Engineering Systems Doctoral Seminar ESD.83-- Fall 2011

Class 14

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MIT ESD
Massachusetts Institute of Technology
Engineering Systems Division

Class 14 overview

- Welcome, Overview and Introductions (5 min.)
- Learning objectives and your Learning Summaries (Sussman)
- Student Evaluation (on your laptops)
- Break
- The emergence of the field of engineering systems (Magee)
- Some final words (Sussman)
- Next Steps-- Party (tonight) and Individual Interviews (Friday)

- Review of learning objectives
- Review of learning summaries

Topics & Guests

Class	Topic	Guest
1	ESD: Present and Future – Using Social Science and Engineering in Research & Problem Solving	Moses
2	How do we know what we know? - Cumulative Knowledge Generation	Kaiser
3	Modeling Paradigms in ES: Useful Models and modeling approaches	de Weck
4	System & Enterprise Architecture: Frameworks, Models & System Representation	Rhodes
5	Uncertainty and its analysis in Engineering Systems	Webster
6	Complexity in Socio-technical Systems	Kauffman
7	Complexity and Urban Systems	Zegras
8	Network analysis in Socio-technical Systems	Gonzalez
9	Historical Roots of Engineering Systems	
10	Poverty as a problem in complex systems (& empirical study)	Banerjee
11	Human Dynamics and Cognitive Science in Engineering Systems	Pentland
12	Sustainability and Engineering Systems	Selin
13	Engineering Design and Design of complex socio-technical systems	de Neufville

Learning objectives

- Basic Literacy
- Interdisciplinary capability
- Historical roots
- ES and observations, data sources and data reduction
- Critical analysis
- Links across domains
- Scholarly Skills
- Social Objectives

More Learning objectives-- after the fact

- A style of thought and approach
- A respect for the views of others
- The art of constructive criticism
- Recognizing there can be value even in flawed work
- Recognizing when you are about to hear an ideological statement-- the magic word

Learning Summary-- Categories I

- Boundaries and Visualization-… the crucial importance of both defining a system's boundaries clearly and being open to redefining them………… It was interesting to see where different researchers drew the boundaries in their own work. Prof. Gonzalez…….who explicitly said directly influencing…public policy was beyond the scope of what she wanted to do…compared with Prof. Selin whose work focused very heavily and analyzing and evaluating policy options. (JW)…..Selin visually represents the disconnect between mercury contamination and the policies intended to reduce it (MD)

Learning Summary-- Categories II

- The “ilities”-- extremely useful in helping me understand the unifying features across different complex systems (JW)………. In general, I consider the -ilities can be a helpful guide in framing our PhD topics and establishing a committee (JR)……….. The concept of the ES -ilities may help illuminate valuable research paths to probe the value and impact of user-based innovation in the military (SF)

Learning Summary-- Categories III

- Models-- Unlike traditonal physics models in ES, quantum-like behavior occurs at both limits of model development; at small physical scales, ES modelers account for the highly individualized ……of humans and at large ones, ES modelers must consider that social, economic and political behavior often occurs in the form of Taleb's "black swans"…. All ES models *are* truly wrong (emphasis in original)…in order to effectively apply ES models, researchers must perform a *qualitative* analysis of their model's construction, application and predicting power. (MD)

Learning Summary-- Categories III

- And related to the previous…. Until we have a better understanding of how aggregate human behavior affects the system, it will be difficult to understand the effects of individual actions. (JR)

Learning Summary-- Categories IV

- *Architecting Principles of System-of-Systems* by Maier-- cited by many of you as changing your way of thinking

Learning Summary-- Categories V

- C.P. Snow, *The Two Cultures*--   was an otherstanding opening to the course; the tension between the social and the technical that Snow alluded to was manifest in almost every class discussion (SF)--cited by several others too----and a related thought --- …it is heartening that there is an exceedingly rich body of scholarly work that bridges the gap between the social and technical aspects of large-scale systems…… (JK)

