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Teaching an Engineering Systems Doctoral Seminar: Concepts and Structure

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Abstract

This paper describes the current state of the evolving engineering systems doctoral seminar in the Engineering Systems Division (ESD) at MIT. This subject is required for all first year engineering systems doctoral students. It is intended to bring them into the culture of ESD, and to establish a common base on which subsequent subjects can build. It is the first of three required subjects that make up the core of the ESD doctoral program. The seminar is intended to provide students with the foundations and context of engineering systems, largely focused on providing an appreciation for the many facets of socio-technical complexity. We discuss the seminar's pedagogy, learning objectives, assignments and readings, and provide insights gained from teaching the course.

Key Words: engineering systems, doctoral education

1. Introduction

By establishing the Engineering Systems Division in 1999, MIT has embarked on a bold experiment – bringing together diverse areas of expertise in engineering, management and social sciences into what is designed to be a new field of study. This poses a particular conundrum for the engineering systems educator, namely: how to define and teach a *testable* set of common knowledge? This paper describes the current state of the evolving engineering systems doctoral seminar, a fundamental element in our engineering systems education program. This is the first course in a set of three required courses in the MIT ESD doctoral program. The other two courses are Models, Data and Inference for Socio-technical Systems (ESD.86) and Social Science Research Methods (ESD.87). Taken together, the three courses define the set of testable common knowledge for doctoral students in ESD. The doctoral seminar was initiated in 2002 by Joel Cutcher-Gershenfeld and one of the co-authors, Christopher L. Magee. It has been team taught by two faculty members every year except one. The instructors have each had an affiliation with ESD, though they have backgrounds and other appointments in different traditional academic disciplines. Additionally, the seminar features weekly invited guest speakers from academia and industry. The team-teaching arrangement and use of guest speakers adds depth of expertise while also guarding against the course being captured by a single perspective. Beginning in 2007, a teaching assistant was added to the instructing staff to facilitate weekly discussion sessions on the course readings and other ideas raised in the class. The

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current state of the seminar, as offered in the fall semester of 2008, is described in this paper. But we hasten to add that this course is an evolutionary work, as the field and the instructors' perspectives change.

This seminar is simultaneously designed to codify what we presently know and to give direction for future development in the field of engineering systems. Such material comes from a broad knowledge set and thus at least some readings and guests change from year to year. Nonetheless, the focus across a broad range of topics in Engineering Systems remains the same.

Section 2 discusses the seminar concepts, including the pedagogical context, course themes and learning objectives. Section 3 addresses the seminar structure, including a typical class session and an overview of the 2008 seminar weekly topics. Section 4 provides a detailed description of the seminar assignments. Insights developed by the instructing staff are discussed in Section 5. The complete 2008 book review list can be found in the appendix.

2. Seminar Concepts

This section discusses the pedagogical context, course themes and learning objectives.

2.A Pedagogical Context and Overview

The doctoral seminar is designed to help facilitate the transition from being a student taking courses from experts to being a doctoral candidate, and ultimately a colleague, with a distinctive voice as a scholar. There are few issues covered in the seminar in which there are simple right and wrong answers. In most instances critical thinking and constructive engagement of the issues is most important.

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One challenge of teaching in a nascent field such as engineering systems is that the "goal posts are moving." This requires a dynamic approach, and indeed the doctoral seminar has changed substantially over the years as the field evolves and as the teaching staff learns more about how to present the material. A second challenge involves accommodating the diverse backgrounds of the students, who typically have substantial professional experience ranging from military service to environmental regulatory management, and hold graduate degrees from MIT and elsewhere.

Pedagogically, we have learned to emphasize active learning and particularly peer-learning. Peer learning enables the students to appreciate their differing backgrounds and experiences, while surfacing the need for all to grow in their academic depth and breadth.

2.B Themes

Six themes were discussed and revisited throughout the seminar, as shown below in Table 1. These themes served to interconnect topics or methods that may have initially seemed disparate, and helped to illustrate the pervasiveness of engineering systems issues in society.

Table 1: Doctoral Seminar Themes

Theme 1	Uncovering and understanding the roots of the field of ES and their relevance to contemporary engineering systems issues and concepts.
Theme 2	Advancing the field of engineering systems by practice and differing modes of research, such as simulation, theory and observation.
Theme 3	Considering the structure, function and dynamics of complex systems.
Theme 4	Systems Thinking: what is it, who does it, who doesn't do it?
Theme 5	What is *design* in the engineering systems context?
Theme 6	Considering the set of various complex system characteristics and seeking understanding of Critical Contemporary Issues (e.g. sustainable development, healthcare, global security, etc.) in the context of these characteristics.

