Engineering Systems Doctoral Seminar

ESD.83 – Fall 2011

Session 2

Faculty: Chris Magee and Joe Sussman
TA: Rebecca Kaarina Saari
Guest: Professor David Kaiser

Session 2: Agenda

- Welcome and Overview of class 2 (5 min.)
- Dialogue with Professor Kaiser (55min)
- Break (10 min.)
- Discussion of other papers (lead Jonathon Krones, 30 -40 min)
- Theme and topic integration (Magee)
  - Science and Research
  - "Stupidity" and Research
  - **Cumulative knowledge in engineering and science**
  - Attributes for enabling knowledge accumulation
  - The Induction/creation question

- Next Steps -preparation for week 3- (5 min.)

Stupidity and Research

- What is the difference between Science and Research?
- Why might doubt be essential for good research?
- What is the difference between dogma and "well established" theory?
- The essence of the enlightenment is that there is ***no unquestionable*** authority on "what is" or "why"

Cumulative Aspects of Science and Engineering/Technology

- The research (science) process with science (knowledge) as the output
  - Falsifiability
  - Laws, principles and theories in the natural sciences
  - On the "validity of knowledge"
  - **What characteristics indicate and/or enable accumulation of knowledge?**
- The engineering or design process with technology as the output
  - What evidence supports technology as cumulative?
  - What enables technology to be cumulative?
  - The induction/creation problem revisited

Falsifiability

- Popper on pages 47-48 gives a 7 point summary of what distinguishes scientific and non-scientific knowledge- he gives an overall statement as *"the criterion of a scientific status of a theory is its falsifiability or refutability or testability"*
- What are some example statements, theories or hypotheses that are
  - Falsifiable?
  - Non-falsifiable?

Falsifiability II

- Falsifiable Theories ("Good" Explanations= hard to vary):
  - Evolution is slow: The age of the earth is 4.x billion years and life first started about 3.y billion years ago
  - The rate of the earth's cooling is reduced by the ongoing internal thermonuclear reactions;
  - In a magnetic material, increasing the *applied magnetic field* aligns the *domains* increasing the resulting field;
  - The speed of light is constant and independent of the speed of the observer's platform
  - People invariably choose the alternative that maximizes their own utility function
  - Decisions are all about choosing among existing alternatives

Falsifiability IIa

- Non-falsifiable Theories ("Weak" Explanations = very flexible):
  - Early childhood events determine one's later dreams and mental difficulties
  - When three or more stakeholders are involved with a project, *anything* can happen;
  - The best organizational design is dependent upon numerous environmental factors
  - It has to be because a supernatural effect made it so.

Falsifiability III

- Popper on pages 47-48 gives a 7 point summary of what distinguishes scientific and non-scientific knowledge- he gives an overall statement as *"the criterion of a scientific status of a theory is its falsifiability or refutability or testability"*
- Confirmation is easy if "theory" is very adaptable. If there is little or no falsifiability, it can never be disproven although it may fall out of favor or become non-fashionable.

Physical Laws from Wikipedia

- A **physical law** or **scientific law** is a scientific generalization based on empirical observations of physical behavior (i.e. the **law of nature** [1]). Laws of nature are observable. Scientific laws are empirical, describing the observable laws. Empirical laws are typically conclusions based on repeated scientific experiments and simple observations, over many years, and which have become accepted universally within the scientific community. The production of a summary description of our environment in the form of such laws is a fundamental aim of science.
- WOULD FEYNMAN and POPPER AGREE WITH THESE STATEMENTS?

Scientific Laws

- **Fluid mechanics**
- Archimedes' principle
- **Force, mass, and inertia**
- Kepler's three laws of planetary motion
- Newton's three laws of motion
- Euler's laws of rigid body motion
- Newton's law of universal gravitation
- **Heat, energy, and temperature**
- Newton's law of cooling
- Boyle's law
- Law of conservation of energy
- Joule's first and second law
- The four laws of thermodynamics
- **Quantum mechanics**
- Heisenberg's uncertainty principle
- Others, such as Roger Penrose with his 2004 book *The Road to Reality* (subtitled "A Complete Guide to the Laws of the Universe") argues that there are a large number of established laws of science. Some laws, such as Descartes' *first law of nature*, have become obsolete.

