Experimentation Design in Software Engineering & Computer Science

Ways to Acquire Knowledge

Adapted from

SWE 763 : Software Engineering Experimentation

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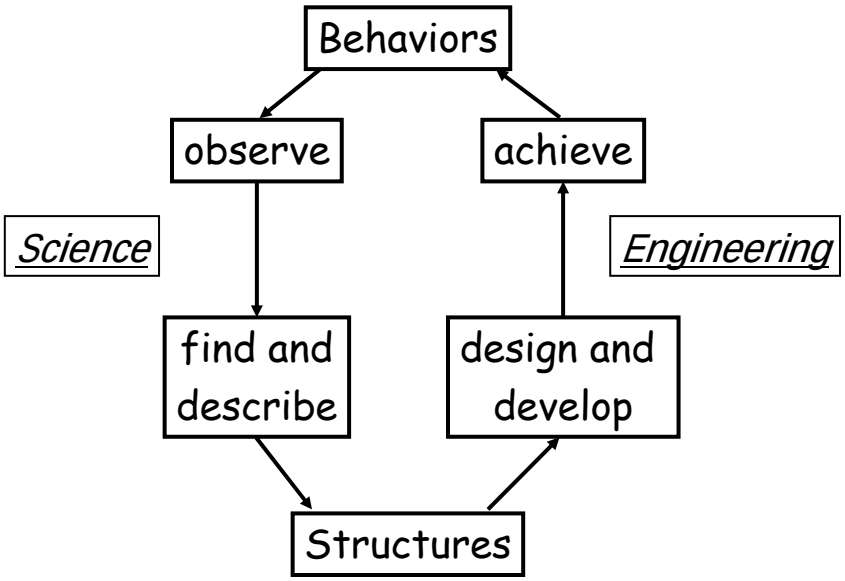
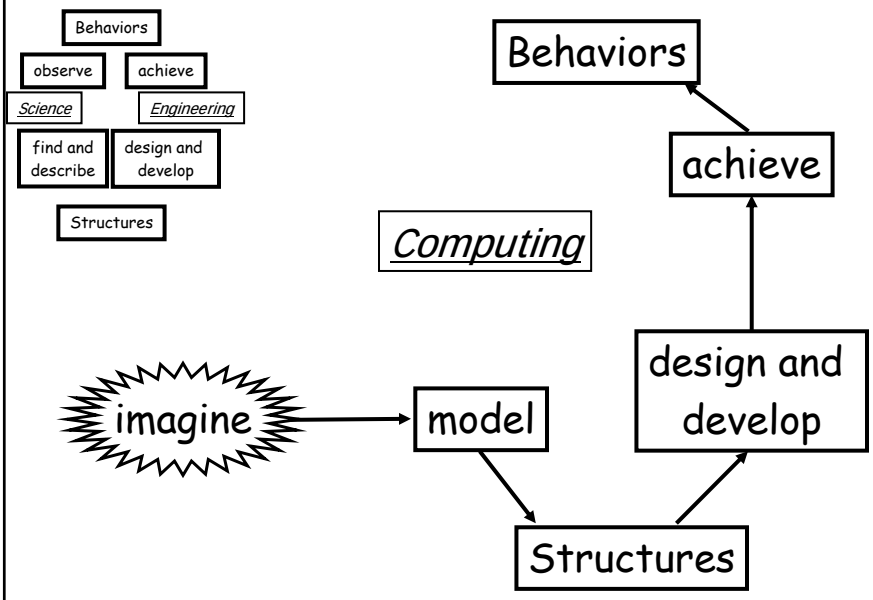
Goals of Science and Engineering



