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SANDIA NATIONAL LABORATORIES

"Wicked" Engineering: Sandia's perspective

Presented to:
Defense Science and Technology Agency

Singapore

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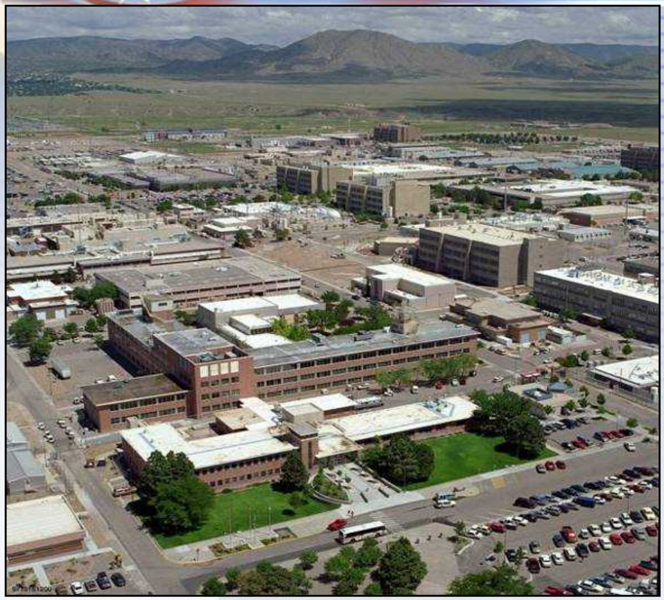
NNSA National Nuclear Security Administration

Sandia National Laboratories

Sandia is a Multi-Program National Laboratory

- National Security Laboratory
  - Primary Mission: Nuclear Weapons
  - Broader mission to meet national security needs
- Complex, multidisciplinary problems of national importance
- Research, development & application
- Unique facilities and equipment
- World-class staff: 75% Ph.D. & M.S.
- Partnerships with military, universities, and industry