Learning Summary-- Categories VI

- Scale & scope, function, structure and temporality (from de Weck, Roos and Magee)-- cited by a number of you…..to be an excellent organizing principles to both classify and study a broad range range of systems (BY)

Learning Summary-- Categories VII

- Community (aka peer learning)--I find it very interesting to hear how people in different domains interpret problems and solutions and I really enjoyed the many viewpoints that I got to experience over the course of the semester (JT)

Learning Summary--miscellaneous

- …attaining broad acceptance of ES findings requires getting people to fundamentally change the way they understand the world, themselves and their place in the world. This is a very important insight into engineering systems, dramatically raising the bar for the execution and presentation of ES research….. (DG)

Learning Summary--miscellaneous

- The current novelty of the field permits debate over its role, language and practice, as well as vast freedom to select research domains and methodolgies. But will ES see rapid growth…..only to be plagued and stifled creativity and routine production of ES "mechanics?" (SZ)

Learning Summary--miscellaneous

- …….is there a universal way for us to get familiar with the system, then target a specific problem with minimum time spent to meet minimum specialty requirements, but still be able to find an optimal solution? (XZ)

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- We (the instructing staff) learned a great deal from reading your learning summaries
- We hope to learn still more from reading your evaluations, which is what we will do next on your laptops

The Emergence of Disciplines - Learning Objectives

Understand apparent distinctions between disciplines and fields

Explore examples of the way disciplines (and fields) have previously emerged.

Appreciate the nature of "academic expectations" (basis of academic wars) relative to the emergence of fields and disciplines

Appreciate the link between *strong* engineering and an "adequate" science synergy

Examine the implications for Engineering Systems (and ESD doctoral students)

Definitions **from** *American Heritage*

Discipline

6) A branch of knowledge or teaching

Field

5a) An area of human activity or interest

5b) A topic, an area or subject of academic interest or specialization

5c) Professional Employment

Thus discipline is more "purely academic" whereas field implies "practice" as well. Some of the characteristics of fields and disciplines as judged academically and discussed in the coming material are quite similar but the focus of practice vs. academic knowledge is distinguishing. Law, medicine and business are usually not considered disciplines despite existing within academia and doing research. Labeling engineering a field rather than a discipline raises opposition within academic engineering –but nonetheless may be appropriate.

The Coming of Materials Science by R. W. Cahn, 2001

Overview of the emergence of Materials Science as a Discipline (last 100 years and particularly 1940-2000)

This discipline (or should it be labeled a field since it is largely aimed at education of practicing engineers?) emerged by ***integration*** from ceramics, metallurgy, polymer science, etc. with new knowledge encompassing frameworks for understanding diverse materials and new observational methods.

Selected Questions by Cahn..

- How do disciplines/fields evolve? (not always combination or integration of existing)
- Can a discipline be *interdisciplinary*?
- Is Materials Science a real discipline?

Additional questions:

- At what level in a knowledge hierarchy do we ask the questions?
- Do we consider fields vs. disciplines?

Cahn's Characteristics of Academic Disciplines and Fields within academia

- Degree granting departments, agreed upon textbooks
- Journals and meetings - Global "invisible colleges"
- Naming agreement: International Council for Science …(ICSU) *(important body in naming with UNESCO etc links…*
  - *Engineering fields have recognized organizations (national and international) whose members include practitioners and academics within the discipline/field. These organizations are often somewhat separate for engineering practice vs. academic research.*
- Common frameworks and qualitative methods
  - *For engineering fields this focuses on design approaches*
- Common methods for observation and quantification
  - *For engineering fields, this includes quantitative problem-solving methods that are often employed within engineering design*
- Related, if not common, problems
- Understood relationships to other *disciplines/fields-proves difficult with fields within engineering because of necessary growth away from "Historical Roots".*

How have Disciplines and Fields Evolved?