2.C Learning Objectives

The learning objectives listed below in Table 2 were established for the 2008 seminar. These objectives were developed based upon prior teaching experience in the seminar and in conjunction with the Teaching and Learning Laboratory at MIT.

Table 2: Doctoral Seminar Learning Objectives

1. Basic Literacy	Understand core ES concepts and principles and a basic literacy in the various aspects of engineering systems.
2. Historical Roots	Understand the intellectual roots of key concepts and principles and the historical emergence of the ES field.
3. Inter-disciplinary Capability	Ability to reach out to adjacent fields in a respectful and knowledgeable way and the ability to engage with other ES scholars in assessing the importance to ES of new findings in related fields.
4. Linkages Across Domains	Ability to identify links and connections across different fundamental domains relevant to ES.
5. ES Data Sources	Ability to professionally search for relevant data sources for ES problems and to appreciate the accuracy and potential value of such sources.
6. Critical Analysis	Ability to critically assess research and scholarship aimed at furthering knowledge in ES; development of defendable point of view of important contributing disciplines in ES.
7. Scholarly Skills	Ability to write a professional-level critical book review; a beginning-level ability to develop and write an ES research proposal; ability to present, lecture and critically analyze material from outside one's prior experience.

Section 5 provides a mapping of the learning objectives to particular course assignments.

3. Seminar Structure

This section discusses the seminar structure, including the list of weekly topics for the semester and an example of a typical week.

3.A Structure of Weekly Seminar Topics

Although certain topics, readings and invited guests change from year to year, the emphasis on socio-technical complexity remains the same. The topics in the seminar have been broadly classified around two main categories, which we term "ES Foundations" and "ES in Context." This reflects an initial attempt to designate certain domains as "foundations" of knowledge in this field, and the recognition that engineering systems principles must also be studied in context. It is not a precise distinction in that classes on "context" will still involve core theory and classes on "foundations" will involve discussion about application. Still, we have found it to be a helpful structure, when not applied rigidly.

The topics from the fall 2008 semester are shown below in Table 3.

Table 3: Representative Structure of Seminar Topics (Fall Term 2008)

Session	Category	Topic
Week 1	Introduction	Overview of Engineering Systems Knowledge, overview of course, discussion of assignments, and data sources available through MIT
Week 2	Introduction	Perspectives from the leadership of the MIT Engineering Systems Division, Engineering Systems Themes
Week 3	Foundations	Emergence of Engineering Systems as a Field and Historical Perspectives on Engineering Systems
Week 4	Context	Safety: A Systems Approach
Week 5	Foundations	Uncertainty and Flexibility: Scenario Planning and Real Options
Week 6	Foundations	Human Nature and Organizational Systems
Week 7	Foundations	Complexity Theory, Agent Models and Economics
Week 8	Mid-term review	Student Presentations for Assignment #1: Data Sources
Week 9	Foundations	Regulations, Standards and Protocols
Week 10	Context	Cities as Complex Systems
Week 11	Foundations	Networks and Critical Infrastructures
Week 12	Context	Energy and Environmental Analysis
Week 13	Foundations	Views of Strategy
Week 14	Context	Healthcare
Week 15	Conclusion	Architecting Engineering Systems as a Field of Study: Integrating Context and Foundations within the Academic Environment

3.B Structure of a Seminar Week

The typical weekly activities during the semester include a one hour instructing staff coordination meeting (Monday), students' submission of written questions on the assigned readings (Tuesday), a three-hour class session (Wednesday), and a one-hour recitation led by the teaching assistant (Friday). These activities are illustrated in Table 4 below.

Table 4: Weekly Seminar Activities

Monday	Tuesday	Wednesday	Thursday	Friday
1 hr. instructing staff meeting	Written questions on weekly readings due to student redactor	3 hr. class session, readings for next week posted online	No scheduled activities	1 hr. recitation

3.C Structure of a Class Session and Recitation

The typical structure of a three-hour class session including the planned durations of activities can be found in Table 5 below. The redactor presentation, report from the front activity and book review will be discussed in detail in Section 4. It is important to note that many of the activities are student-led to encourage peer interactions, as well as the large allocation of time for discussion, consistent with active learning principles.

