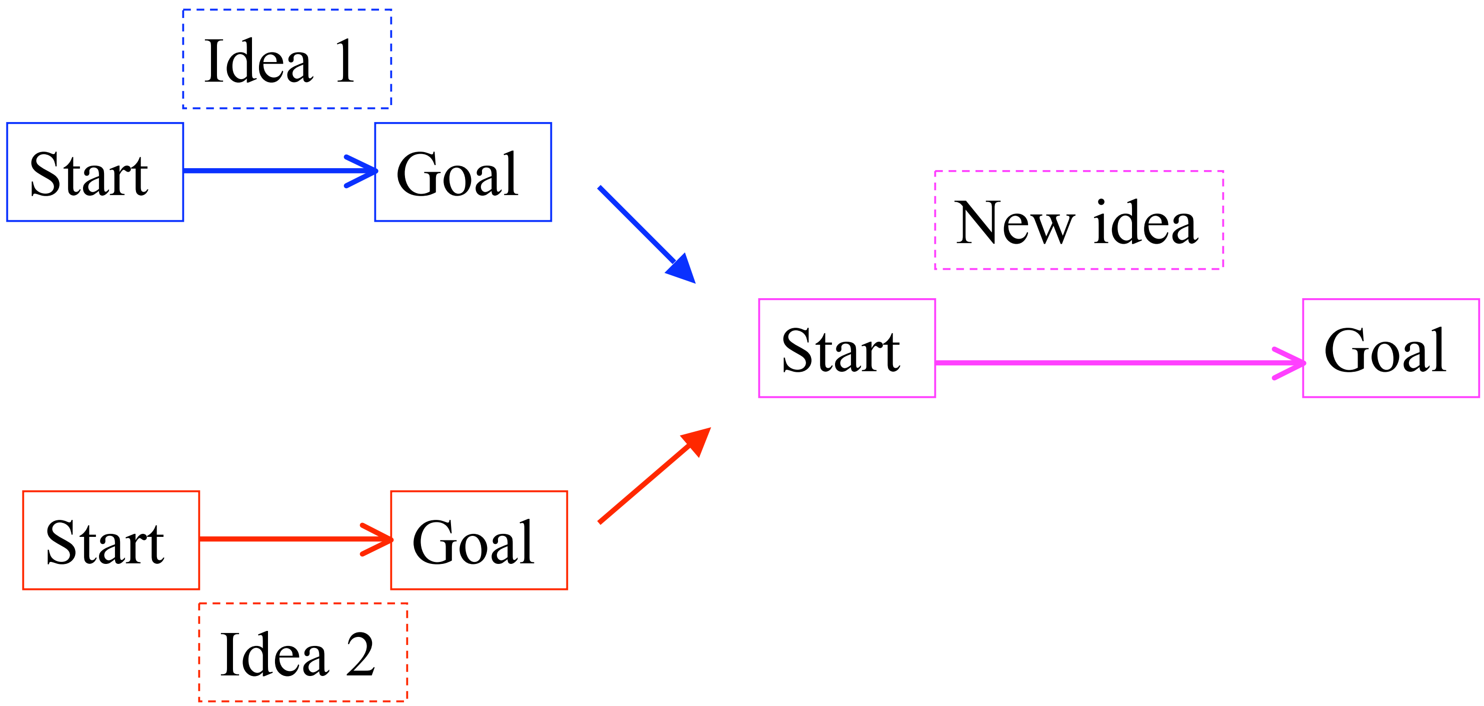
# Solving problems

- Extend known methodology to a new field



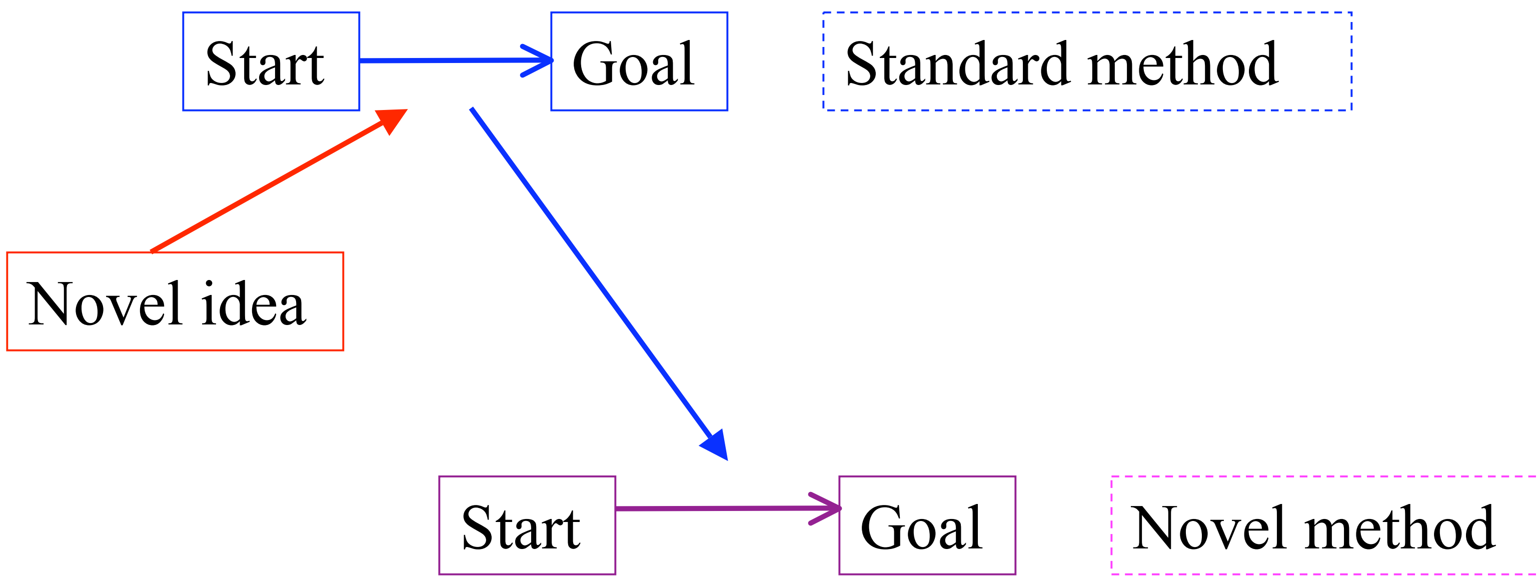
# Solving problems

- Combine two existing ideas/methods into a new idea/method



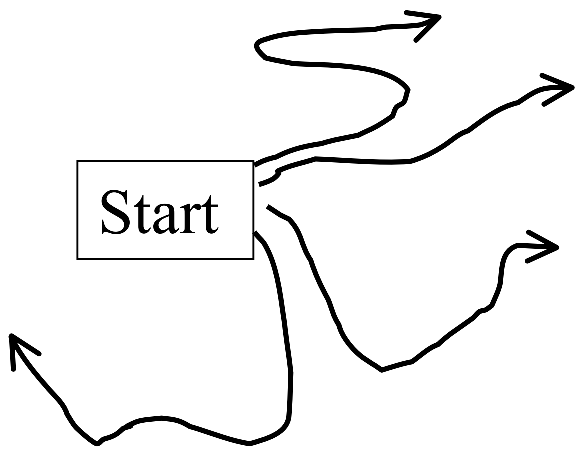
# Solving problems

- Combine a standard method/idea with a novel method/idea



# Solving "problems"

- Innovators/discoverers often have no idea of what their goal is … but they have a loosely formed idea for a research area



# Let's look at some scientific papers to see some examples of problem solving

- See if you can find the new approach that was used in the paper

# Let's also look at some scientific papers to see how scientific work is organized

- Background material
- Define the problem that is being addressed
- Justification/rationale for the work
- Experimental methods/equipment
- Data and data analysis – tables, graphs
- Discussion
- Conclusion
- Acknowledgements and References

*The actual work is often not nearly as organized and logically done as the papers indicate!!*

# Solving problems takes time

"To do real good physics you need absolutely solid lengths of time, so that when you're putting ideas together which are vague and hard to remember … it's very much like building a house of cards and each of the cards is shaky, and if you forget one of them the whole thing collapses.  You don't know how you got there and you have to build them up again, and if you're interrupted and kind of forget half the idea of how the cards went together – your cards being different parts of the idea – it's easy for it to slip, it needs lots of concentration – that is, solid time to think."

