Course Syllabus -- Fall Semester 2014

AME-503: Advanced Mechanical Design
(aka: Innovative Design Thinking for New Product Development)

Ang Liu, Ph.D.
Visiting Assistant Professor;
Aerospace and Mechanical Engineering Department
Manager, the Viterbi iPodia (ViP) Program Office
Office: Denney Research Center (DRB) 260
Phone: 213-740-8429; Email: angliu@usc.edu

Course Sections: 28863R (on-campus) and 29033D (off-campus)

Course Unit: 3 Units

Prerequisite: A graduate student standing in engineering is required (or with a special approval by the instructor). *This is a degree required course for MSPDE (Master of Science in Product Development Engineering)*

Class Hours: Tuesdays, 6:40pm to 9:20pm

- 6:40pm to 7:50pm (70 minutes) – session I
- 7:50pm to 8:10pm (20 minutes) – session break (**optional**)
- 8:10pm to 9:20pm (70 minutes) – session II

Class Location: USC Olin Hall of Engineering (OHE) 100-B

Office Hours: 5:00pm to 6:00pm, on Tuesdays

- Face-to-face meetings held in DRB-260
- Phone meetings via 213-740-8429
- Skype VoIP (Skype Username: angliu_oc)

Teaching Assistant: Chu-Yi Wang (AME Department)
Email: chuyiwan@usc.edu; Tel: (626)372-2966
Office Hours: 3:30pm-5:30pm, on Thursdays; Location: VHE202

Course material and syllabus content per Prof. Stephen Lu, used with permission.

1. Course Background, Goal and Objectives:

As the competitions for more function, higher quality, lower costs, swift delivery and life-cycle accountability of products and systems intensify rapidly, the industry has reached a strategic inflection point (SIP) where nothing short of fundamental changes will do. To succeed on today's highly-competitive global technology market, the company must totally revamp the traditional product development processes and systems thinking so that designers can creatively "do-the-right-thing" first, and then effectively "do-the-thing-right". This graduate-level course introduces an "innovative design thinking" (IDT) framework and methods which can systematically guide rational and optimal engineering decisions through the functional design (i.e., choose functional requirements based on customer needs), conceptual design (i.e., ideate design parameters based on functional requirements), and technical design (i.e., determine parametric values based on design parameters) phases. The fundamental decision principles, logic foundations, relevant design theories and applicable innovation methods which collectively constitute the IDT framework will be explained in this course. Real-world examples of using IDT in various product industries will be included to help the students' understandings of the basic concepts.

The goal of this course is to prepare students with the necessary foundations and skills to become an innovative design thinker who can choose design targets rationally and solve design problems optimally. In a typical undergraduate engineering design curriculum, main focuses are placed on using physics-based engineering knowledge to perform technical analyses to support evaluations of mechanical components design. Some advanced-level undergraduate design courses briefly discuss design theories and methodologies, with emphases on specific design procedures. These analysis-based design approaches, which are mostly "bottom-up" in nature, and procedural-oriented design processes, which are without deep theoretical understandings, are not sufficient for students to deal with the real-world design tasks when they join the industrial workforce, nor to comprehend the state-of-the-art of engineering design research when they enter the graduate school.

As the first graduate-level engineering design course at the AME department and a program required course of the Master of Science in Product Development Engineering (MSPDE) degree, this course - Advanced Mechanical Design (or Advanced Topics in Mechanical Systems Design, or more appropriately called: Innovative Design Thinking for New Product Development) bridges the gaps between students' undergraduate education in engineering components design (i.e., bottom-up and analysis-based) with graduate-level advanced issues in engineering systems design (i.e., top-down, synthesis-based). Following a synthesis-based innovative design thinking framework, the students will learn how to rationally identify break-through design opportunities from market intelligences and then carry out innovative conceptual designs during a new product development process. Equipped with knowledge from AME503, the students should have sufficient backgrounds to utilize proven design theories, methods and techniques developed from recent design researches to enhance their abilities to perform advanced engineering design of technical products, processes, and systems. In short, AME503 is an important transition from the undergraduate-level bottom-up analysis-based components design to the graduate-level top-down synthesis-based systems design.