Falsifiability IV

- Popper on pages 47-48 gives a 7 point summary of what distinguishes scientific and non-scientific knowledge- he gives an overall statement as *"the criterion of a scientific status of a theory is its falsifiability or refutability or testability"*
- Confirmation is easy if "theory" is very adaptable. If there is little or no falsifiability, ***the theory is pseudo-science.***
- Popper makes the point that "pseudo-science" can contribute – it should not be considered necessarily inferior. So why might we care about his "demarcation line"?

Accumulation of Knowledge

- Does falsifiability relate to knowledge accumulation? How?
- Theories/explanations that are not falsifiable cannot be built upon because in a sense they explain everything already.
- All useful theories contain strong prohibitions (Popper). Prohibitions mean we know a lot about where not to look for new knowledge.
- Specific hard to vary explanations have great "reach". We can use predictions to learn new knowledge when they "seem" not to work (Feynman page 13)
- Without falsifiable theories and hard testing, one can end up with "theory du jour".
- Thus, I think that Popper's "demarcation line" is a key characteristic of cumulative knowledge- but using words like pseudo-science or lack of rigor are not helpful in understanding

The role of mathematics in science

- Feynman, Einstein and many others have commented upon the "mysterious" power of mathematics to describe reality.
- How does the role of mathematics relate to our theme today(**accumulation of knowledge**)?
- In my opinion, there is a strong link because mathematical formulations are naturally much more testable/falsifiable.
- However, **in new fields the first conjectures are always non-mathematical** and we cannot count on mathematics having a strong role in all fields at any point in time.

Mathematics and Knowledge Accumulation

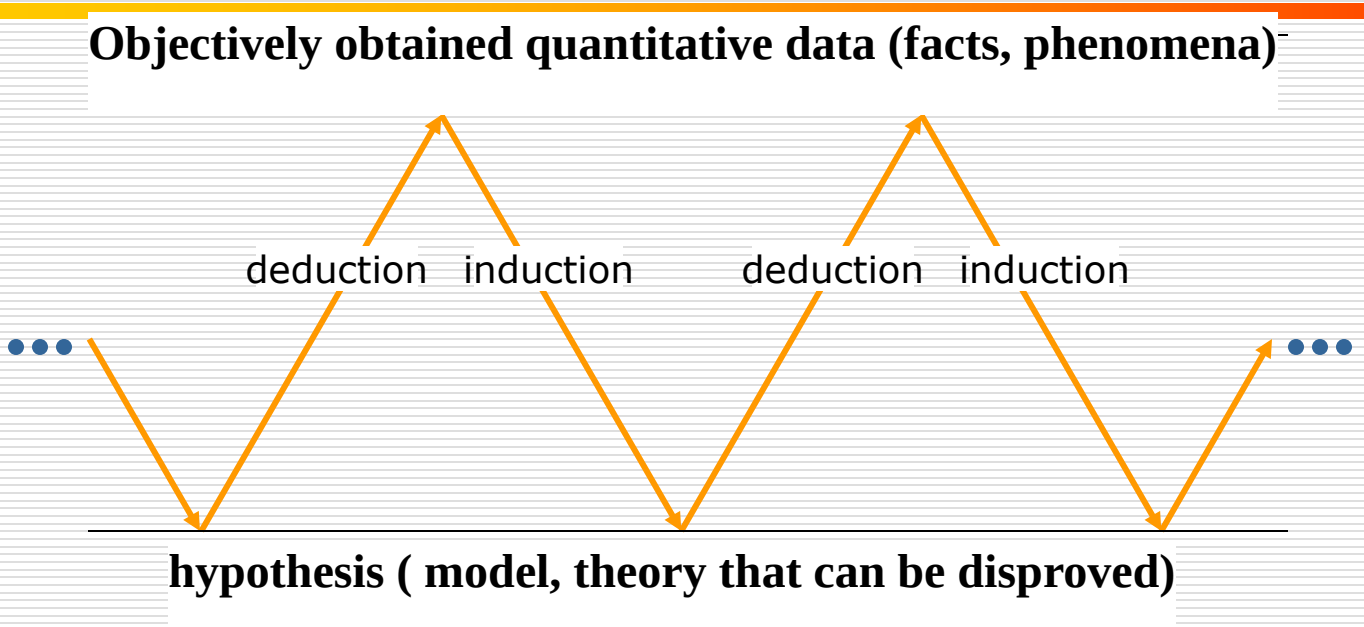
- Is a mathematical basis *necessary* for knowledge accumulation?
- Lord Kelvin "If you cannot measure it, you do not know what you are talking about"
- Evolutionary Theory and Darwin- the most important scientific development in the period during which Kelvin lived had no equations. Does this show that math is not essential for accumulative science?