…With Distributed Facilities to Meet National Needs



Albuquerque, New Mexico

Tonopah Test Range, Nevada

Kauai Test Facility, Hawaii

Livermore, California

Yucca Mountain, Nevada

WIPP, New Mexico

Pantex, Texas

Sandia National Laboratories

Our Core Purpose

Securing a Peaceful and Free World through Technology

Nuclear Weapons

Safe, Secure, Reliable Weapons

Defense Systems and Assessments

Detection

Remote Sensing and Verification

Integrated Military Systems

Energy, Resources, and Nonproliferation

Energy

Safety and Security

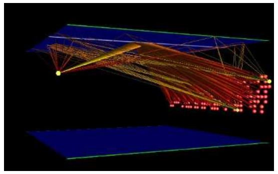
Critical Resources

Efficiency

Homeland Security and Defense

Chem-Bio Defense

Cyber Protection



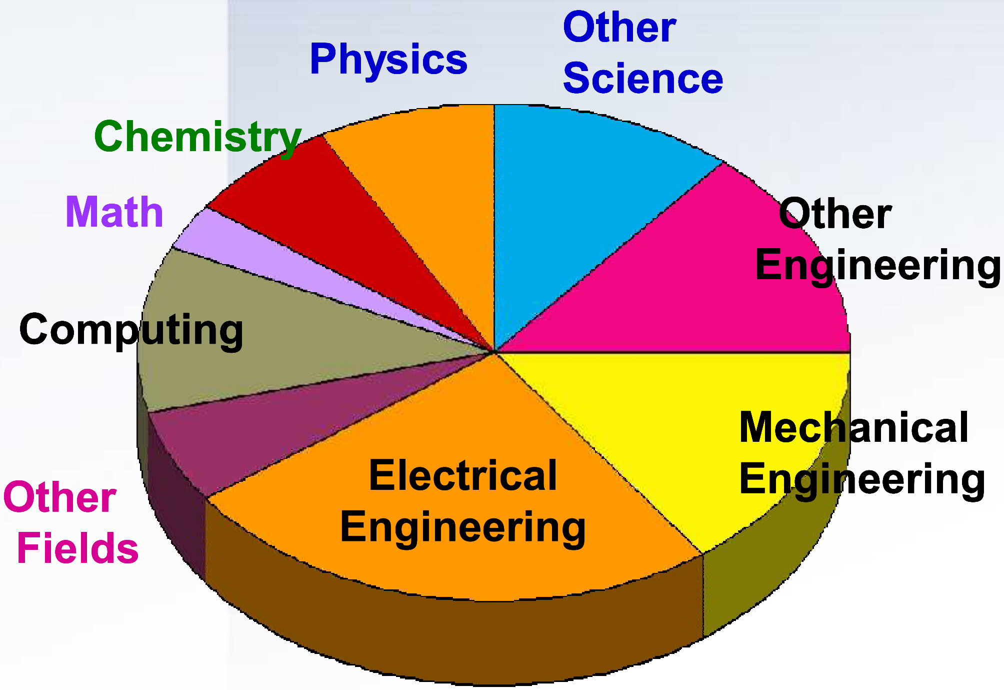
Explosives Countermeasures

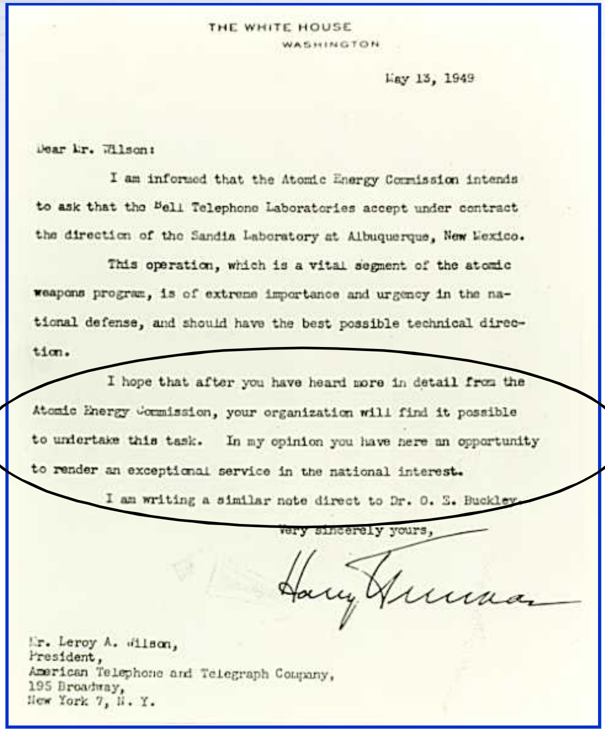
Sandia National Laboratories

We have Served the Nation since 1949
"Exceptional Service in the National Interest"

Highly Skilled Workforce

- More than 8,600 full-time employees
- More than 1,500 PhDs and 2,700 MS/MA
- $2.33 billion FY06 total budget





THE WHITE HOUSE
WASHINGTON

May 13, 1949

Dear Mr. Wilson:

I am informed that the Atomic Energy Commission intends to ask that the Bell Telephone Laboratories accept under contract the direction of the Sandia Laboratory at Albuquerque, New Mexico.

This operation, which is a vital segment of the atomic weapons program, is of extreme importance and urgency in the national defense, and should have the best possible technical direction.

I hope that after you have heard more in detail from the Atomic Energy Commission, your organization will find it possible to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

I am writing a similar note direct to Dr. O. E. Buckley.

Very sincerely yours,

Harry Truman

Mr. Leroy A. Wilson,
President,
American Telephone and Telegraph Company,
195 Broadway,
New York 7, N. Y.