*From "The Pleasure of Finding Things Out" by Richard Feynman, p. 19*

# Importance of doubt and the fallibility of authority

"Another of the qualities of science is that it teaches the value of rational thought, as well as the importance of freedom of thought; the positive results that come from doubting that all the lessons are true… Learn from science that you must doubt the experts. As a matter of fact, I can also define science another way: Science is the belief in the ignorance of experts."

*From "The Pleasure of Finding Things Out" by Richard Feynman, p. 186-187*

# Scientific Integrity - an integral part of science

"… That is the idea that we all hope you have learned in studying science in school … It's a kind of scientific integrity, a principle of scientific thought that corresponds to a kind of utter honesty – a kind of leaning over backwards. For example, if you're doing an experiment, you should report everything that you think might make it invalid – not only what you think is right about it … Details that could throw doubt on your interpretation must be given if you know them."

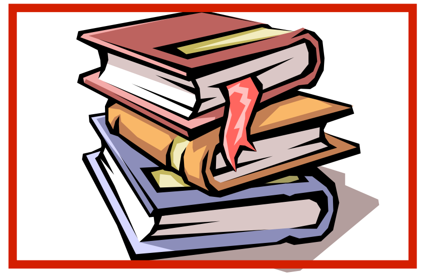
*From "The Pleasure of Finding Things Out" by Richard Feynman, p. 209-210*

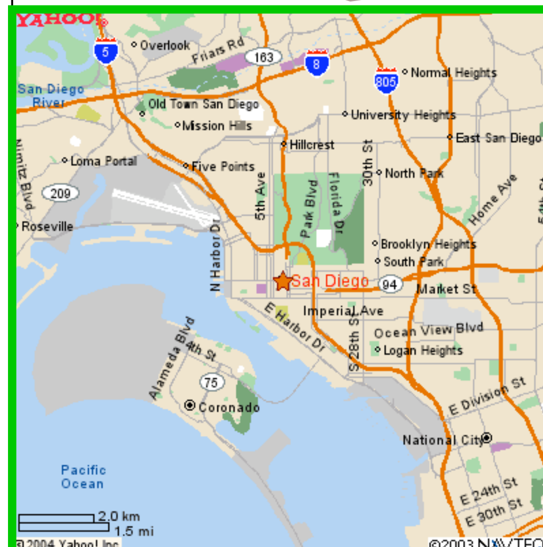
"For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled."

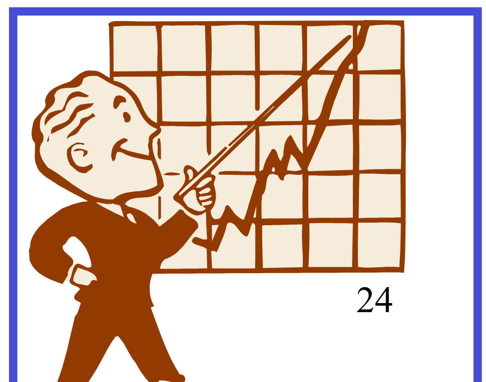
Richard Feynman, Challenger Commission Report

# Solving problems: my general approach

- Define the problem: what am I trying to find do
- Learn relevant background information:
  - papers, patents, review articles, books, web site, vendors that make relevant equipment/materials, competitors that have done related work
- Develop multiple approaches to solve the problem
- Investigate the most likely approach first. If it doesn't work, investigate alternate approaches
  (analogy: going from point A to point B: use freeway, but if jammed, try alternate route)
- Summarize data into tables and charts that can be understood by someone else a year from now
- Analyze and summarize data and results in report
- Use these results as the basis for further work
  (and be persistent and don't get discouraged)