"Problem of Induction"

- No logical basis exists for establishing "*that those instances of which we have no experience, resemble those of which we have experience" (*Hume in Popper)
- How do successful conjectures arise?
- What about generalizations?

- Are they "wild guesses" that happen to be right (as one might take away from Popper)?

The Iterative Learning Process



A falsified theory serves as a stronger basis for "guessing" a better theory. There are leaps but not without "some prior giant shoulders" (or "multitudes of shoulders in an extensive pyramid") to stand on. Feynman emphasizes that existing theories allow one to make informed mathematical guesses but that experiment is the final arbiter.

How do we go about making better guesses? (later)

Cumulative Aspects of Science and Engineering/Technology

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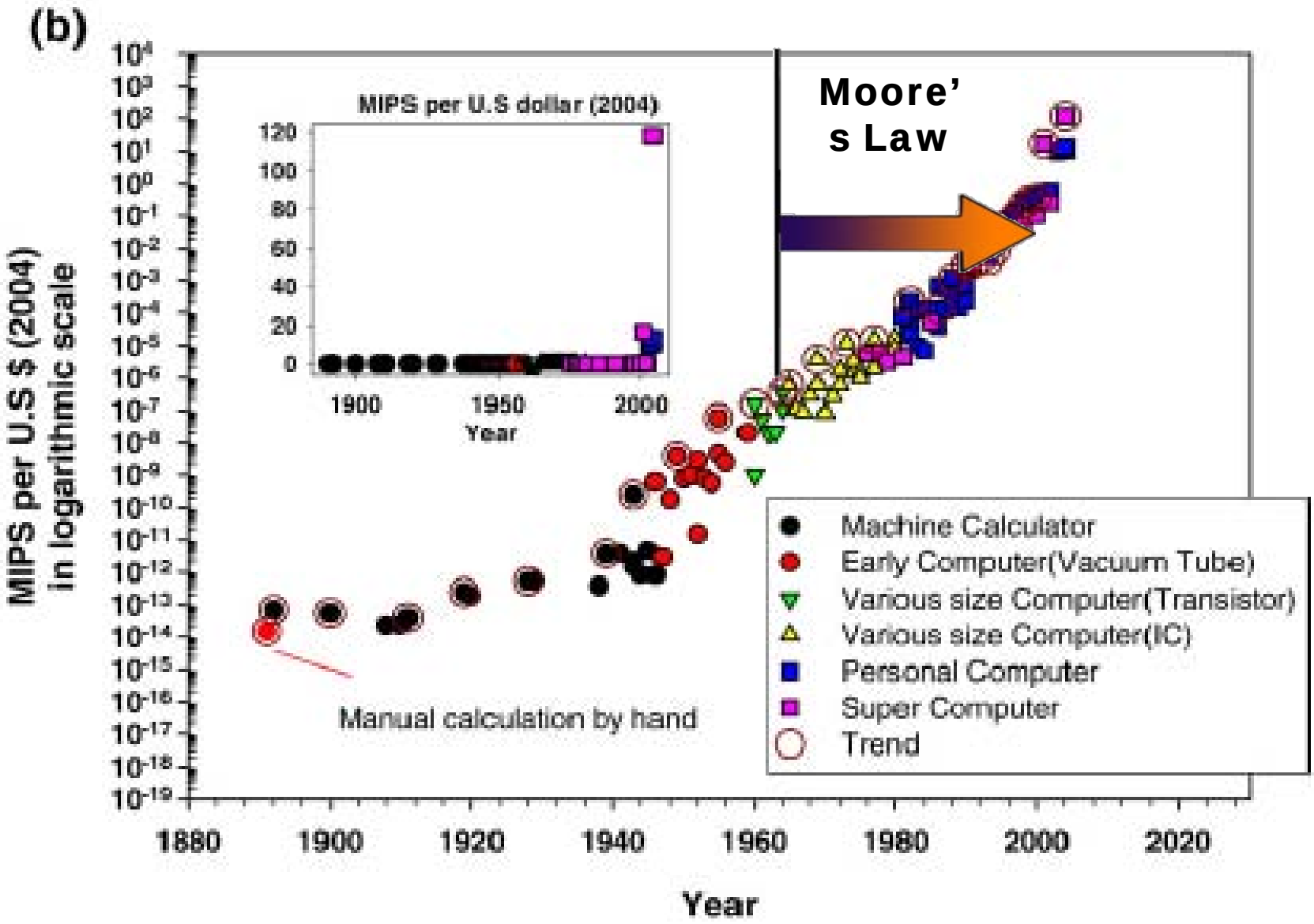
Cumulative knowledge 2

