

# Essay on Teaching Contributions

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### 1. Teaching Philosophy and Innovation

#### On Pedagogic Aspects

Learning is a complex process. The student has to go through several steps from acoustic and visual reception, comprehension to memorization, internalization and finally externalization. This last step means that the student has acquired the ability to project the material back into the outside world by explaining the concepts and notions to others or by applying them in the solution of meaningful problems. In the context of CDIO it is paramount that the student understand the context and strategic value of the material in the conception, design, implementation or operation of a particular system or its place in society and the physical world at large.

#### On Student Motivation

Student motivation should come from within, from a thirst of new knowledge, from natural curiosity and a desire to acquire skills and knowledge, which will make a difference in the world. Students are motivated if a subject is presented in an interesting, lively way. The class should be a bi-directional communication, where students are challenged with questions at regular intervals. A particularly interesting motivator is competition. This is exploited in robotics courses, but could be extended to theoretical classes with e.g. benchmark computational competitions. It is important to praise and somehow reward all participants at the end regardless of the results.

#### On the use of media

New technologies such as computer projections and CAD/CAE/CAM work offer new possibilities but also carry some danger with them. Learning might actually be hampered by an overload of visual information and the essentials might get lost compared to the good old days, where only blackboard and chalk existed. Thus, these multiple media have to be used sparingly to emphasize very important concepts or to show real world applications. The use of high quality printed handouts and selected key publications from the literature supplements the students own notes and provides a solid body of reference on the subject which is of long-term value. Due to the flood of printed media a good set of hand-written notes given out by the teacher might be very effective as well.

#### On problem sets and examinations

Learning by doing is most effective. And the difference in grasp and depth of knowledge between a listener and a for-credit student is generally very significant. It is during the long hours of solving interesting, challenging and meaningful problem sets, which fit well in the context of the theoretical material presented in class, that the mind grows and actual skills are acquired. This is especially true if problems are posed (and solved beforehand by the professor!), which cannot be solved by applying a simple cookbook recipe, but rather require several steps of decomposition, analysis and synthesis. The problem sets should not be too long to avoid frustration. Examinations are required to create academic pressure and force the student to internalize important concepts and equations and to view the subject in a broad, unified way and - last but not least - to obtain meaningful grades. The use of case studies in engineering should be explored, where they can add value and anchor concepts in the real world.

Innovation Nuggets: Integrated Modeling and Simulation class, Multi-objective Optimization and Tradeoff Analysis class, benchmark competitions, engineering case studies, stressing the strategic value of the material and relation to CDIO context.

## 2. AA existing courses

The following class would be my choice, when it comes to teaching a course from the existing course 16 curriculum. The course description has been modified from the catalog and would probably have to be shortened somewhat.

### **16.851 Satellite Engineering**

alternate title: **(Spacecraft Design and Engineering)**

G (Fall) H

Prereq.: Permission of Instructor

Units: 4-0-8 (previously 3-0-9)

Introduction to spacecraft design and engineering. Definition of space systems engineering, requirements flowdown, mission analysis and space environment. Orbital mechanics, coverage analysis, launch and constellation design, non-Keplerian perturbations, Hill's equations. Attitude determination and control with emphasis on 3 axis stabilized vehicles. Space communications including link budget, carrier frequency allocation and compression. Power generation and distribution for near-Earth and deep space missions. Thermal management system, structural design, deployment, mechanisms, pyrotechnics and payload integration. Reliability, serviceability, vehicle assembly, integration and testing. Configuration and architecture considerations. Field trip to a commercial satellite manufacturer.

- midterm and final examinations
- no class project
- weekly problem sets
- field trip to satellite manufacturer, field trip report focusing on a different topic for each student (clean room and assembly procedures, test and integration, customer involvement, market and customer base, payload integration ...). All reports are then bound together as a deliverable of the class.