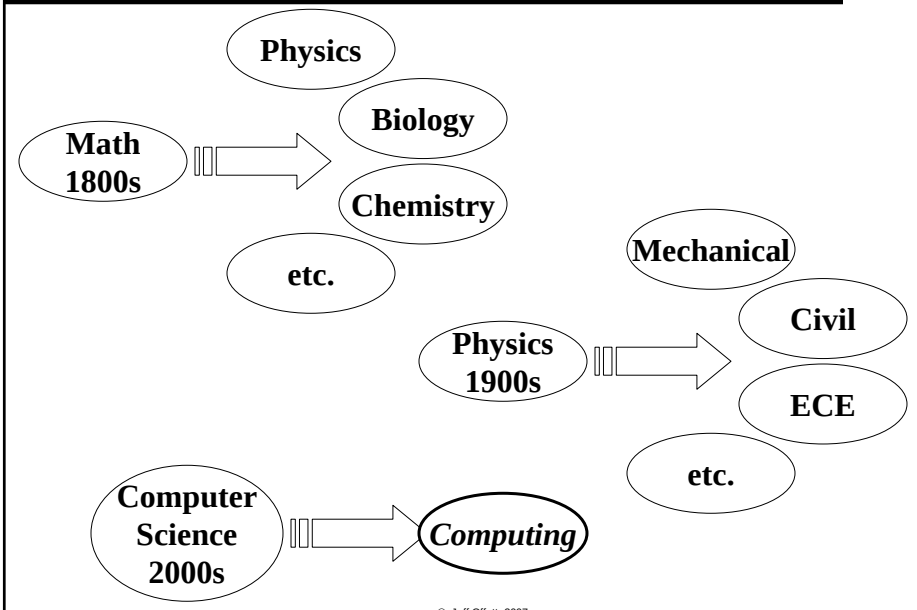
Computing Doesn't Quite Fit



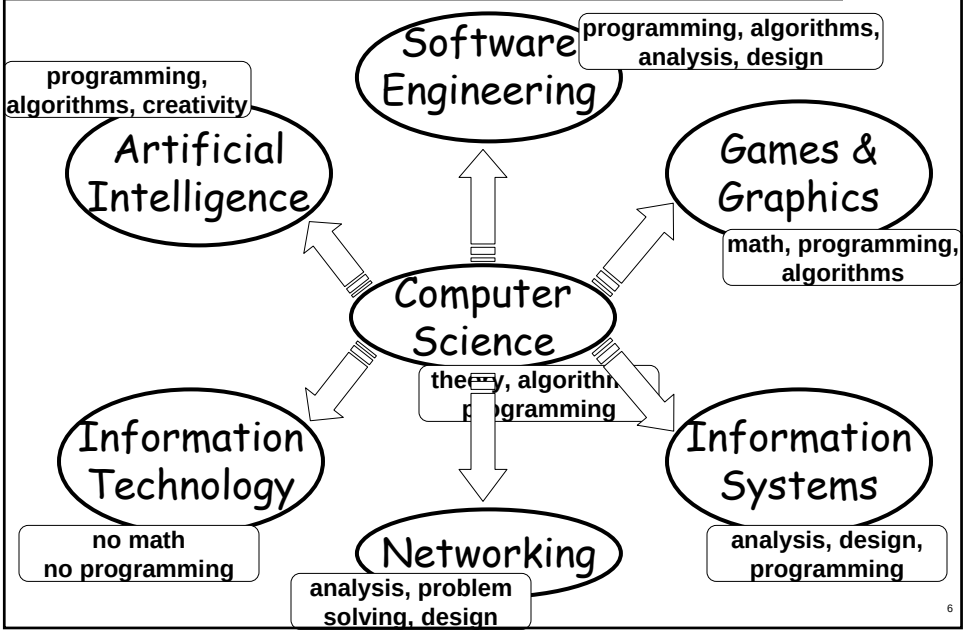
The Changing Face of Computing

- 1980
  - 80% of people in IT industry were programmers
  - CS curricula were based on the research interests of the faculty (automata, OS, compilers, AI, …
  - Almost no experimentation
- 2007
  - < 20% of people in IT are programmers
  - Industry and research interests have diverged
    - CS departments struggle to get people to teach compilers
  - Curricula have changed very little – added networks and graphics

Historical Perspective



Computing Departments (2020)



Computing and Science

- All science requires validation
- Computing almost invariably requires experimental validation
- The behaviors, based on our imagination, must be validated
  - Because they come from our imagination, the validation must be empirical
  - Our goal is to solve problems with computing … the solutions must be demonstrated and validated through executing software

Measuring and Science

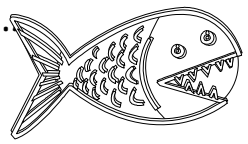
When you can measure what you are speaking about, and express it in numbers, you know something about it.

– Lord Kelvin, 1889

http://zapatopi.net/kelvin/quotes.html

What is a Scientific Test

- The Budweiser Test
  - In a bar, people who liked another brand best were given a "live" challenge – which beer is better?
  - Results?
    - 50% chose Budweiser over their favorite beer!!!
  - Conclusion:
    - Budweiser is better !!!
- Hmmm … something's fishy …



Scientific Test

- Test: Live TV, lots of noise and confusion.
- Subjects wouldn't be able to tell any difference, so we should expect each beer to be chosen …
- Half the time!
- There are three kinds of lies …

Lies, Damn Lies, and Statistics

Lies, Damn Lies, and Statistics

Berkshire Eagle, October 7, 1993 page A3 (An AP story from Boston)

Guns in the home found to increase risk of death

- People who keep guns at home nearly triple their chances of being murdered, usually by friends or relatives, but fail to protect themselves from intruders ...
- The article goes on to describe how the study was conducted, summarizes aspects of the population cross sections and conclusions of the study, and concludes with a refutation by a representative of the NRA
- Paul Blackman, research coordinator at the National Rifle Association, criticized the study ...
  - "These people were highly susceptible to homicide," he said.
  - "We know that because they were killed."