- Do you believe that technology (the output of the engineering/design process) is cumulative?
- How might one measure or determine empirically that technology is or is not cumulative?
- *Measuring* the performance level (design objectives) over time..



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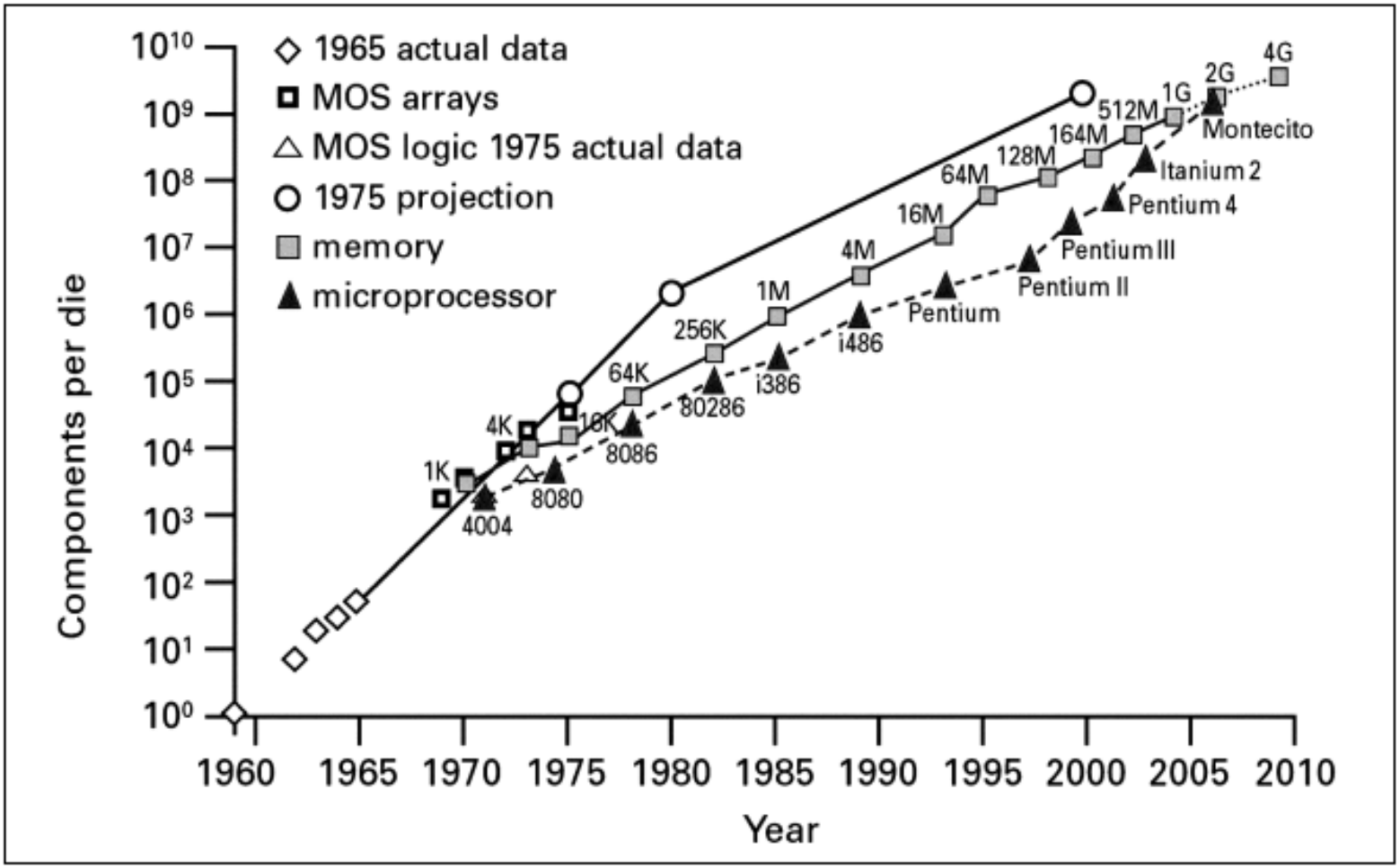