The specific learning goals of this course include:

1. Understand the innovative design thinking framework, which consists of "do-the-right-thing" rationally and "do-the-thing-right" optimally.
2. Clarify the notions of social and brute realities, the concepts of rationality and optimality, and their different roles in the functional design, conceptual design and technical design phases of product/system developments.
3. Learn the basics of empirical innovation principles, the Axiomatic Design theory, and the TRIZ (Inventive problem-solving method) and how they can be used in a complementary manner to support innovative design thinking.
4. Practice those empirical principles of understanding true customer needs (basic and functional features) and stimulating future customer wants (i.e., excitement features).
5. Practice the Axiomatic Design process and basic design axioms to generate and compare initial design concepts through direct synthesis reasoning (vs. iterative analyses).
6. Practice the usage of TRIZ methods to improve initial design concepts by formulating and resolving various systems and technical contradictions.
7. Put all the innovative design thinking principles and practices together in a big picture of complex engineered systems to highlight the key takeaways of the course.

2. <u>Lecture Scope and Learning Modules:</u>

This course is composed of following 11 learning modules, each is covered in one class lecture:

1. An Introduction of Design and Design Thinking

- What is design, and how is it different from problem solving?
- Design vs. analysis (determinism, reductionist vs. constructionist)
- What is design thinking (how designer reasons)?
- Why study design thinking (normative, prescriptive, and descriptive)?
- Key principles (prescriptions) of good design thinking

2. Innovative Design Thinking (IDT) for New Product Development

- What is innovation and how is it different from invention?
- A socio-technical paradigm of technology innovation
- What is breakthrough innovative (supply vs. demand)?
- How to use IDT to develop new breakthrough products?
- The 2-D reasoning framework of IDT (structured abstraction)
- The Structure (X-axis) - types of decisions in IDT (CN → FR → DP → PV)
- The Abstraction (Y axis) - levels of details in IDT (e.g., AHP Methods)
- The three design phases from CN, to FR, to DP, to PV

3. IDT Functional Design (CN --> FR): Choose Innovative Design Targets Purposefully

- Why Functional Design in IDT (Customer Needs vs. Functional Requirements)?
- Who is Your Real Customer, How Do You Understand Their Lifestyle?
- Use QFD to Solicit Customer Voices and Needs (CN - What)
- Choose Functional Requirements (FR - How) to Satisfy CNs
- Factors to Consider When Choosing FRs
- Organizing the Chosen FRs as Design Targets

4. IDT Concept Generation (FR --> DP): A Logic Foundation to Ideate New Concepts

- Conceptual Design: the Generation and Improvement Phases
- What is a Design Concept (a Mapping from FR to DP) in IDT?
- Generating New Concepts by Making Logic Propositions
- Two Types of Logic Propositions: Analytic vs. Synthetic Propositions
- The Analysis, Synthesis, and Constraint Operations to Ideate Design Concepts
- Zigzagging between Decomposition, Mapping, and Constraint Operations

5. Step 1 of Concept Generation: Form an Initial Option Space by Logic Propositions

- What is conceptual design, and why it is important?
- What is a design concept (i.e., means to satisfy a functional requirement)?
- Functional requirements vs. design constraints (the constrained-by operations)
- Seeding, categorizing, and ranking multiple design concepts
- A spotlight metaphor for seeding initial design concepts
- Working examples of seeding initial design concepts

6. Step 2 of Concept Generation: Organize Concept Options by Functional Dependency

- Functional vs. physical dependencies
- Systems complexity and functional dependency

- The Independence Axiom of design (i.e., independent FR-DP as the ideal design)
- Categorizing uncoupled, decoupled and coupled design concepts
- Working examples of uncoupled, decoupled and coupled design concepts