We focus on engineered systems

Nuclear Weapons

Ballistic Missile Defense

Multispectral Thermal Imager Satellite

Explosives Detection Portal

Synthetic Aperture Radar

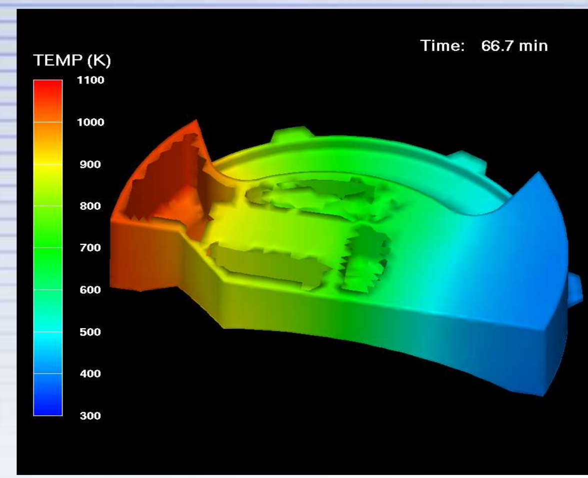
Critical Infrastructure

Sandia National Laboratories

…Supported by World-Class Science, Technology, and Engineering Capabilities

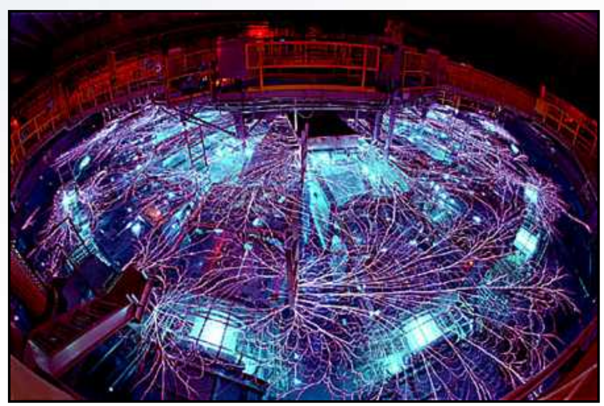
Robotics and Intelligent Machines

Weapons and Energy Testing

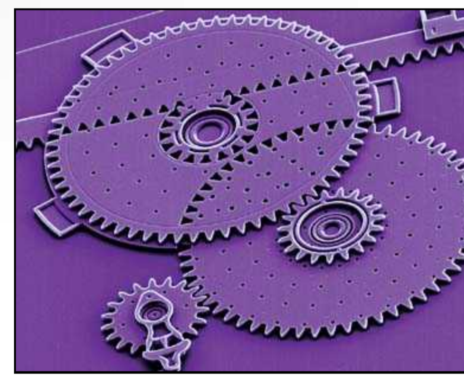


Engineering Sciences

Materials and Processes



Pulsed Power Sciences



Microelectronics and Photonics

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To fulfill our national security role, we must engage globally

Nuclear Deterrence

Support for the warfighter

Energy Security

Terrorism

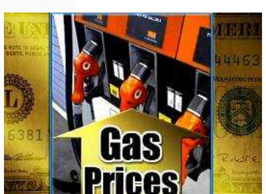
Political Instability

Waste

Energy Disruptions

Climate

Water



Proliferation of SNM and Weapon Expertise

These areas involve wicked problems!

Nuclear Weapons

Safe, Secure, Reliable Weapons

Defense Systems and Assessments

Detection

Remote Sensing and Verification

Integrated Military Systems

Energy, Resources, and Nonproliferation

Energy

Safety and Security

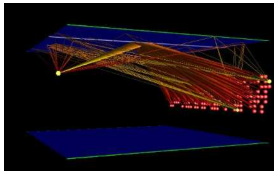
Critical Resources

Efficiency

Homeland Security and Defense

Chem-Bio Defense

Cyber Protection



Explosives Countermeasures

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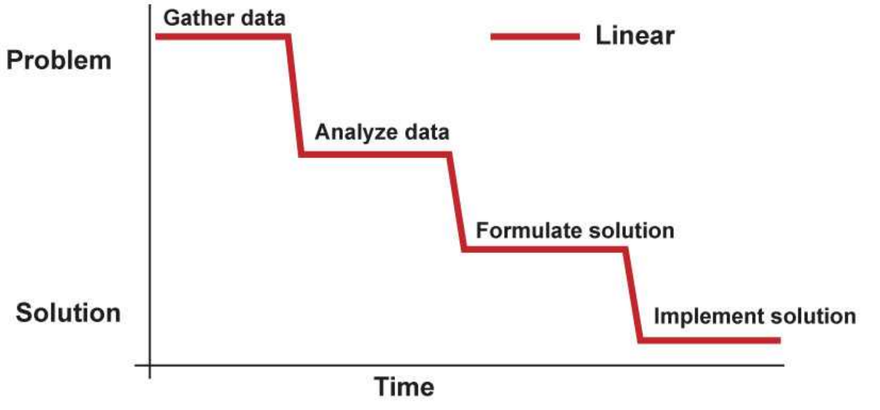
What is a “wicked” problem?

- There is no definitive formulation of a wicked problem.
- Solutions to wicked problems are not true-or-false, but good-or-bad.
- There is no immediate and no ultimate test of a solution to a wicked problem.
- Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
- Every wicked problem is essentially unique.
- Every wicked problem can be considered a symptom of another problem.
- The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem’s resolution.
- The planner has no right to be wrong.
- We are using the term “wicked problems” to characterize national-laboratory-level problems we see in our future: complex and dynamic systems problems in which the burden of solution does not lie on one domain.