Table 5: Representative Structure of a Class Session

Activity	**Leader**	**Duration**
Introduction and objectives	Faculty	5-10 min.
Redactor presentation and facilitated class discussion	Student	25 min.
Invited guest presentation and class discussion	Guest	60-75 min.
Break		10 min.
Book review and facilitated class discussion	Student	15-20 min.
Report from the front and facilitated class discussion	Student	15 min.
Seminar faculty presentation (as appropriate)	Faculty	20-45 min.
Next steps and class logistics	Faculty	5 min.

A weekly one-hour recitation was added to the course in 2007 in response to feedback from prior participants. It allows additional time for discussion on the lecture topics and the student questions. The recitation is led by a teaching assistant, who is an experienced ESD doctoral student. The role of the teaching assistant is to serve as a discussion facilitator and to create linkages to relevant concepts and sources. On occasion, a portion of the session is devoted to special topics, including leadership, doctoral process management (e.g. finding a research group, committee selection, milestones, etc.), and feedback on the course. The teaching assistant maintains a near-peer relationship with the students to facilitate an environment for candid dialogue. The faculty rarely, if ever, attends.

4. Seminar Assignments

This section contains the seminar assignments as they were provided to the course participants. Section 5 will discuss the assignments in the broader context of the learning objectives.

4.A Assignment 1: Engineering Systems Data Sources and Representations

This assignment was distributed at the first class session (September 3rd). It involves a paper and presentation, and constitutes 30% of the final grade. The assignment description follows.

> During the first week of the term, students will select a specific engineering system that is highly relevant to their scholarly interests. During the following six weeks, students will be expected to utilize library and internet sources to identify and collect multiple sets of data that are informative regarding aspects of the chosen engineering system. These may be either time-series data sets or cross-sectional, comparative data but both are usually best. Types of available data are discussed in the table below, though students are encouraged to identify and collect data beyond that which is indicated in the table. Students will be expected to prepare a short paper (due on October 8th) documenting the specific data sources identified, with the raw data included in the appendix. At least one set of data must be presented in charts or graphs that provide a particularly instructive or informative perspective (representation) on the chosen engineering system. Students will also be expected to make a brief (5-7 minute) presentation on their system and the range of data sources identified on October 22- week 8. The presentations should also include 2-3 ESD-style research questions or hypotheses about their systems. These are not expected to be extremely refined research questions or hypotheses with detailed literature reviews and analysis to support them; the emphasis is for students to find interesting first-pass research questions that cover both the technical and social complexity of the systems under study.

Assignment 1 is intended to help students choose appropriate boundary definitions for their engineering systems of interest, and familiarize them with the numerous sources of data and collection methods relevant to engineering systems research. Additionally this assignment requires students to organize and categorize diverse data sets into meaningful system representations and develop rough drafts of engineering systems-type research questions. The oral presentations from this assignment (about 15 minutes per student) are delivered during the Week 8 Mid-term Review. It is intended that the data gathered during this assignment may be reused in some form for the class projects of the subsequent two ESD doctoral program core courses.

4.B Assignment 2: Report from the Front

This assignment was distributed at the first class session, but with a different due-date for each student. The goal is to have one "report from the front" presentation per week. It requires a brief presentation and facilitation of an approximately 10 minute discussion. This assignment is considered as a component of the overall class participation grade. The assignment description follows.

> Each week will have a "report from the front" in which a student is assigned to come to class prepared to discuss an item in the current news that relates to the themes and concepts of the doctoral seminar. Each student will have one opportunity to make this presentation. We will alternate weeks. In one week the student will be asked to choose an article from the New York Times, from their Sunday, Monday or Tuesday edition; in the alternate week the student will select an article from the current issue of the well known newsmagazine The Economist.
>
> The student is responsible for sending a web link of the article to his or her classmates and the instructing staff by the Tuesday before class at 6 p.m. If you have trouble getting a web link please contact one of the instructing staff.
>
> The student will briefly present the salient points of the article, how he or she sees it connected to the doctoral seminar topics, and then facilitate a discussion by the other students on this article. We will particularly want you to relate it to readings and discussions from past classes; we recognize that this will be easier as the term progresses.