7. Step 3 of Concept Generation: Select a Preliminary Concept by Physical Uncertainty
- Why do we need to rank-order design concepts?
- From implemental uncertainty to information content of design concepts
- Target value, design range, mean value and system range of FR-DP
- The Information Axiom of design (i.e., lowest risk FR-DP as the ideal design)
- The information Axioms, robust design, and six sigma of design concepts
- Working examples of rank-ordering and choosing design concepts

8. IDT Concept Improvement (FR ← DP): Reduce the Complexity of Designed Concepts
- Definition of complexity of technical artifacts (relative complexity)
- Complexity as an evolving property of a technical system under design
- Functional dependencies and system complexities
- Types of artifact complexity resulted from design decisions
- Strategies of dealing with different types of complexity to simply design

9. Step 1 of Concept Improvement: Model Dependency/Complexity as TRIZ Contradiction
- Two kinds of concept improvement scenarios (coupled FR-DP or more FRs)
- Using an inventive problem solving method (TRIZ) to improve design concepts
- Technical system, design resource, ideal design, design contradiction
- Laws of evolution of technical systems toward the ideality
- The TRIZ problem solving framework (abstraction and instantiation)
- Working examples of TRIZ inventive problem solving

10. Step 2 of Concept Improvement: Use TRIZ Matrix to Resolve System Contradictions
- Using basic parameters to translate to a standard TRIZ problem
- What are TRIZ invention principles?
- What is a system (or technical) contradiction?
- Converting a "coupled-FR" design concept to a TRIZ system contradiction
- Using TRIZ solution matrix to find standard solutions for system contradictions
- Resolving system contradictions can reduce the coupling of design concepts
- Working examples of resolving system contradictions

11. Step 3 of Concept Improvement: Use TRIZ Principles to Resolve Physical Contradictions

- What is a physical contradiction?
- Principles of separation in time, space, system, condition, etc.
- Converting a "coupled-DP" design concept to a TRIZ physical contradiction
- Using separation principles to find standard solutions for physical contradictions
- Converting a system (or technical) contradiction to a physical contradiction
- Working examples of resolving physical contradictions

3. Office Hours:

Standard office hours are from 5:00pm to 6:00pm, on every Tuesday. On-campus students can come to DRB-260 for face-to-face meetings. Group meetings, using Skype for example, with the Instructor during office hours are also possible in the same manner. As well, students are encouraged to meet with TA during the TA office hours.

4. Textbooks:

No required textbook is assigned. Lecture notes in the form of PowerPoint slides will be provided for each IDT lecture weekly. However, students are encouraged to gain easy accesses to the following two books as recommended reference books (items 1 and 2 in bold-face are the key references):

1) **"Axiomatic Design – Advances and Applications", by Nam P. Suh, the Oxford University Press.**
2) **"Systematic Innovation – an introduction to TRIZ", by John Terninko, Alla Zusman, and Boris Zlotin, St. Lucie Press.**
3) "*Creating Breakthrough Products – Innovation from Product Planning to Program Approval*", by Jonathan Cagan and Craig M. Vogel, Financial Times, Prentice Hall.
4) "*Complexity: Theory and Applications*", Nam P. Suh, Oxford University Press, USA
5) "*Product Design and Development*", (the third edition), Karl T. Ulrich and Steven D. Eppinger, the McGraw-Hill Companies, Inc.
6) "*The Design of Things to Come: How Ordinary People Create Extraordinary Products*", Craig M. Vogel, Jonathan Cagan, and Peter Boatwright, Wharton School Publishing.
7) "*Engineering Design – A Systematic Approach*", G. Pahl and W. Beitz, Springer-Verlag
8) "*Product Design – Techniques in Reverse Engineering and New Product Development*", by Kevin Otto and Kristin Wood, Prentice Hall.
9) "Engineering of Creativity – Introduction of TRIZ Methodology of Inventive Problem Solving", by Semyon D. Savransky, St. Lucie Press, CRC Press Company.

The instructors may recommend additional reading materials and website reference resources during the semester whenever appropriately.