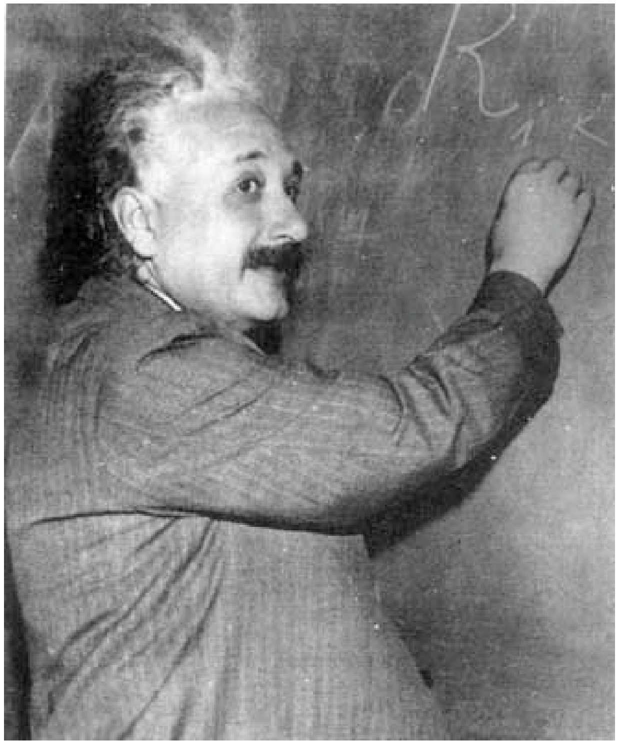




# Summary

- No single scientific method: ban hypotheses
- Many ways to do science and solve problems
- Scientists formulate multiple alternate approaches to solve problems
- Science performed depends on the state of the field you are working in
- Scientists operate under various constraints
- Science takes extended lengths of time
- Scientists should have doubt and integrity



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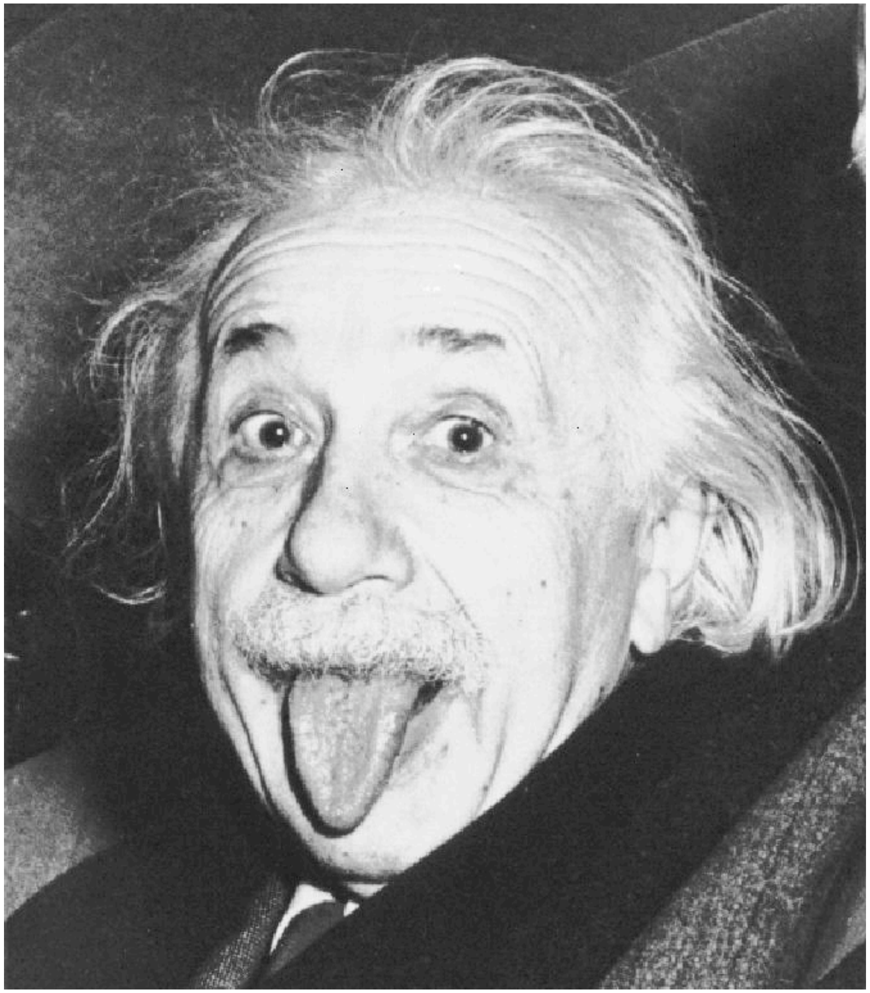

***… Scientists have fun!***