FIGURE 9. Integrated circuit complexity, actual data compared with 1975 projection. Source: Intel.

Courtesy of Intel Corporation. Used with permission.

From Moore, G. E. "Moore's Law at 40"

Technical capability time dependence

- TC = f(K) where K accumulates over time as TC advances
  - dTC/dt = α f(K) $= \alpha$ TC
  - TC = exp(α t); EXPONENTIAL ..

- **Most importantly, exponentials** (even if not forever) **directly indicate accumulation** and no case (~50) denies exponentials for technological change.

Cumulative knowledge 2a

- Do you believe that technology is cumulative?
- How might one measure or determine empirically that technology is or is not cumulative?
- **What cognitive mechanisms might apply**?
- Analogical Transfer: key learning process used by experts in science, engineering (invention) and the arts for creating novelty
- Partial or full "transference" between technological areas: "technology (science) can reap tremendous benefits when practitioners (researchers) move from familiar subjects to new challenges", existing capability used in next advance, engineering principles growth, **the accumulation of scientific knowledge**, etc.

Cumulative knowledge 3

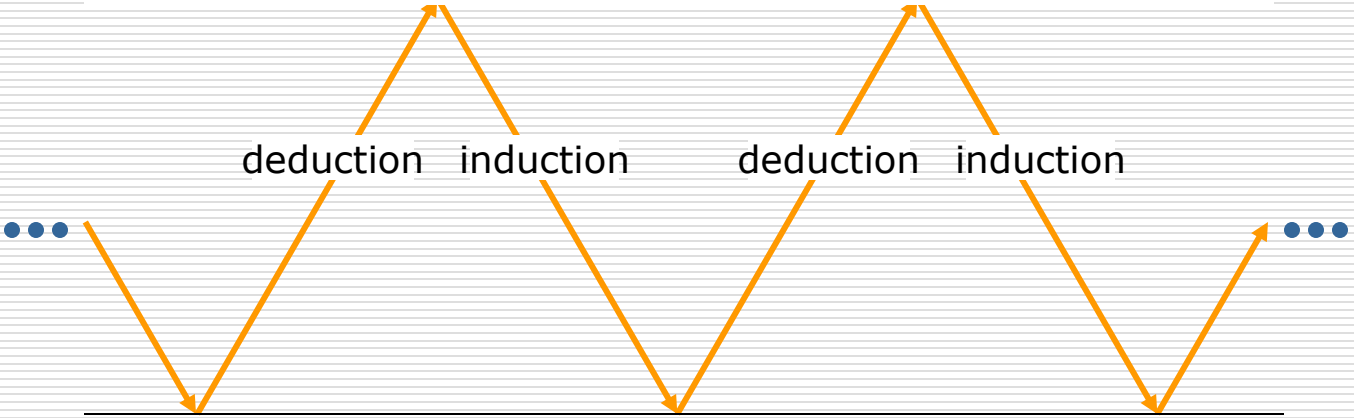
- Is scientific knowledge cumulative- that is that current new knowledge builds upon (all) knowledge that came previously?
- What are possible cognitive mechanisms for accumulation?
- **Is cumulative knowledge apparent in socio-technical systems**?
- MBA experience, ……funding by research agencies (globally)
- What is needed to accelerate the cumulative process in socio-technical systems?

What characteristics indicate and/or enable accumulation of knowledge?

- **Falsifiable theories** (Explanations that are hard to vary);
- **Critical** vs. dogmatic **thinking;**
- The use of **mathematics** and other logic methodology in analysis of observations and creation of theory;
- Strong existing **Knowledge Structures** (more later in course) that enable the **analogical transfer** process
- **Iterative** theoretical and experimental cycles moving from "myths" to well-defined qualitative frameworks to more tightly defined quantitative theories;

The Iterative Learning Process

Objectively obtained quantitative data (facts, phenomena)



hypothesis (model, theory that can be disproved)

As this process matures,
what new can the models accomplish?

The major accomplishment will be the rapid facilitation of a transition to engineering (vs. craft approaches) for the design of complex social/ technological systems. This accompanies the transition from pseudo- science to science