#### Why is this course important?

It provides the basic knowledge and tools for graduate students who wish to work in the space industry or in a spacecraft systems engineering and design environment. Also it provides the necessary set of skills for subsequent "mission"-oriented and teamwork based courses such as 16.89 and ensures that in-depth technical analysis will be included there.

#### What would I change from the way it was taught in the past?

Prof. Walter Hollister has taught this course very well in the past. Recently the responsibility for it has been shared between Prof. Hastings, Prof. Miller and Col. Keese. I took the class in the fall of 1997 and thoroughly enjoyed it. The major changes I would make are to de-emphasize spin stabilized spacecraft, to include spacecraft configuration and architecture aspects, to include serviceability as an emerging trend and to carry out a field trip to a commercial satellite manufacturer in the region.

**Unified Engineering I-IV**: Dynamics, signals and systems, modeling and simulation

### 3. AA proposed new courses

As part of the innovation of the curriculum in the department I am proposing to add the following new course to the Aerospace Systems Division of Instruction:

#### **16.9xx Integrated Modeling and Simulation**

G (Spring) H

Prereq.: 16.070 Introduction to Computers and Programming  
18.085 Mathematical Methods for Engineers I or equiv.  
Solid MATLAB knowledge

Units: 2-2-8

Addresses the fundamental principles and techniques of integrated modeling for aerospace and other complex systems. Focuses on analytical and numerical aspects of multi-disciplinary simulation during conceptual and preliminary design. Topics include controls-structure interaction, optical ray tracing and structural motions, thermo-mechanical analysis and electrical network analogy, coupled field analysis with fluids, electromagnetic waves and multi-physics simulations. Coupling of analytical equations from various disciplines. Two distinct numerical approaches are contrasted: The use of commercial high-fidelity codes with binary or ASCII interface programs versus low-fidelity modeling in a common computational environment. Theoretical issues explored include data transfer, model validation, speed and accuracy tradeoffs, non-dimensionalization and scaling, normalization, numerical ill-conditioning, stability and convergence. Simulation using Monte Carlo methods and sensitivity analysis. Roles of integrated modeling in conceptual design, architecture trade studies, error budgeting and technology roadmapping. Specific problem cases from actual aerospace projects and end-of-term benchmark competition.

- Biweekly graded problem cases with programming and simulations by students
- Term project or benchmark computation competition due at the end of the term\*
- no final exam or weekly problem sets

\* Definition of “benchmark competition”: A standardized integrated modeling problem is given to the students, where the “exact” answer has been determined by experiment and is known only to the instructor. The students are given precise written specifications about the problem including geometry, material properties, boundary conditions, loading, friction assumptions, environmental conditions etc... and a deadline to submit the simulation answers. The students are free to choose the modeling methodology, simulation software, numerical algorithms and convergence criteria, but are not allowed to confer with each other. The winner of the competition is the one whose answer shows the smallest deviation from the “exact” answer.

#### Why should this course be added?

The traditional way of solving analytical and numerical problems involving modeling and simulation have included a single discipline and are a part of today’s offerings: (e.g. 16.160 Computational Fluid Dynamics, 16.21 Techniques for Structural Analysis and Design). Integrated modeling and design have emerged as a necessity for multi-disciplinary design and optimization (MDO), since they support top-level design and architecture decisions early in a program. A number of challenges, which do not appear in single discipline modeling, are addressed such as ill-conditioning for phenomena, which occur over disparate time and spatial scales. This is an emerging need in many aerospace and non-aerospace programs, which is not currently being satisfied by the academic curriculum. Note: This course might be broadened such

that it would appeal to the entire ESD community, provided that examples are shown from a variety of engineering fields.

M.I.T. Courses, which are related to this offering, but are distinct from it:

1.153J (1.019, ESD.76J) Systems Simulation, D. Simchi-Levi  
2.03-2.04 Modeling Dynamics and Controls, T. R. Akylas, S. H. Crandall, N. Hogan  
2.063 Sound and Structural Vibration, Staff  
2.093 Computer Methods in Dynamics, K.J. Bathe  
6.336J Introduction to Numerical Simulation, J. K. White, J. Peraire, A. T. Patera  
16.920J Numerical Methods for Partial Differential Equations, J. Peraire, Patera, White  
11.127 Computer Modeling for Investigation and Education, E. Klopfer

Why am I qualified to teach this course?

