# From Solving Homework Problems to Solving Research Problems to Solving Real-World Problems

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# Introduction

- Transition from an undergraduate student to a graduate student and then after graduation

- **Before graduate school:**
  - Mostly trained to solve homework problems

- **In graduate school:**
  - Ability to solve research problems is the key for success

- **After graduation, in industry and entrepreneurship:**
  - Must solve real-world problems

# Solving Homework Problems

- **Example**: Prove that $\{\mathrm{sinc}(t-n)\}_n$ is an orthogonal basis for bandlimited functions $\mathrm{BL}([-\pi,\pi])$

- **Required skills for solving homework problems**:
  - Knowledge
  - Creativity
  - Persistence

- **Typical:** Problem $\rightarrow$ Solution
  - Problem is well defined
  - Know that a solution exists!

# Solving Research Problems

- **Example**: Can we recover a function from its samples?
- Research problems are typical fuzzy and open ended
  - Problems are **not** clear and well-defined
  - Problems are **not** even exist before
- **Key**: being able to ask the right questions and refine them
- We need not just to solve the problem but also convince the world that we actually solve it!
  - Perform experiments to confirm the theory
  - Demonstrate the impacts in real applications and technology

# Solving Real-World Problems

- **Examples**: Apple, Google, Facebook

- Key is to find a product/market fit, or figure the right thing to build -- the thing customers want and will pay for

- Require:
  - Understand customers and market
  - Identify the value proposition
  - Get product out quickly: minimum viable product
  - Iterate: build, measure, learn (repeat)
  - Know how to sell

# Research Model

*"Most advances are made in response to a need, so that it is necessary to have some sort of practical goal in mind while the basic research is being done; otherwise it may be of little value."*

John Bardeen

University of Illinois Professor in

Electrical Engineering and Physics

Two-time Nobel Prize winner in Physics

# Baarden's Criteria for Choosing Research

The research problem has to be strong in all following 3 criteria:

1. The supporting technology must be ready
   - Can NOT be "pie on the sky"

2. The research must be intellectually challenging
   - Can NOT just be on a "back of an envelop"

3. The outcomes of the research must help the society

# Five Steps in Solving a Research Problem

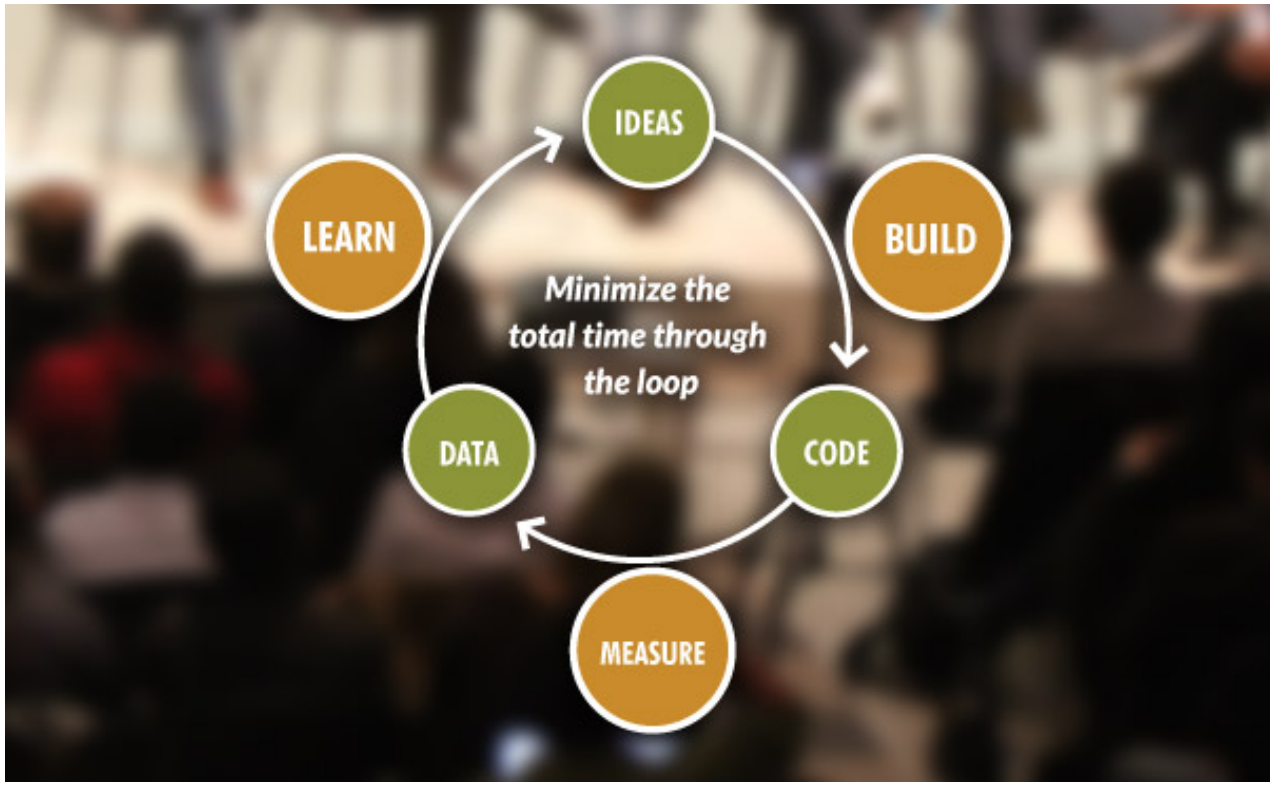
- **Step 1:** Define the problem (scope, area,…)
  - Review literature (lot of reading, but *not* too much)
  - Gain deep understanding *by doing* (implement, experiment,…)
- **Step 2:** Formulate the problem (into a homework problem)
  - Find the right model, setup
  - Introduce assumptions to simplify the problem
- **Step 3:** Solve the problem (like solving a homework problem)
  - Many times need to validate with experiments, applications
- **Step 4:** Interpret the solution
  - Go back to the original problem: new insights, new methods,…
- **Step 5:** Disseminate the results
  - Papers, presentations, patents,…