Physical Chemistry

- From a deep dissatisfaction with Chemistry by a few pioneers and then by worldwide research by lots of new Ph.D's
- Merger but still in its parent discipline
- All Founders Nobel Laureates

Chemical Engineering

- Driven by industrial needs particularly relative to education- *does this indicate that it is better thought of as a field?*
- A bitter divorce from Chemistry
- The idea of unit operations to generalize practical processes

In general, fields (if we choose to differentiate them from disciplines) usually arise from evolving and more sophisticated practice which establishes a need for education of practitioners. Fulfilling these educational needs is generally enabled by fundamental research directly related to the practical aims of the field and this research output is generally ***the mechanism for achieving academic credibility and for strengthening engineering practice.***

How have Disciplines Evolved?

- Polymer Science
  - Started from attempts to understand natural products
  - Eventually, after struggling with key concept, became focused on design and production of synthetic materials (*does this indicate it is best labeled a field?)*

- Colloid Science
  - Came and went as branch of applied chemistry

- Solid-State Physics
  - Crucial to formation of materials science but remains part of physics with strong relationship to solid state chemistry

How have Disciplines Evolved?

Solid Mechanics

- Long history with robust intellectual foundation but academically mostly remains a sub-discipline in both (*the fields of*) Mechanical Engineering and Materials Science

Operations Research

- *Grew up in WWII for Mathematical Modeling of Complex Practical Problems (thus started as a field?)*
- *Now is reasonably strong academically but only a few departments use this title as OR is usually imbedded within other fields –a sub-discipline in(for example, industrial engineering or business schools)*
- *Has been somewhat "captured" by optimization- One of OR's sub-disciplines*

Industrial Relations

- *Number one societal challenge post WWII, with land-grant schools established around the country*
- *More recent erosion of support and loss of standing in business school accreditation standards as its* ***practical importance has been judged to be less important***

“parepistemes” and foundations

Par(a)- subsidiary

Epistemology- a domain of knowledge

Thus a specialty or sub discipline

Importance for focusing research (smaller “invisible college”)

Not directly aimed at solving a practical problem

Cahn argues strongly for the importance of parepistemes in discipline evolution

Since engineering fields such as material science or mechanical engineering are basically aimed at solving practical problems (and educating people to do so), one could conclude that such academic “parepistemes” are particularly useful in order for an engineering field to receive academic credibility.

Cahn concludes that it is “through the harsh trial of academic infighting that disciplines win their spurs.”

Are there other reasons **for a strong math and science base for engineering**?

Problem analysis and design (knowledge structure for extrapolation)

Reductionism

Daniel Dennett defends scientific reductionism—which he says is really little more than than materialism—by distinguishing between this and what he calls "Greedy reductionism": the idea that every explanation in every field of science should be reduced to particle physics or string theory. Greedy reductionism, he says, deserves some of the criticism heaped on reductionism in general because the lowest-level explanation of a phenomenon, even if it exists, is not always the best way to understand or explain it.

Anderson clearly defends reductionism (despite many who misstate his position) but uses the term "Constructionism" for an extension of reductionism that he thinks is incorrect

How are "Greedy reductionism" and "Constructionism" as defined by Dennett and Anderson related?

In my opinion, no difference except that Anderson says there are *fundamentals* at higher levels that may be essentially irreducible

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Reductonism II

E. O. Wilson in his 1998 book *Consilience* discusses reductionism in various places:

For example, starting on page 58

"The cutting edge of science is reductionism"

"*The love of complexity without reductionism makes art; the love of complexity with reductionism makes science.*"

"*Dissection and analysis* is the *primary* scientific activity but synthesis and integration are also essential."

What about engineering practice?

Perhaps (at least in practice)…

Synthesis and Integration is the *primary* engineering activity but dissection and analysis are also essential

Reductionism III

How might "scientific reductionism" (dissection and analysis) fit with some themes in ESD 83 ?