I have gained extensive knowledge in integrated modeling and coupled field analysis since 1989. The cornerstone is linear and non-linear modeling of plasticity, structural dynamics, crack initiation and growth. I have added to these optical ray tracing, heat transfer and controls. I would need some help in creating some meaningful EM/structures and fluid/structures interaction examples. Have done extensive work in MATLAB with IMOS, MACOS and most toolboxes. I am familiar with commercial codes such as NASTRAN, MARC, ABACUS, ANSYS, STK, Ansoft, HFSS, Femap and Zemax (Optics). Have carried out research for the NGST Integrated Modeling team at NASA GSFC. Have taken 6.336J at M.I.T.

The following course is a joint proposal together with Prof. David W. Miller. The contents of the course presented here have been coordinated with him:

### **16.8xx Aperture Physics for Space Applications**

G (Spring) H

Prereq.: Permission of Instructor

Units: 3-0-9

Covers the fundamentals, applications and future trends of large multi-aperture systems in space. Wavelength range of interest is from RF to optical. Electromagnetic wave propagation and single aperture case. Fourier optics including optical transfer function (OTF) and point spread function (PSF). Segmented and sparse arrays including Golay and Cornwell configurations. Michelson and Fizeau interferometers. Apodization. Array maintenance strategies such as deployable trusses and separated formation flying spacecraft. Metrology and active optical control. Applications from synthetic aperture radar (SAR), astrophysical imaging, astrometry and nulling. Trends in large-aperture sensorcraft design.

- Weekly problem sets
- Mid-term and final examination

Why should this course be added?

The use of space for high-resolution space science, earth observation and surveillance is becoming more prevalent. As the need for increased aperture size emerges there are cost trends and launch fairing constraints, which represent significant challenges. These can be overcome by intelligent multi-aperture systems, which coherently combine the incoming electromagnetic waves. The phasing and pointing precisions become more stringent with shorter wavelengths and require the use of optical control. This course will appeal to all students interested in telescope

design, space based interferometry, earth observation and space science. Course will be designed such that a detailed optical background will not be a prerequisite.

M.I.T. Courses, which are related to this offering, but are distinct from it:

6.661 Receivers, Antennas, and Signals, D.H. Staelin

Why am I qualified to co-teach this course?

The principal responsibility for this course would presumably lie with Prof. Miller. My contributions would come in the single aperture case, mainly calculations of angular resolution, encircled energy etc, as well as phasing and pointing performance calculations for optical control. Material from a two part optical lecture prepared with Soon-Jo Chung could also be beneficial to this course. My single aperture work focused on NGST, but I have completed analyses for SIM and TPF and studied the multi-aperture case of a Golay-3 satellite.

#### **4. ESD proposed new courses**

The following courses are proposed as additions to the ESD offerings

##### **ESD.xxx Multi-Objective Optimization and Tradeoff Analysis**

G (Spring) H - ESD

Units: 3-0-9

Prereq: 15.093J Optimization Methods or permission of instructor

Review of linear and non-linear constrained optimization formulations. Scalar versus Vector optimization problem examples from systems engineering and architecting of complex systems. Utility and Value analysis. Isoperformance for continuous and discrete variables.

Heuristic Optimization methods: Taguchi, Simulated Annealing, Genetic Algorithms, univariate search strategies. Relationship between system performance optimization, specifications and margins. Vector optimization and pareto optimality. Secondary objective functions including cost, risk and robustness. Scalarization of vector optimization. Preference orders, weightings and human value/judgements. Specific examples from aerospace, mechanical, civil engineering and management. Systems engineering and architecture context. Case studies.

Why should this course be added ?