Rittel and Weber, 1973

The opposite of wicked: Tame problems have similar characteristics

- Well-defined problem statement
- Definite stopping point
- Right or wrong solution
- Similar to others of same class
- Solutions easily tried and dropped
- Few alternate solutions



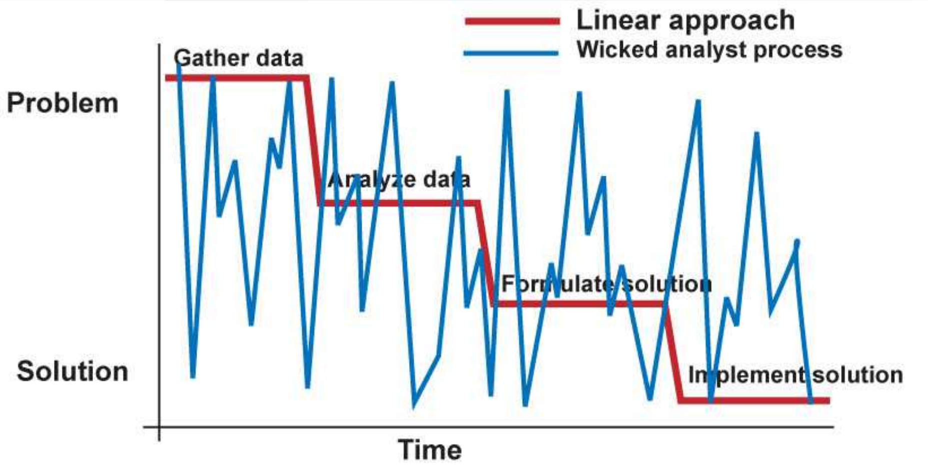
Traditional wisdom for solving complex problems: the "waterfall"

Jeff Conklin, Wicked Problems and Social Complexity

Trying to tame a wicked problem can lead to:

- **Freeze problem definition prematurely**
- **Measure variables, drive toward targets**
- **Ignore complicating factors**
- **Select from a few over simplified solution options**
- **Give up, do as you are told**
- **Assert problem is solved**

People taming wicked problems with different perspectives, backgrounds, organizations, and goals leads to escalating confusion, conflicts, and paralysis



Pattern of cognitive activity of one wicked engineer: the "jagged" line

Jeff Conklin, Wicked Problems and Social Complexity

Dealing with Wicked Problems

The approach:

- "Formulate the mess"
- Develop a spiral (not linear) process
- Share awareness of changing context
- Communicate often, with high fidelity, to all levels
- Focus on system issues, not just pieces.
- Remember: "success is the devil"
- Trust each other as the game changes

Reference: System Thinking, Jamshid Gharagedaghi

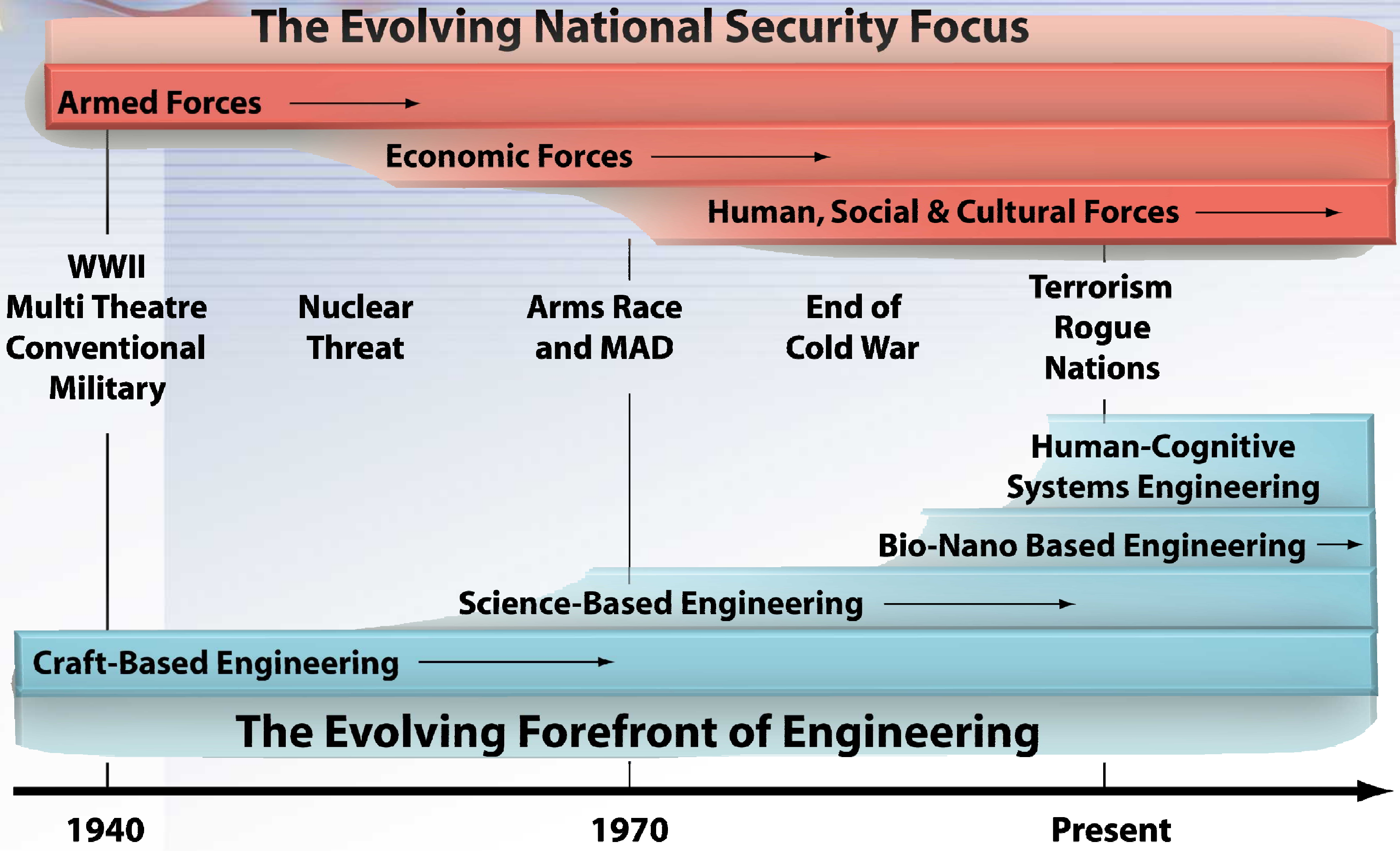
The first step is to admit that the problem is not tame.