- Falsifiability
- Cyclic learning
- Cumulative knowledge

How does Anderson's concept of fundamentals at higher levels in a knowledge hierarchy fit into ESD 83?

Anderson speculation

Can we think of any higher level fundamentals in socio-technical (or engineering) systems?

Aggregate demand and supply vs. price? The concept of supply-demand equilibrium?

Time and income budget consistencies- do they reflect simple heuristics widely used so that like the ideal gas law “work” even with complex lower level details?

Other regularities at higher levels in systems with social and technical complexity?

Small worlds?, Normal distributions, “fat-tail distributions”, ***exponential*** *technical capability growth*, ***logistic*** *substitution curves?*

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Anderson speculation II

To reach the level of *fundamentals* at any level of abstraction, what is needed?

Regularity and predictable behavior (*observation* based)

The fundamental has to be useful in a variety of applications (a keystone or important foundation for cumulative growth of knowledge)

Falsifiable *mathematical model* that predicts the behavior and shows effects of other variables (and consilience?)

Anderson Speculation III

	Regularity	Keystone	Model
S-D equilibrium	YES	YES	YES BUT
Time and income budgets	YES	YES	?
Small Worlds	YES	YES ?	YES BUT
Distributions	YES	YES	YES BUT
Exponentials	YES	YES	YES BUT
Logistic curves	YES	YES	YES BUT

Fundamentals at higher levels of sociotechnical or engineering systems

There are potentially many that may or may not be derivable from lower levels

Economics is one major source but so are other domains and fields

Their weakness is lack of robust experimental testing/falsification of models, inadequate mathematical models and sometimes lack of connection to other fields.

My view is that ESD must contribute to the fundamentals but cannot expect to be dominant (could ME have developed mechanics or A/A fluid dynamics?)

Where does the preceding discussion leave us relative to Engineering Systems?

All analogies can be dangerously misleading

Industrial/societal need is very clear

Supporting science is developing but challenges remain

Progress against criteria (see next slides) appears reasonable

Engineering Systems Status (2003) against the Characteristics of Academic Disciplines/Fields

Characteristics	Status of ESD
Degree granting departments, agreed upon textbooks	MIT has started a "matrix" department with similarity to units at other universities; scope and textbooks are uncertain
Journals and meetings - ***Global*** "invisible colleges"	Journals and "invisible college" is starting – see External Symposium
Naming: International Union of …(ICSU)	Naming game still very open
Common frameworks and qualitative methods	Common frameworks and methods ***are emerging***
Common methods for observation and quantification- parepistemes	Common tools for quantification and modeling approaches are also emerging
Related, if not common, problems	Super set of common problems in discussion
Understood relationships to other fields	Scope and interfaces to other disciplines still open

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Engineering Systems Status (2008) against the Characteristics of Academic Disciplines/Fields

Characteristics	**Status of ESD**
Degree granting departments, agreed upon textbooks	MIT has started a "matrix" department with similarity to units at other universities; *textbooks do not exist*. **Textbook series under development in ESD – definite issue.**
Journals and meetings - ***Global*** "invisible colleges"	Journals and "invisible college" is starting – see Second Symposium and ongoing plans for more events by 40 Universities. INCOSE and INFORMS and parts of IEEE are possible homes so a new society may not be needed
Naming: International Union of …(ICSU)	Naming game still very open but "Macro-engineering" is a real possibility – under discussion at University group.
Common frameworks and qualitative methods	Common integrative frameworks and methods for complex system design are relatively strong compared to other engineering fields.
Common methods for observation and quantification-parepestimes	Common tools for quantification and modeling approaches are emerging (modern network theory and agent-based modeling are two important examples) and OR in general gives important methods (**Possible issue**)
Related, if not common, problems	Super set of common problems in discussion that all involve "messy" complexity (combined human/social and technical complexity).
Understood relationships to other fields	Not yet fully clear but a working hypothesis is that it is an engineering field that brings the social sciences into the underlying disciplines which support engineering (adding to physics, math, chemistry, and now biology)