*"There are many things one doesn't understand and therefore, we ask them why don't you just go ahead and take action, try to do something? You realize how little you know and you face your own failures and you simply can correct those failures and redo it again and at the second trial you realize another mistake or another thing you didn't like so you can redo it once again. So by constant improvement, or should I say, the improvement based upon action, one can rise to a higher level of practice and knowledge."*

Fujio Cho (President of Toyota)

# Lean Process

- Introduced by Toyota for lean production
- Popularized by Eric Ries for lean startup [see figure below]
- Research should follow the same process: lean research



# Define/Formulate a Research Problem

- **Fact**: Most of engineering problems are ill-posed!

- Often we need to redefine/reformulate the problem to make it solvable
  - Imposing realistic assumptions
  - Add constraints
  - Simplify the problem or model

- **Engineers**: We are allowed to change the problem!

- Many times, being able to define/formulate a research problem is half of the work!

# Some Techniques in Formulating Problems

- Keep simplifying the problem until it is solvable (e.g. to a special case) and then try to generalize/extend the solution
  - Simple problem often gives clear insight and intuition
  - If we cannot solve a simple version of the problem then we also cannot solve the complex version
- Multiresolution technique: start with a coarse and solvable problem and successively extend it to make it more realistic
- Ask the converse questions
  - **Example**: we know that **bandlimitedness** leads to **samplable**; but what are **other samplable signals**?
- Some time need to build
- Look at the data!

# Questioning Attitude

- Questioning attitude is one of the most important qualities of a creative person
  - Mistake: a question is an admission for not knowing something
- A creative person should have a healthy skepticism about existing answers, techniques, and approaches
  - Questioning attitude helps to sense the problem and lead to creative solution
- Primary quality of creative problem-solver: constantly developing Constructive Discontent
- The most admired one at meetings is the penetrating questioner

# The Power of Figures and Lists

- Figures are very powerful for visual thinking and developing intuition
  - Try to draw figures of what you are thinking or presenting
  - Figures of results with signals and images often lead to the right intuition

- Lists effectively focus conceptual energy and produce written record of the output
  - Keep a notebook that list all of the thoughts that have occurred
  - Make a list during brainstorming sessions: ideas lead to ideas
  - List the attributes. Below each attribute, list many alternates Consider different combinations.
  - Use "check list" such as one in *How to Solve It* by Polya