How Sandia views “wicked problems”

- A technical or engineered system appears (at least initially) to be an important element in the "solution or mitigation" of the problem
- Social, economic, ethical, political, and business aspects of the problem are evident when considering the problem in a broad context (the engineered system is just a "component" of the larger system in which it must operate)
- A broad and diverse group of people are stakeholders to the problem now and possibly in the future (this may not be apparent without significant probing and consideration of direct/indirect impacts and consequences)
- The stakeholders have different understanding and perspectives of the "problem" - for some, there may not be a "problem"
- The cost of the technical/engineered system is significant (otherwise one can use trial and error to examine various solutions)

Examples: Designing a proliferation-resistant, terrorist-resistant portable nuclear reactor - Designing border security systems - Reducing humans' impact on global climate change - Defeating IEDs

Engineering has evolved to a highly complex discipline



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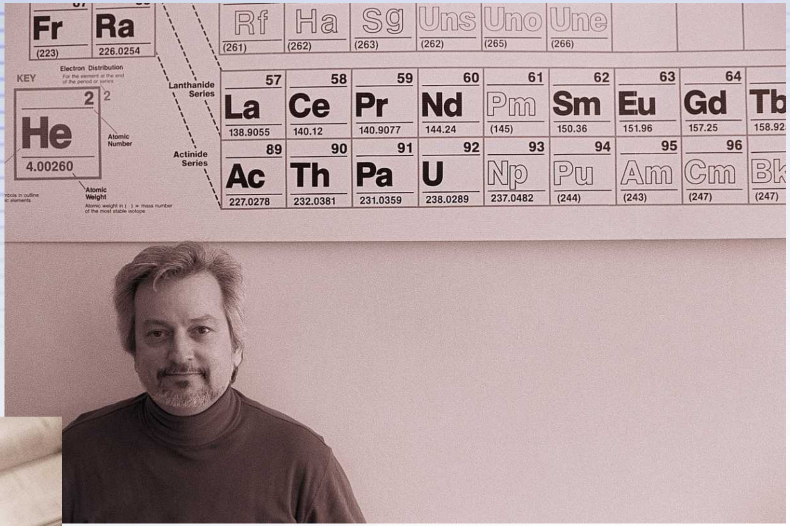
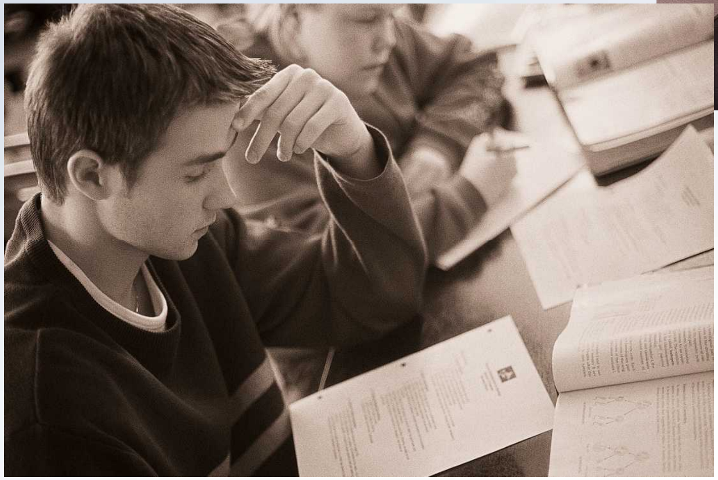
Engineering education evolved to meet the needs of professional practice