5. Course Website:

Students' learning of this graduate course is supplemented by a website (Blackboard System) on USC's DEN instruction system (https://www.uscden.net). All students will have full access to this website (AME503_20143). Students should browse around the entire site to familiarize themselves with various areas and functions of this course website.

6. Grading Scheme:

Students will be graded according to the following grading scheme:

- **20% -- Two (2) research paper study reports (individual efforts)**
    - (10%) the first paper study report
    - (10%) the second paper study report
- **40% -- Team design project presentations and reports (team efforts)**
    - (10%) the first design review presentation
    - (10%) the second design review presentation
    - (10%) the third design review presentation
    - (10%) the final Provisional Patent Application (PPA) report
- **10% -- After class design exercises (individual efforts)**
- **30% -- Final Examination (individual efforts)**

Note that, 40% of a student' final grade (i.e., for team design projects) is determined based on his/her teamwork performance. All work done by the team is first given a "team grade". This team grade is then weighted for each member based on a confidential self-evaluation by all teammates at the end of the semester. Each student will be asked to fill out a questionnaire, which evaluates every team member (including him/herself) for the percentage contribution to the teamwork in different categories. The evaluations are averaged in order to find each student's contribution and the weighting factor is made proportional to the average. For example, if you have 3 students on your team and each makes the same (33%) contribution, then all will get the same grade as the team grade. However, if one of your team members makes a 40% contribution, one a 25% contribution, and the third 35% contribution, then the individual grades will be corrected by the difference from 33%. Thus, for example, if the team grade on your case study presentation is 85%, then the first student would get 92% (85 + (40-33)), the second would get 77% (85 + (25-33), and the third 87% (85 + (35-33)).

7. Learning Components

- **Paper Study Reports (20%)**

Two (2) relevant research papers will be assigned for detail readings and comments. For each assigned paper, students will be asked to write a study report up to 5 pages in length, 12 pt, type, typewritten, double-spaced, with maximum 1" margins.

Students are expected to use and reference as much as possible the materials discussed in classroom lectures in developing these paper study reports. Please avoid repeating the content of the paper. Reports are due at the beginning of the class (see the Course Schedule below). Students can turn in paper study reports one week late for 50% of the credit. No credit will be given afterwards.

- **Team Design Project (40%)**

The best way to learn design thinking for new product development is to work on a real product development project. Eight (8) design teams, each with 4-5 students (depending on the final class enrollment number), will be organized to design a new product/service following the innovative design thinking framework. Given the following problem statement, every design team is to formulate their innovation opportunity by choosing a few design targets and specify some design constraints. Then, teams must generate design concepts to satisfy the chosen targets and constraints. The final project deliverable will be the conceptual design of a technical system that can prevent bicycle thefts. The design concepts must be represented as virtual or physical models that clearly illustrate/explain the working principles and how they function together to satisfy the customer needs. No construction of live-scale real systems nor physical prototypes is required.

Problem Statement: As bicycles regain their popularity as an economic and environmentally friendly means of local transportation, bike thefts have become a major problem in many metropolitan areas of urban lives (e.g., shopping malls, metro stations, college campuses, etc.). Many simple and complex products exist on the market today to address this problem; but none provides good solutions that can meet all the challenges of modern urban lives. There are real customer needs for a new technical system (e.g., hardware, software, service, etc.) that can effectively and economically prevent bicycles parked outdoors from being stolen easily. Your team is charged to design such a technical system to satisfy this customer need on the competitive market.

Team progresses are to be reported in three (3) design review presentations scheduled on September 23, October 28, and December 2, 2014. Each design team is expected to make a 20-minute review presentation of its results up to that stage to receive comments/questions from the class and approvals from the instructor before proceeding further. As much as practical, offcampus students are encouraged to come to the campus (or call in) to join these live review presentations. Based on the performances and efforts at that phase, a team grade (each for 10% of the semester grade) will be given, and then weighted by the above team-grading scheme for individual grades.