Eating and Talking

- Japanese eat very little fat and suffer fewer heart attacks than British or Americans
- On the other hand, French eat a lot of fat and also suffer fewer heart attacks than British or Americans

Conclusion: Eat what you like. It's speaking English that kills you.

Be Careful Who You Fool

The first principle is that you must not fool yourself – and you are the easiest person to fool.

– Richard Feynman (Nobel Physics, 1965)

Six Ways to Acquire Knowledge

1. Tenacity
2. Intuition
3. Authority
4. Rationalism
5. Empiricism
6. Science

1. Tenacity

Knowledge based on superstition or habit

- Examples:
  - "Good research can only be done by those in their 20s"
  - "OO design has too many subroutine calls and is too inefficient"
  - Java is too inefficient for real use
- Exposure: The more we see something, the more we like it
- Tenacity has
  - No guarantee of accuracy
  - No mechanism for error correction
- Knowledge from tenacity is prejudism

2. Intuition

Guesswork: An approach that is not based on reasoning or inference

- Examples:
  - I think he is a nice person
  - It's probably going to rain today
- We do not really understand why we believe it
- No way to separate accurate from inaccurate knowledge
- Can be used to form hypotheses
- Can be very misleading

3. Authority

Accepted because it comes from a respected source

- Examples:
  - Religion
  - Totalitarian government
  - Rules our parents taught us
- No way to validate or question the knowledge
- Not the same as asking an expert – we can accept, reject, or challenge an expert
  - Teachers are experts, not authorities

4. Rationalism (Reasoning)

Acquisition of knowledge through reasoning

- Logical deduction
- Assume knowledge is correct if the correct reasoning process is used
- Middle ages relied almost exclusively on rationalism
- Important for theory and pure math
  - A mathematical proof is rationalism at its best
  - Theoretical physics … experimental physics
- Easy to reach incorrect conclusions
  - False premises
  - Mistakes in the reasoning or steps skipped
- Use rationalism to arrive at a hypothesis, then test with the scientific method

5. Empiricism

Acquiring knowledge through experience

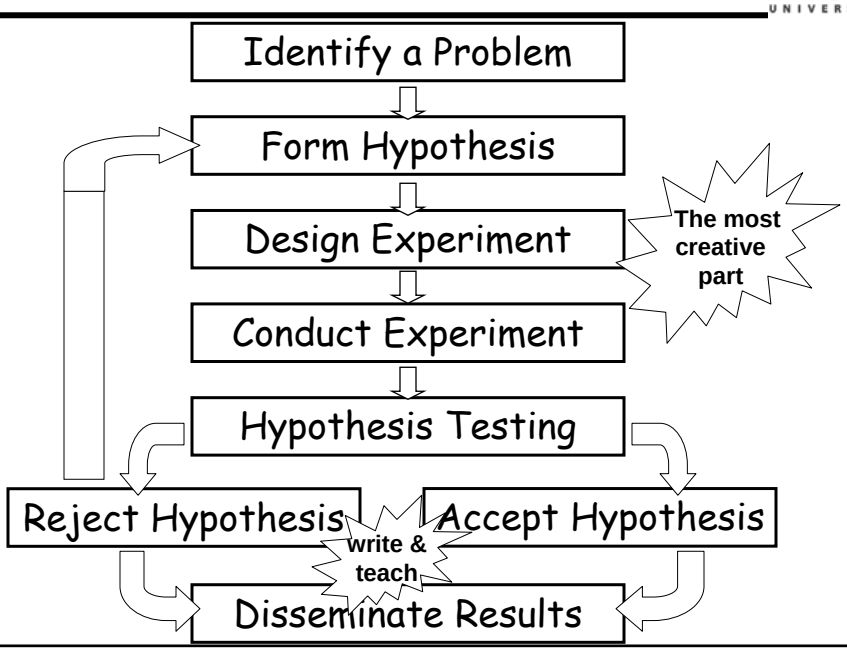
- "I have experienced it, therefore it is true"
- Experience is subjective and hard to control
- "I wrote 3 programs without designing and they worked – designs are worthless!
  - Who wrote them?
  - What programs?
  - Was the the design present but just unwritten?
- Much of computer "science" is just empiricism

6. Science

Testing ideas empirically according to a specific testing procedure that is open to public inspection

- Based on reality
  - Scientists have to look at the fire, not the shadows
- Separate personal beliefs, perceptions, biases, attitudes, emotions
  - We all have biases; science helps us ignore them
- Based on objectively observed evidence

Scientific Method



21

Excellent Scientists

- Lots of decent scientists who are excellent researchers and lousy writers
- Lots of decent scientists who are okay researchers and excellent writers

Excellent scientists do both!