Engineering Systems Status **(2011)** against the Characteristics of Academic Disciplines/Fields

Characteristics	Status of ESD
Degree granting departments, agreed upon textbooks	MIT has started a "matrix" department with similarity to units at other universities; **First two books in Textbook series out and two more following.**
Journals and meetings - ***Global*** "invisible colleges"	Journals and "invisible college" is starting – see Third Symposium and ongoing plans for more events by 40 Universities. INCOSE and INFORMS and parts of IEEE are possible homes so a new society may not be needed
Naming: International Union of …(ICSU)	Naming game still very open but "Macro-engineering" is a real possibility – under discussion at University group. **I prefer sociotechnical engineering.** Engineering Systems confuses too many people.
Common frameworks and qualitative methods	Common integrative frameworks and methods for complex system design are relatively strong compared to other engineering fields.
Common methods for observation and quantification- parepistimes	Common tools for quantification and modeling approaches are emerging, : OR in general gives important methods (**Definite issue**)
Related, if not common, problems	Super set of common problems in discussion that all involve "messy" complexity (combined human/social and technical complexity).
Understood relationships to other fields	A strong working hypothesis is that it is an engineering field that brings the social sciences into the underlying disciplines which support engineering (adding to physics, math, chemistry, and now biology)

Where does the preceding discussion leave us relative to Engineering Systems? II

All analogies can be dangerously misleading but progress against criteria appears reasonable.

Industrial/societal need is very clear -***thus a field is emerging***

Supporting science is developing- this may not lead to a new scientific discipline but rather to significant changes in existing disciplines such as biology, economics and perhaps physics. The science involves new understanding at higher levels of abstraction that apply in different domains-particularly in socio-technical domains.

Twin threats

- ***Lack of development*** of strong "parepistemes" and non-use of emerging science will threaten academic credibility and not support strong engineering practice
- ***Capture of field*** by a strong parepisteme or supporting science could eliminate practical significance and not allow the needed change in engineering education (incorporation of social sciences in underlying foundation) to occur.

Where does the preceding discussion leave us relative to Engineering Systems Doctoral Students?

What difference might it make if you are a graduate of the division where the important initial work was done?

What role/influence on this possible outcome might ESD Doctoral students have?

Some final comments (Sussman)

My Favorite Quotes of the Semester I

- Art is a lie that tells the truth-- Pablo Picasso

My Favorite Quotes of the Semester II

- A hammer is a useful tool, but you wouldn’t want to use one to wash windows.

IF ESD.83 had a final exam!?

- Here are some questions
- Listing these questions doesn't mean the teaching staff necessarily knows the answers…or agrees what the answers are!

If ESD had a final exam…….

- What would C.P. Snow think about the development of the Engineering Systems Division at MIT?
- How about Popper?

If ESD had a final exam…….

- Systems engineering is a field that traces back 60+ years. Engineering systems is much newer. Compare and contrast these two fields.
- The terminology of "systems engineering" and "engineering systems" has proven confusing. If you were naming the field of engineering systems and ESD back in 1998, what other names might you suggest?

If ESD had a final exam…….

- Engineering systems been taught almost exclusively at the graduate level. It's time for a SB in engineering systems here at MIT. Discuss pro or con.

If ESD had a final exam…….

- There is no such thing as a engineering systems method. Discuss pro or con.

If ESD had a final exam…….

- What seminal thinkers does the field of engineering systems owe the most to? List some and discuss.

If ESD had a final exam…….

- If you could have a cup of coffee and a chat with one of the following, who would you choose? Explain
  - Euler, Marshall, von Neumann, Weiner, Shannon, Forrester, Little, Snow, Kahneman, Simon, Kauffman, Banerjee/Duflo, Schumpeter, Belichick

If ESD had a final exam…….

That’s all, folks!

See you tonight and Friday

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