# Using Other People's Ideas

- An especially powerful way of increasing creativity is to interact with other people, especially if they think differently than you
  - Do homework together
  - Take courses outside your traditional areas
  - Ask for ideas on your problem from a large number of people
  - Bounce ideas off of a peer or group of people

- The main distinction of "star performers" is they have a reliable network of information/advice providers
  [from a study of Bell Labs researchers in 1992]

- Much creativity now is taking place between disciplines

# Look at Data

- Get insight from data and experiments
  - If you find an interesting algorithm or method, go ahead and implement it and test it on your data
  - Print out the results, stuck them on the wall, stared at them…
  - Eventually ideas for improvements and novel methods came up…
- Use metrics on obtained data to track your progress
- Talk and seek comments/feedback from other people

# Required Skills for Solving Research Prob

- Knowledge (much wider)
- Creativity
- Persistence (much more)
  - If we keep trying hard, something good will come out

- **Ask good questions**
- Faith (this problem can be solved!)
- Flexibility (if not, how can I reformulate it to be solvable!)
- Communication skills for disseminating results
- See the the big picture
- Organized, motivated, and have a sense of purpose

# Key Features of U.S. Engineering Education

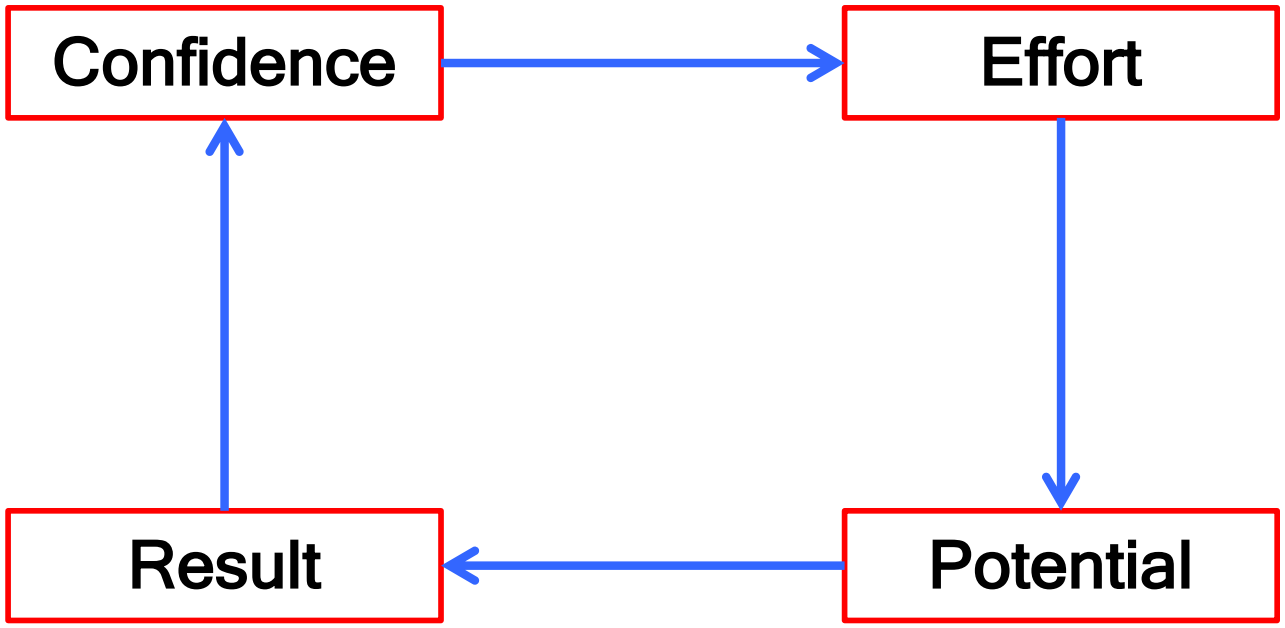
1. **Emphasis on doing**
   - Clearly stated in course objectives
   - Weekly homework and projects
   - Do not just "*provide information*"
     but instead focus on "*learning to learn*"

2. **Immersion**
   - Teach knowledge in context of problems, issues, and questions
   - Iterate: learn-do-learn-do-…
   - Hand-on design projects throughout the 4 years of study