This assignment is intended to demonstrate that a wide variety of interesting complex socio-technical engineering systems are "everywhere." Further, it is an opportunity to relate the systems from the news to the complex system themes discussed in class.

Table 6 provides a sample of the article titles students selected for the report from the front assignment.

Table 6: Sample of Titles for Report from the Front Articles

Source	**Date**	**Article Title**
NY Times	9/9/08	"Google tightens data retention policy – again"
Economist	9/18/08	"A rising tide: scientists find proof that privatizing fishing stocks can avert a disaster"
Economist	10/23/08	"Clouds and judgment: computing is about to face a trade-off between sovereignty and efficiency"
NY Times	11/3/08	"Hints of comeback for nations first superhighway"

4.C Assignment 3: Redactor Role

This assignment was distributed at the first class session. Each student serves as the redactor once during the semester. The assignment entails compiling and organizing the written questions from the class on the weekly readings. The readings relate to the weekly topic and often include writings by the invited guest instructor. The redactor initiates the class discussion with a presentation of approximately 10 minutes, and then facilitates a broader class discussion for a total of 25 minutes. This discussion sets the stage for the class session, which includes guest and faculty interaction with the students generally going more deeply into certain of the topics covered in the assigned readings. This assignment is worth 15% of the final grade. The assignment description follows.

> Once each semester, each student will serve as redactor for the session. Weekly, each student in the class is asked to provide 3-5 discussion questions to prime the class for the guest or seminar faculty presentation. The redactor will organize the questions into coherent categories and will lead a discussion of which questions are of most importance and interest for further discussion in class and beyond.
>
> The redactor is expected to bring 17 copies of the categorization of the questions to class for easy reference.

This activity is a major part of the peer-learning process and is also important in forming a cohesive cohort, as the students learn to appreciate the background and experience of their classmates. An example of the class readings and redactor categorization of the students' questions (taken from week 2 of the semester) is provided below.

Reading assignments for week 2:

- Ackoff, R.L., "Systems, organizations, and interdisciplinary research," General Systems Yearbook, Vol. 5 (1960), Society for General Systems Research, pp. 1-8.
- Churchman, C. West. *The systems approach*, Dell Publishing Company, New York, 1968. (Chapter 1, pp. 1-15)
- Holland, John H., "Complex adaptive systems," Daedalus, Vol. 121, No. 1, (Winter 1992), pp. 17-30.
- Rouse, William. "Complex engineered, organizational & natural systems: issues underlying the complexity of systems and fundamental research needed to address these issues," Engineering Directorate, National Science Foundation, Washington DC, June 2007.
- Senge, Peter. *The fifth discipline: the art and practice of the learning organization*, Doubleday, New York, 1990. (Chapter 4 and Appendix 2)
- Simon, Herbert A., "Prediction and prescription in systems modeling," Operations Research, Vol. 38, No. 1, (Jan.-Feb. 1990), pp.7-14.
- Tilles, Seymour, "The manager's job: a systems approach," Harvard Business Review Vol. 41, No. 1, (Jan.-Feb. 1963), pp.73-81.

Table 7: Example of Redactor Categorization Scheme for Week 2 Readings

Category		**Number of Questions**
I	Modeling	5
II	System boundaries	4
III	Categorization as an Engineering System	9
IV	Architectures	3
V	Engineering Systems education	10
VI	Research goals and direction	6
VII	Management	6
	TOTAL	43

4.D Assignment 4: Book Review

This assignment was distributed at the first class session, with it being due on a different date for each student to enable on book review being presented each week. This assignment requires a written (approximately 750 word) book review and brief class presentation. This assignment constitutes 10% of the final grade. The assignment description follows.

> Once during the term, students will be expected to prepare and present brief book reviews selected from the options listed – or books independently suggested by the student. Each book review should be written in a format comparable to a published book review in a professional journal – conveying the key message of the book and providing appropriate critical analysis as well.
>
> Note: Do not select books to review that you have already used in prior courses – the aim here is to push the frontiers of your knowledge. Also, if you are unfamiliar with writing book reviews, examine the reviews published in 2-3 leading scholarly journals. In general, a review should have an introductory paragraph with a framing thought, followed by a *very brief* summary of the book's key arguments, an evaluation of the books strengths and limitations, a placement of the book in the larger literature, and concluding comments.

The book review list for this assignment is included in the appendix.