22

Be Problem Solvers

- As Computer Science & Software Engineering majors, you have proven yourselves to be good problem solvers
- Much of life is about solving problems
- Education is not about skills, it is about knowledge
- Use your education knowledge to help you:
  - Think rationally
  - Question authority
  - Solve all of life's problems

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Part II

Terminology and Concepts

Descriptive Research

Used to discover trends and tendencies

- *Observational studies*: systematic measurement of behavior
  - interrater reliability: degree to which independent observers agree on their coding of data
- *Archival studies*: examine records of past events and behaviors
- *Surveys*: asking questions about attitudes, beliefs, and behavior

Scientific Experiment

Used to understand effects

- Changes a set of variables to elicit a response
- Imposes a *treatment* on a group of *objects* or *subjects*
  - Treatment defines a way to change variables

Correlational Research

Used to establish associations between variables

- *Correlation coefficient*: statistical measure of the strength and direction of association between two variables (varies between –1.0 and +1.0)
  - *Positive correlation*: As one variable increases the other also increases
  - *Negative correlation*: As one variable increases the other decreases

Basic Experimental Terms

- *Hypothesis*: A testable prediction about the conditions under which an event will occur
- *Theory*: An organized set of principles used to explain observed phenomena
- *Operational Definition*: A specific way in which a variable is measured or manipulated (*treatment*)

Experimental Variables

- *Independent variable* : Changed by the researcher to determine if it causes a change in the dependent variable
- *Dependent variable* : Measured by the researcher to determine if it is affected by the IV

- *Confounding variables* : Other explanations for the results
  - Driving skills of parents, amount of time driving, emotional problems
- *Measured variable* : If the dependent variable cannot be directly measured, we measure a related variable to approximate
  - Accidents, tickets, attempts to pass the driving test, drivers Ed grade

Validity

- ***Internal validity*** : degree to which there is certainty that the IV caused the effects on the DV
- ***External validity*** : degree to which the results from a study can be generalized to other situations and people
- *Conclusion validity* : degree to which conclusions relationships in the data are reasonable
- *Construct validity* : degree to which inferences can be made from the specific objects in your study to the theoretical constructs on which those objects were based

Experimental Bias

- *Bias*: A flaw in the experimental design or conduct that can change the dependent variable
  - This is often due to an inadvertent introduction of a confounding variable
- *Bias (psychology)*: A flaw introduced by an experimenter whose expectations about the outcome of the experiment can be subtly communicated to the participants in the experiment
  - Often happens when experimenters are also subjects

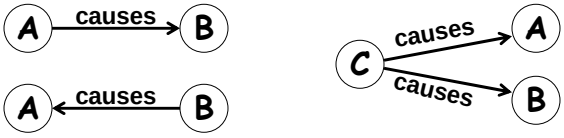
Example

Data flow testing finds more faults than branch testing

- Independent Variables: Data flow, branch testing
- Dependent Variable: Faults found
- Confounding Variables: tool support, characteristics of subjects, specific values chosen, knowledge of testers, …
  - Effects the internal validity
- Bias: If I invented data flow, I expect it to do better

Correlation and Causality

- *Correlated*: Two things always happen at the same time
  - Brake lights and car slowing down
- *Causality*: Understanding what causes something to happen
  - Brake light causes the car to slow down ?
- If A and B are correlated:



Pressing brake activates brake light AND slows car down …

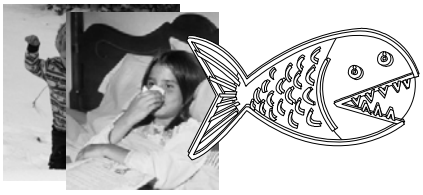
Correlation and Prediction

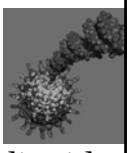
- Correlation: if A happens, then B happens
  - Brake lights and car slowing down
- Causality: if A happens, then it causes B to happen
  - Pressing brake slows the car down
- *Predictability*: if A happens, I can predict that B will happen

We do not need to show causality to have predictability

Confusing Correlation and Causality

- In "*the old days*", we believed that being cold caused us to get colds





- Colds are caused by viruses, not temperature
- Viruses breed in warm, damp, low-oxygen, carbon-dioxide rich environments
- In cold weather, we close our windows and turn up the heat … creating …
- Virginia gets a secondary cold season in July-August … when the weather turns hot and humid …

Cognitive Dissonance

- We feel uncomfortable when new data or a new model contradicts a previously held model
- Revising our mental model to accommodate new data is hard
  - We resist the new idea
- Successful scientists are not bothered by cognitive dissonance
  - *Vive la difference*!