- "An Engineer AND a scientist?" Increase in mathematics and science content through 1920s to 1950s





"An engineer and a gentleman?" Increase in liberal arts, social sciences 1960-1990s

And a growing body of literature outlines the future changes for engineering

- **Equip technical professionals to help define, not just solve, problems**
- **Increase their ability to think critically across domains**
- **Increase creativity, innovation, and impact**
- **Striking similarities to "Wicked" engineers**

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The implications for the education of engineers

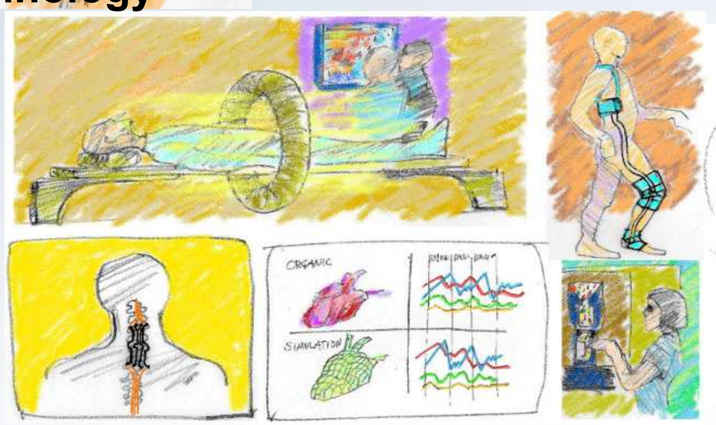
- At undergraduate and graduate levels:
  - Increased emphasis on multidisciplinary, team-oriented group design projects to
    - Challenge students to work across domains
    - Stimulate innovation and creativity through the integration of multiple perspectives
    - Cultivate “T-shaped” professionals of the future
- In post-graduate or professional environments:
  - Continuing education to broaden technically deep professionals to become systems thinkers
  - Continuing emphasis from leadership for life-long learning

Rapid advances in technology will challenge engineers to become systems thinkers and lifelong learners

Information technology

- **Engineering education must teach students how to learn new areas, not how to master old skills or problem sets.**

Dynamic global security



Biotechnology advances

Neurosciences

Wicked engineering programs will attract a different kind of student with real advantages

- More diverse
- More systems-oriented
- “T-shaped” technical depth as well as intellectual breadth
- Better positioned to take leadership roles in industry, government
- More flexible/adaptable backgrounds, perspectives and skills

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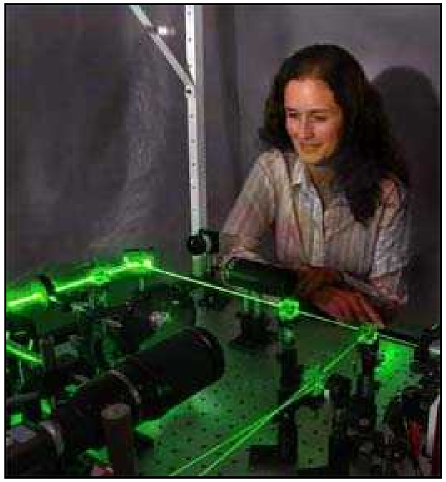
Wicked engineers need a different kind of education

- Embedded complex systems thinking
- Interdisciplinary as well as multidisciplinary
- Problem-based learning, experiential learning, gaming/simulation



This must be done at the undergraduate, graduate, and postgraduate levels….

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Benefits of cultivating engineers who can work on wicked-hard problems

- Better able to deal with complex, systems-level problems
- Better able to postulate effective roles for technology
- Better able to consider system interdependencies and unintended consequences
- Better able to collaborate across disciplines and domains