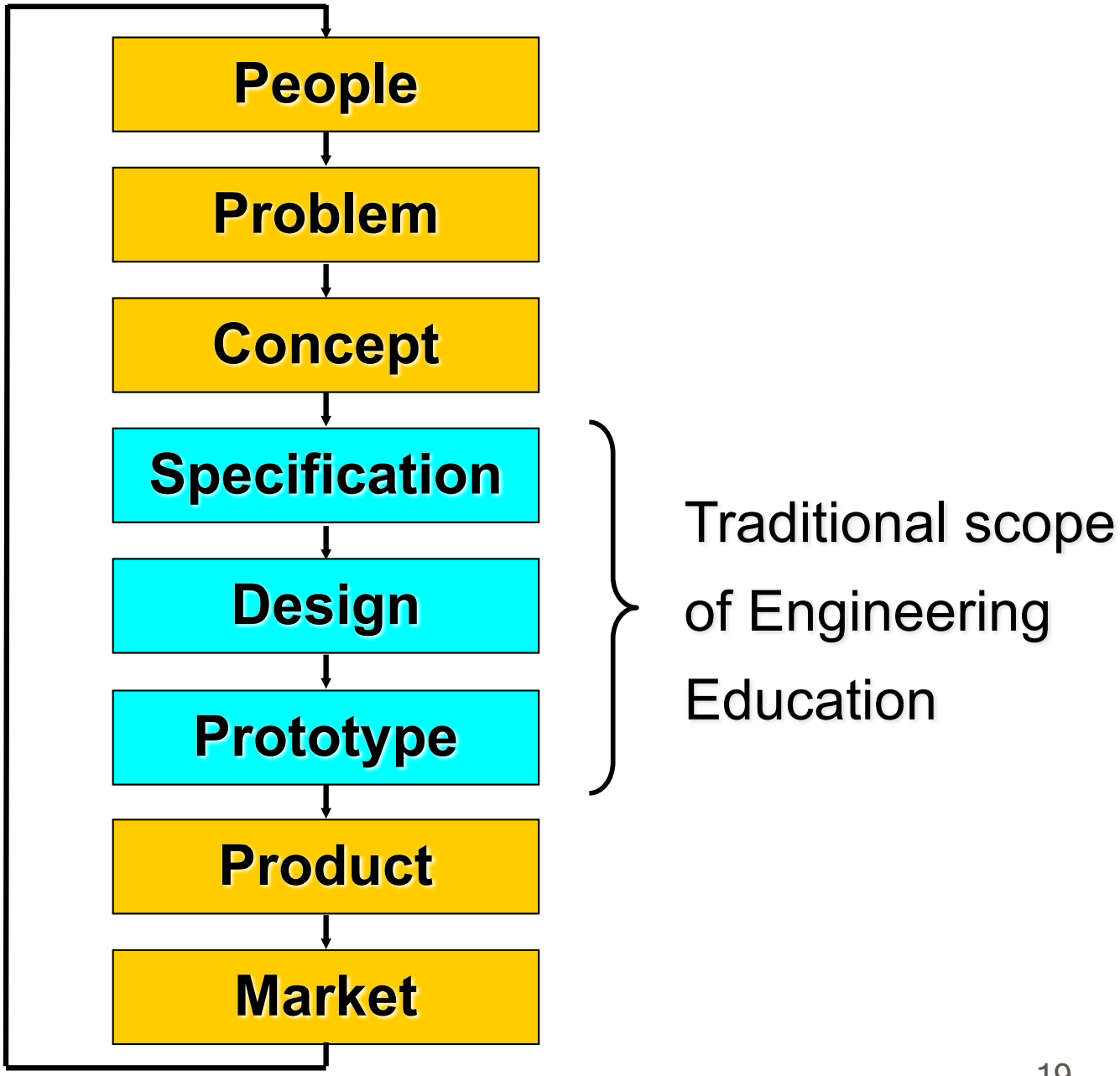
*"The great aim of education is not knowledge but action"*

Herbert Spencer (1820 - 1903)

# The Flying Wheel



# Engineering in the Real World



*“Your work is going to fill a large part of your life, and the only way to be truly satisfied is to do what you believe is great work. And the only way to do great work is to love what you do. If you haven't found it yet, keep looking. Don't settle.”*

Steve Jobs (CEO of Apple Computer)