Experimental Design

- Choosing variables, subjects, objects, process and analysis method
- *Pilot study*: small-scale experiment used to design the full experiment
  - Identify potential confounding variables
  - Refine experimental design

Avoiding Bias in Experimental Design

- *Control*: Ensuring the confounding variables do not influence the results
  - I want to measure whether maintenance programmers understand programs better by studying statecharts or reading comments
  - Comments already existed in the program, statecharts generated by experimenter
  - Statecharts were of much higher quality
  - Programmers understood statecharts better …
- Must control for differences in quality

Avoiding Errors of Judgment

- *Randomization*: Objects are assigned randomly to experimental groups
  - *Randomized block design*: Divide subjects into homogeneous blocks, then randomly assign from each block
    - Programmers: undergraduate students, MS students, PhD students, professional
- *Replication*: perform the experiment again, with different subjects, experimenters, or experiment design
  - Most reviewers will not accept replicated experiments

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Part III

Problems Specific to our Fields

Software Engineering

1. The biggest obstacle to software engineering experimentation is that our populations are unknown
   - What is a representative collection of programs?
   - Faults?
   - Developers?
2. Second : Industry won't cooperate
   - In other engineering fields, companies provide access to data, resources, processes, and people
3. Third : "Knowledge inversion" – senior scientists often do not know as much about experimentation as younger scientists

1. Unknown Populations

- How many programs are enough for external validity?
- Are seeded faults as good as natural faults?
- Does using students bias the results?
- How do we analyze our results?

1. Statistical Tests and Software

- Experimental data based on programs cannot, with validity, be subjected to inferential statistical tests since the population is unknown
- An unknown population nullifies any statistical result that would be obtained, regardless of the number of programs
- Only descriptive statistics can be used
  - For example, log linear analysis
- That is, statistical hypothesis testing, at least in the statistical sense, is not accurate

2. Industry Cooperation

- Researchers need access to data from industry to know how techniques work in practice
- Two years ago, my student applied a high-end testing technique to real-time, safety-critical software, finding several bugs
  - She was refused permission to publish, because "customers might think our software is not perfect"
- Seven years ago, a former student applied a test technique I invented to Cisco's routing software, finding several bugs, one very severe, saving millions of dollars
  - $750,000 bonus!
  - Almost fired for telling me
  - Her boss asked me to sign a non-disclosure agreement, afterwards
- Very difficult to get research funding from industry

3. Knowledge Inversion

- Every *generation* of computer scientists has taken a step forward
  - ’70s – ’80s: No validation at all
  - ’80s : We built systems
  - ’80s – ’90s : Results on small sets of data
  - ’90s : Careful experimental design, larger data sets
  - 2000s : Sophisticated statistical analysis of results
- Many journal and conference reviewers lack knowledge to evaluate experiments

Principles to Follow

1) We make progress through continuous, sustained, small, steps – not technological breakthroughs
   - Scientists take baby steps
   - The “big step” is the last of many
   - The Web was the last of thousands of baby steps

2) Collect your data very carefully
   - Identify and control variables
   - Document all decisions
   - Save all data – you may have to repeat the experiment years later

Principles to Follow (2)

3) Collecting is not the goal, analysis and conclusions are the goals
   - Don't lose the forest in the trees
   - Conclusions matter more than measurement

4) Data are uncertain and fallible – design experiments to allow for problems
   - In real science, we always have too many variables
   - In real experiments, we always lose some data

5) Non-inventors need to carry out experiments
   - If I validate my invention, I'm hopelessly biased

Principles to Follow (3)

6) The goal of an experiment in software is to help companies develop better software, cheaper
   – The goal should NOT be to publish another paper

Experimentation Design in Software Engineering & Computer Science

Summary

- SWE and CS are "*inventive*" fields
- Evaluation means determining how useful our inventions are
- Experimentation is the most widely used way to evaluate SWE & CS research

Expectations for evaluation increases every year

Be Problem Solvers

- As IB students, you have learned to be good at solving problems
- Much of life is about solving problems
- Education is not about skills, it is about knowledge
- Utilize your education knowledge to help you:
  - Think rationally
  - Question authority
  - Solve all of life's problems