The current catalog of optimization courses at M.I.T. focuses heavily on two areas: The first is Linear Programming (simplex, interior points methods, large scale optimization) which are widely applicable and can solve many problems in management, revenue optimization, production planning, scheduling etc.. The second area is related to systems, which can be described by a set of continuous PDE's. Here convex, constrained optimization methods such as steepest gradient search, projected gradient, Newton's method etc... are important and covered well in the existing offerings. In my view there appears to be a gap in the area of heuristics and multi-objective optimization. Even though heuristic methods are mentioned in most optimization course syllabi there is usually only one lecture (out of ~ 20) devoted to them. This does not reflect the true importance of these methods in MDO. Multi-objective optimization is another emerging field, since many systems are usually trying to satisfy multiple, often conflicting performance, cost and risk objectives. The offering of this course would support teaching and research in Architecture and Systems Engineering, since many problems have non-linear objectives or constraints and are amenable to heuristic optimization and tradeoff analysis. As can be seen below the vast majority of optimization courses are taught in a management context and not in a systems engineering and architecture context.

M.I.T. Courses, which are related to this offering, but are distinct from it:

6.252J Nonlinear Programming, D.P. Bertsekas, R.M. Freund

15.093J Optimization Methods, D. Bertsimas, R. M. Freund

15.094 Systems Optimization: Models and Computation, D. Bertsimas, R. M. Freund

15.066J System Optimization and Analysis for Manufacturing, S.C. Graves, J.P. Clark

15.083J Combinatorial Optimization, D.J. Bertsimas

15.057 Systems Optimization, S. Schulz (SDM offering)

15.053 Introduction to Optimization, J.B. Orlin

Why am I qualified to teach this course?

I would need some help here, at least initially. I feel comfortable, however, with multi-objective optimization, the traditional LQR type problems and isoperformance, which is the topic of my Ph.D. thesis. Other people have done more work in heuristic optimization (Taguchi, Simulated Annealing e.g. Cyrus Jilla or genetic algorithms, e.g. Brett Masters), but the fundamental body of knowledge exists in order to condense a powerful course.

Ideas for other courses, not mature enough to warrant a detailed write-up:

Model-Reality Correlation: related to 6.435 System Identification, but this course would focus on an existing theoretical model of a system, which is tuned to reflect actual measured data. The system can be technical or societal in nature. If the system is not time invariant, then the system identification has to be repeated continuously. Potential topics: State estimation, Kalman filtering, fusion of actual system telemetry or prototype test data to update a virtual model of the system. These models create value in support of design and optimization, AI/autonomy algorithms for embedded systems, resource management for systems, efficient fleet operations for vehicles with varying usage patterns/spectra. Topics are optimum observability, sensor selection and placement, filtering, data redundancy and fill-in for missing data. Physical-parameter based model updating.

Technology Management: History of technological evolution and progress since the industrial revolution, Kondratieff cycles, technology S-curve model and obsolescence, role and organization of R&D in an organization, assessment and evaluation of technologies, technology portfolio, intellectual property and competitiveness, international situation, *technology transfer* (This is the one topic where I can claim to be some sort of an expert, since I was in charge of a \$20M technology transfer program: vehicles of technology transfer, regulatory and competitive hurdles, measures of transfer effectiveness etc....) The other topics are probably better covered by a number of other faculty around campus (e.g. Thomas J. Allen, Edward B. Roberts, Lester C. Thurow, James M. Utterback, Eric von Hippel). To my knowledge the only TM course taught under that name at M.I.T is: 15.355 Technology Management for General Managers, E.B. Roberts. This is restricted to Sloan Fellows, but is probably of interest to the wider ESD community.

Evolving Systems Architecture: Challenges and Methods for Architectures and systems which evolve over time. This evolution can be controlled or occurring naturally. Natural degradation, upgrading of modular systems, but maybe this aspect could be included in 6.882J/ESD.34J.

Olivier de Weck, March 29, 2001