The final results and innovative aspects of team designs are to be documented as a Provisional Patent Application (PPA) report, according to the requirements defined by the U.S. Patent and Trademark Office (http://www.uspto.gov), as the team project final report. Team PPAs, which count 10% of the semester grade, are due right before the final exam at 6:40pm on Tuesday, December 16, 2014. All the required sections and necessary information of a typical PPA, as specified by the U.S. Patent and Trademark Office, must be included in the final PPA report. A list of “patent claims” should include all technical details and justifications to be reviewed and evaluated for their innovativeness.

- **After Class Design Exercise (10%)**

At the conclusion of each learning module taught through the weekly lectures, the instructor will assign a few detailed and specific design exercises for students to reflect the key lecture content. The purpose of such exercises is to deepen student’s theoretical understanding of the key concepts within each module and to enhance student’s practical capability of employing certain design principles to address real-world problems. These design exercises are to be finished by every individual student independently after class. The exercise will be assigned on a weekly or biweekly basis, depending on the teaching/learning progress, and the result must be submitted to the TA no later than the next exercise is assigned. Late submission will result in no grade. A total of up to 10 exercises will be assigned, making each exercise count 1% of your semester grade. Variations of certain design exercises may become questions of your final examination.

- **Final Examination (30%)**

Final exam is open-book, limited to the materials that have been discussed in classroom lectures, design team projects, and/or paper studies. Questions are open-ended, but are made brief and point specific as much as possible. They often require only short answers that show your comprehension of concepts, definitions, approaches, and tools covered. Make-up exams will only be offered on a very limited base, when there is absolute proven need for the students. No written make-up exams will be available. Final grades are due within 72 hours after the scheduled "official" final exam date. Therefore, students must contact the instructor, ahead of time, to make arrangements to complete their make-up.

8. Course Schedule

A tentative course schedule, which includes weekly learning subject and activities, is as follow. The Instructor reserves the right to change this schedule during the semester to better fit students' learning needs and progresses.

Week	Date	Learning Activity and Subject	Paper Study and Design Project
1	08/26	An Overview of Course Syllabus	Team assembly begin
2	09/02	An Introduction of Design and Design Thinking	Teams assembly done
3	09/09	Innovative Design Thinking (IDT) for New Product Development	
4	09/16	IDT Functional Design (CN→FR): Choose Innovative Design Targets	Paper study 1 assigned
5	09/23	The first design review presentation (initial design target)	
6	09/30	IDT Concept Generation (FR → DP): A Logic Foundation to Ideate New Concepts	1st presentation slides due
7	10/07	Step 1 of Concept Generation: Form an Initial Option Space by Logic Propositions	
8	10/14	Step 2 of Concept Generation: Organize Concept Options by Functional Dependency	Paper study 1 report due Paper study 2 assigned
9	10/21	Step 3 of Concept Generation: Select a Preliminary Concept by Physical Uncertainty	
10	10/28	The second design review presentation (preliminary design concepts)	
11	11/04	IDT Concept Improvement (FR ← DP): Reduce the Complexity of Designed Concepts	2nd presentation slides due
12	11/11	Step 1 of Concept Improvement: Model Dependency/Complexity as TRIZ Contradiction	Paper study 1 report due
13	11/18	Step 2 of Concept Improvement: Use TRIZ Matrix to Resolve System Contradictions	
14	11/25	Step 3 of Concept Improvement: Use TRIZ Principles to Resolve Physical Contradictions	
15	12/02	The third design review presentation (improved design concepts)	
16	12/09	University Study Day (no class)	3rd presentation slides due
17	12/16	Final Examination (6:40pm to 8:40pm)	Final design PPA due

Academic Integrity:

"The Viterbi School of Engineering adheres to the University's policies and procedures governing academic integrity as described in SCampus. Students are expected to be aware of and to observe the academic integrity standards described in SCampus, and to expect those standards to be enforced in this course."

Students with Disabilities:

Any Student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me (or to TA) as early in the semester as possible. DSP is located in STU 301 and is open 8:30 a.m. - 5:00 p.m., Monday through Friday. The phone number for DSP is (213)740-0776.