4.E Assignment 5: Historical Roots Paper

This assignment was distributed at the third session. It involves students working in groups of two to produce a paper of approximately 1000 words on the historical roots of engineering systems. It constitutes 10% of the final grade. The assignment description follows.

> The field of contemporary engineering system derives from many historical roots. Some selected roots of engineering systems are given in the table below.

Table 8: Examples of Engineering Systems Historical Roots

Author	**Field or concept**	**Starting date (approximate)**
C. Shannon	Communication Theory	1940s
L. Bertalanffy	General Systems Theory	1930s
J. Schumpeter	Impact of Technology on the Economy	1930
S. Ramo	Systems Engineering	1950s
J. Forrester	Systems Dynamics	Late 1950s
H. Simon	Organizational Theory	Early 1940s
N. Weiner	Cybernetics and Control Theory	1950
T. Shelling	Agent Based Modeling	1960s
P. Morse	Operations Research	1940s
L. Euler	Network Analysis	1776
H. Simon	Complexity Theory	1962
V. Hubka	The Science of Engineering Design	1960s
A. Wald	Decision Theory	1939
E. O.Wilson	Sociobiology	1975
R. Richta	Technological Evolution	1960s

From these roots (and others as well) the field of contemporary engineering systems has emerged.

One way (but far from the only way) to characterize the field of contemporary engineering systems is by considering the various methodologies that support the field now. Examples of what we might consider as methodologies for contemporary engineering systems along with key authors are given in the table below.

Table 9: Examples of Contemporary Engineering Systems Methodologies

ES Methodology	**Suggested Authors**
System Dynamics	J. Sterman
Agent Based Modeling	R. Axtell
Benefit Cost Analysis for Project Evaluation	T. Nas
Real Options Analysis	R. de Neufville
Stakeholder Analysis	R. Freeman
Strategy Development	H. Mintzburg, M. Porter
Grounded Theory	B. Glaser, A. Strauss
Decision Making Under Uncertainty	R. Keeney, H. Raiffa
System Architecting	E. Rechtin, M. Maier
Social Networks	D. Watts

We note that some of the same terms appear in both the list of historical roots and methodologies of contemporary engineering system (eg system dynamics, agent based modeling), reflecting the evolution of these concepts. The system dynamics of today is substantially different than the technique developed by Jay Forrester a half-century ago and was likely influenced along the way by other roots.

This relationship between historical roots and current engineering systems methodologies can be approached in one of two possible ways.

The first approach is to choose one of the possible historical roots noted above (or perhaps an additional one you would like to suggest) and trace it forward to indicate its impact on the field of contemporary engineering systems as characterized by the methodologies, also noted above. So you want to identify scholarly work that built upon the root, tracing it through to today's foundation methodology. Some of the roots may impact several of the foundation methodologies.

There is an alternative way to think about the relationship between past intellectual developments and the field of contemporary engineering systems. This involves "backcasting" from where we are today to the roots. In this construction one chooses one of the methodologies of *contemporary engineering systems* and works backwards in time to ascertain from whence it came. Again, a methodology as used today may derive from several of the roots. We have defined

> each methodology as currently used by noting the work of key authors on that methodology. Again, you could suggest additional current methods or authors.
>
> For this assignment, we ask you to work in pairs, which we have specified to create diversity in interests. Each pair will select one historical root and one methodology as currently practiced. We suggest (but don't require) that you choose a root and methodology that are related such that you expect that the root will be one you believe a priori affects your current methodology. The instructing staff will approve your root/method pair. First come, first served since we want to avoid duplication as much as possible. *And remember you are invited to propose other historical roots or current methodologies.*
>
> It will be interesting to contrast what we learn from the two approaches—eg if a root-based analysis shows impact on a methodology, did the methodology-based analysis trace back to that root?
>
> This assignment should involve careful historical research of the literature and result in a single jointly submitted paper that describes both the flow from historical root to current methodologies, and the flow from current methodology to historical roots. The paper should be about 12 pages, including tables and figures you may use to illustrate the interconnections in the literature. (Remember, visual thinking can be powerful) It is envisioned that the references should be extensive (30-40 might be typical).
>
> Some approaches you should include in your paper:
>
> - Contributors *not* listed in the historical roots table and contemporaneous scholarly responses to the work of the author we cite.
> - Citation analysis to estimate the influence of various works as paths between roots and methodologies are developed.
> - Influences on practice and research in various domains/contexts that are clear today.