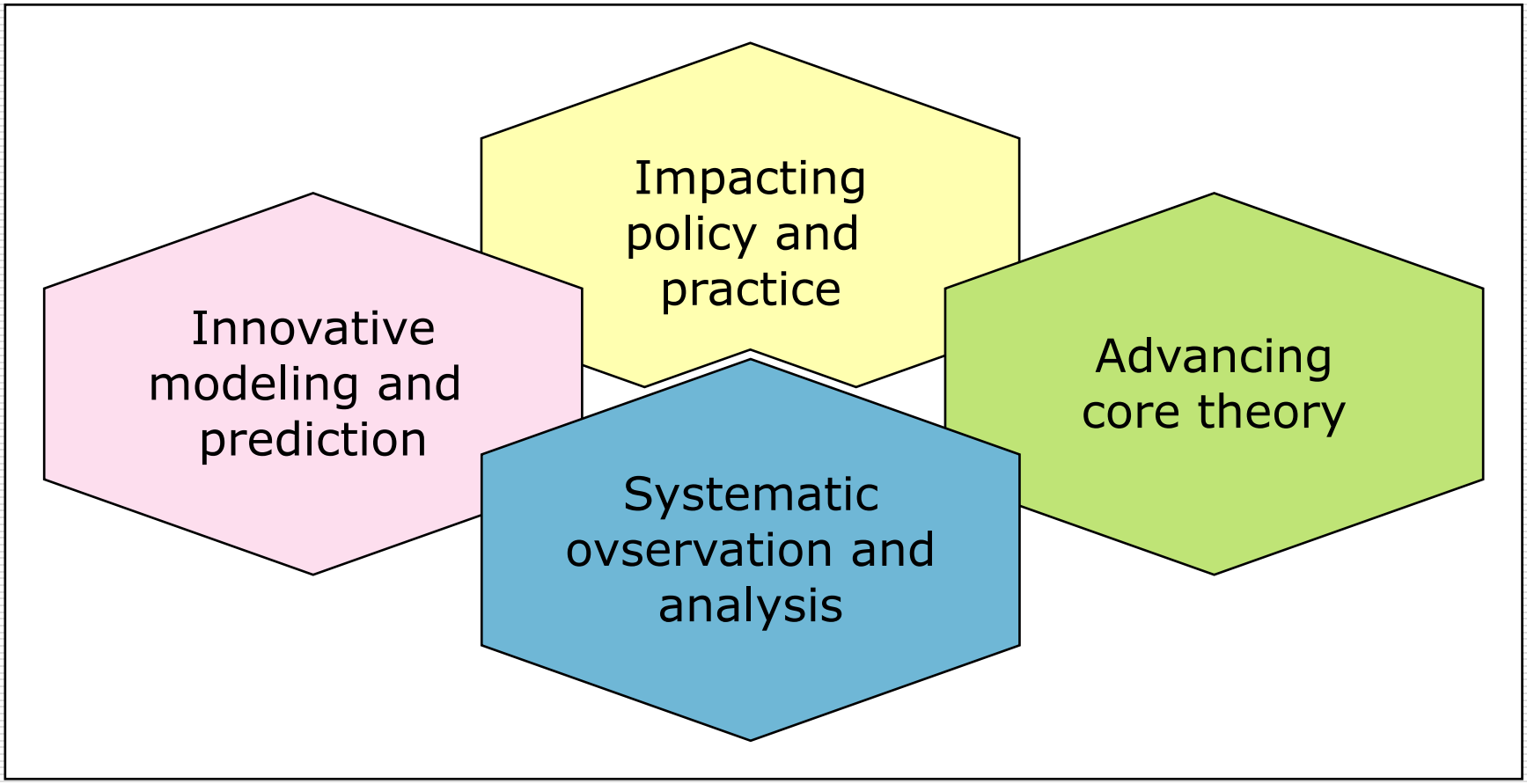
Further topical readings

1. **Readings in a number of other classes**
2. Feynman –*The Pleasure of Finding Things out* and the rest of *CPL* esp. Chapter 7
3. M. Polyani- *Personal Knowledge* (etc.)
4. W. Vincenti, *What engineers know and how they know it*
5. Popper- *Logic of Scientific Discovery* and the rest of *CAR*
6. H. Petroski- *The evolution of useful things*
7. T. Kuhn – *The Structure of Scientific Revolutions*
8. P. W. Medawar- *The Art of the Soluble*
9. I. Lakatos- *Criticism and the Growth of Knowledge*
10. John Dewey- various essays in *The Essential Dewey*
11. Roger Penrose- *The Road to Reality*
12. David Deutsch, *The Beginning of Infinity: Explanations that Transform the World* and *The Fabric of Reality*

Cumulative Knowledge

- A further enabler of cumulative knowledge is to have a research process that includes all four of our previously discussed activities

Strategies for Advancing Engineering Systems as a Field



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Some quotes

- The most incomprehensible thing about the universe is that it is comprehensible. -- Albert Einstein
- Nature uses only the longest threads to weave her patterns, so each small piece of the fabric reveals the organization of the entire tapestry –Feynman
- How can it be that mathematics, being after all a product of human thought which is independent of experience, is so admirably appropriate to the objects of reality? -- Albert Einstein
- "Scientific wealth tends to accumulate according to the law of compound interest. Every addition to knowledge of the properties of matter supplies [the physical scientist] with new instrumental means for discovering and interpreting phenomena of nature, which in their turn afford foundations of fresh generalizations, bringing gains of permanent value into the great storehouse of [natural] philosophy."- Lord Kelvin 1871

More Quotes

- "In physical science the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it***. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind***; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of *Science*, whatever the matter may be." Lord Kelvin
- "Nothing can be more fatal to progress than a too confident reliance on mathematical symbols; for the student is only too apt to take the easier course, and consider the *formula* not the *fact* as the physical reality." Lord Kelvin

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