4.F Assignment 6: Developing a Well-Posed Research Question

This assignment was due on week 14 (December 3rd). It requires a paper of 750 words and constitutes 10% of the final grade. The assignment description follows.

> Select a pressing problem associated with your primary area of scholarly interest, possibly building on the data that you have identified for the data sources assignment.
>
> Write a brief memo that includes the following:
>
> - Overarching Problem Statement – motivation for the research.
> - Specific Research Question – posed broad enough to be relevant, narrow enough to be the subject of a rigorous 18-36 month research study that has a high probability of yielding definitive insights.
> - Additional Request: Be sure to also include an example of a Research

Question in this same domain that is far too broad and an example of one that is far too narrow.

- Summary of Relevant Data, Tools, Methods, Models, and Design – a succinct statement on the way you will go about addressing the research question (recognizing that there is always additional learning that emerges in the research process).

> Thus, the memo should have three major parts, which correspond to "What" you will study (the research question, with the overly narrow and overly broad additions), "Why" the study is important (the problem statement), and "How" you will do the research (the Data, Tools, Methods, Models, and Design). Note that the other two "Ws" – the "Who" and the "When" – are already set. The "Who" is you and the "When" is the approximate time to complete your doctoral dissertation research.

4.G Assignment 7: Learning Summary

This assignment was due during the final week of the semester. It requires a paper of 750 words and constitutes 10% of the final grade. The assignment description follows.

> Document 2-3 key lessons learned that represent new or important insights into Engineering Systems as a field the originated in the doctoral seminar. Also, document 2-3 key lessons learned that represent new or important insights relevant to your doctoral thesis. As an appendix, please suggest any books you have read that you believe would be valuable to add to our doctoral seminar book review list.

5. Discussion

The doctoral seminar is designed to help students make the transition toward becoming a scholar. Since there are few issues in engineering systems with simple right and wrong answers, the seminar emphasizes active learning strategies, whereby the responsibility for learning is placed on the learners. The redactor role, report from the front, and book review assignments all include an element of student-led discussion. During these discussions, the instructing staff mostly refrains from comment, only stepping in if the discussion becomes bogged down. Students have expressed the frustration of feeling somewhat like the blind leading the blind. However this open-ended engagement with the issues of engineering systems is important as students will fall back on their own experiences thereby sharing authentic lessons with the class. This dynamic is crucial to the formation of a cohesive cohort of students.

The invited guest and seminar faculty-led portions of the class typically follow the more common "expert-student" lecture and discussion model. However, students often ask more integrative questions to the expert, such as how their methodology relates to another or more broadly to the engineering systems field.

Engineering systems are, by definition, complex. As a result they may be approached and understood through numerous perspectives. Several activities, readings and faculty lectures emphasize the development of multi-modal thinking styles, including visual, numerical, and logical. Students are challenged to use these skills to create new and useful system representations.

Changes to the course have been made as the field evolves and as the teaching staff learns more about how to present the material. As an example, this year the historical roots assignment was added. Students and faculty alike found this assignment generated many insights. Students were assigned in pairs based on the dissimilarity of their backgrounds, but were free to choose their historical root and contemporary methodology. The pairing of the students worked well and served to make interconnections in the cohort that may not have otherwise formed. However, in view of the through and excellent work produced, perhaps its value of 10% of the final grade was too meager.

Though changes are inevitable and in many cases welcome, it is important that faculty guard against "scope creep." There will simply always be good material left out of any seminar on engineering systems.

With this limitation in mind, the seminar assignments are designed to maximize "bang for the buck" with regard to their linkage to the learning objectives. As illustrated in Table 10 below, each assignment covers several learning objectives, with one or two objectives per assignment bolded and italicized for emphasis.

Table 10: Mapping of Assignments to Learning Objectives

Assignment Title	Deliverable	Learning Objectives Satisfied
1. Engineering systems data sources and representations	Paper & presentation	1) Basic Literacy, 4) Linkages Across Domains, ***5) ES Data Sources***, 6) Critical Analysis, 7) Scholarly Skills
2. Report from the front	Presentation and facilitated discussion	1) Basic Literacy, ***3) Inter-disciplinary Capability***, ***4 Linkages Across Domains)***, 5) ES Data Sources, 7) Scholarly Skills
3. Redactor role	Paper, presentation and facilitated discussion	1) Basic Literacy, ***3) Inter-disciplinary Capability***, ***4) Linkages Across Domains***, 6) Critical Analysis, 7) Scholarly Skills
4. Book review	Paper, presentation & facilitated discussion	3) Inter-disciplinary Capability, 4) Linkages Across Domains, ***6) Critical Analysis***, 7) Scholarly Skills
5. Engineering systems historical roots	Paper	***2) Historical Roots***, 4) Linkages Across Domains, 6) Critical Analysis, ***7) Scholarly Skills***
6. Developing a well-formed	Paper	3) Inter-disciplinary Capability, 4)

research question		Linkages Across Domains, 5) ES Data Sources, 6) Critical Analysis, ***7) Scholarly Skills***
Learning summary	Paper	***1) Basic Literacy***, 2) Historical roots, 4) Linkages Across Domains, 6) Critical Analysis

6. Conclusion

In general, the course is felt to be valuable by participating students and faculty (including the invited guests). The students connect themes throughout the course and it is easily noticed by the faculty (but not necessarily by the students) that the level of discussion in the redactor sessions grows in understanding throughout the term.

At the end of the semester, the seminar instructors meet with each student for approximately one half hour to give the student their final grade and, more importantly, candid feedback on the student's strengths and weaknesses, presented as constructive criticism. Students are asked about their future plans and for their feedback as to how the seminar could have been better structured to contribute to their future professional trajectory. These sessions are designed to be a learning experience for all concerned. This feedback, in conjunction with the standard MIT course evaluation forms, provides input for the continuous improvement of the doctoral seminar. It is certainly the intent of the teaching staff to implement improvements each year.

7. Appendix: Doctoral Seminar Book Review List

This categorized list of books was provided to students for their book review. Books actually selected for the 2008 class are indicated with an asterisk. Though an effort was made to span a broad area of intellectual inquiry relevant to engineering systems, it is by no means intended to be a complete list (and was in fact far reduced from the instructing staff's initial set). Students are given an opportunity to suggest new books to be a part of this list at the end of the semester.

Agent-based Modeling

- *Schelling, T. C. (2006). Micromotives and macrobehavior. New York, Norton.

Complexity/Chaos/Emergence

- *Holland, J. H. (1995). Hidden order: how adaptation builds complexity. Reading, Mass., Addison-Wesley.
- Wilson, E. O. (1975). Sociobiology: the new synthesis. Cambridge, Mass., Belknap Press of Harvard University Press.

Decision Making

- *Allison, G. T. and P. Zelikow (1999). Essence of decision: explaining the Cuban Missile Crisis. New York, Longman.
- *Gawande, A. (2002). Complications: a surgeon's notes on an imperfect science. New York, Metropolitan Books.
- Klein, G. A. (1999). Sources of power: how people make decisions. Cambridge, Mass., MIT Press.
- March, J. G. and C. Heath (1994). A primer on decision making: how decisions happen. New York, Toronto, New York, Free Press; Maxwell Macmillan Canada; Maxwell Macmillan International.

Design

- Schön, D. A. (1991). The reflective practitioner: how professionals think in action. Aldershot [England], Arena.
- Vincenti, W. G. (1990). What engineers know and how they know it: analytical studies from aeronautical history. Baltimore, Johns Hopkins University Press.

Economics and Technological Progress

- *Fogel, R. W. (2004). The escape from hunger and premature death, 1700-2100: Europe, America, and the Third World. Cambridge; New York, Cambridge University Press.
- *Mokyr, J. (2002). The gifts of Athena: historical origins of the knowledge economy. Princeton, N.J., Princeton University Press.

Ethics/ Values

- *Ackerman, F. and L. Heinzerling (2004). Priceless: on knowing the price of everything and the value of nothing. New York, New Press: Distributed by W.W. Norton.
- Rees, Martin. "Our Final Hour: A Scientist's Warning: How Terror, Error, and Environmental Disaster Threaten Humankind's Future in this Century – On Earth and Beyond"
- Sen, A. K. (1987). On ethics and economics. Oxford [Oxfordshire]; New York, NY,

USA, B. Blackwell.

- *Singer, P. (1995). Rethinking life & death: the collapse of our traditional ethics. New York, St. Martin's Press.

History

- *Hughes, T. P. (2000). Rescuing Prometheus. New York, Vintage Books.
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Leadership

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