Design Principles for Freshman/Sophomore Engineering and Technology Students

Jean Le Mée, Gerardo del Cerro, John Razukas
The Cooper Union for the Advancement of Science&Art/
New York City Technical College

Abstract

Through Gateway, we developed at Cooper Union a very successful course which has now been institutionalized and is being taught for the fifth year in a row: EID 103 – *Principles of Design*. The course is presented at Cooper Union at the freshman/sophomore level for between 12 and 20 students each year, and at the New York City Technical College in the Electro-Mechanical Engineering Technology Department.

The first part of the course consists of learning the principles of design through reverse engineering. Working in small teams, students take apart and put back together such items as a floppy disk drive, a toy robot arm, and a model engine. As they go about their work, they sketch, take notes, and answer specific questions to tease out the ideas behind the form and the embodiment of the design. They learn about Functional Requirements, design parameters and their relations, choice of material, economy, and mechanisms before they attempt to design a simple product of their choice, which may vary from a bicycle rack to a CD holder, a better mudguard for a bike, or a more efficient dish rack. To show them the importance of the relation of physics, mathematics, engineering science, materials, experiment design, synthesis, and analysis, we have prepared for them a CD-ROM on Leonardo da Vinci and his flying machine, where we show that, in spite of all his genius, Leonardo could not succeed. It is an interesting, amusing, yet sobering lesson.

Notwithstanding the lesson, the interest of students in Leonardo's machines has led to the development of a very successful mini-exhibition of models of some of his flying machines, which has been featured at the New York City Technical College library and the Brooklyn Union Gas Company headquarters, and reported on the local TV news and in the Press (NY Post).

This article presents details about course content, organization, and assessment, as well as the resulting public exhibition of Leonardo's non-flying machines.

I. Purpose

This course – EID 103: *Principles of Design* – is conceived to introduce students from all disciplines to the concepts of rational design. It is open to first and second year students at the Albert Nerken School of Engineering at the Cooper Union. The emphasis is on product design. The course builds on the experience of design methodology gained by students in EID 101: *Engineering Design and Problem Solving.* At the New York City Technical College it is offered to Electro-Mechanical Engineering Technology students.

II. Course Organization

The course is divided into two parts of five and ten weeks duration respectively, though they are overlapping to provide for continuity and thoroughness. The schedule included at the end of this paper gives a week-by-week plan of the work distribution over the course of the term. Essentially, during the first five weeks, the emphasis is on disassembly–reassembly of a piece of equipment, such as a floppy disk drive. Here, students typically work in groups of two, learning through hands-on experience the importance of giving attention at the design stage to considerations of accessibility, repair, replacement, choice of materials, recycling, and safety. Students develop the ability to make observations and record them in suitable formats for further analysis of the design process. The use of journals, photos, sketching, and benchmarking for reassembly is emphasized. A written report with illustrative visual material and an oral presentation by each group (with each student participating) is due on the fifth week.

III. Chronology of Events

Week 1 We begin by showing students a CD ROM we prepared illustrating Leonardo's difficulty with his flying machines. With the wisdom of hindsight and the accumulated experience of five centuries of discoveries, inventions and know-how in the natural sciences, mechanics, aeronautics, material science, engineering and other arts and sciences, it is easy for us to see how and why Leonardo failed. This does not detract from his achievements. But failure is a great teacher for engineers and this illustrious failure may give us a clue as to what may make for a successful design.

After this brief introduction to the principles of design analysis we proceed to the "hands-on" experience of disassembly–reassembly. As this five week portion of the EID 103–*Principles of Design* evolved, it became obvious that a certain degree of flexibility in presenting the material was required, depending on the background of the students. Most of the students in the class at Cooper have just completed EID 101, which includes an extensive amount of mechanical drawing theory and CAD practice. Emphasis is therefore placed on freehand sketching and the so-called "Brain-Hand-Image-Eye" process of drawing as a continual cycle of development and expression.

An important objective of this portion of the course is the intensity of the hands-on design experience to be learned by the actual disassembly and reassembly of fairly complicated electromechanical devices. Following the "heuristic" teaching method, which encourages the students to discover design concepts themselves by asking questions, the class is at this point divided into groups of two or three, with each group given a 5-1/4 inch computer floppy disk drive to disassemble. Tools are supplied to each group, including precision screwdriver and hex-key sets as well as other miscellaneous items. A short lecture on the concepts of a disk drive are given using the overhead projector and accompanying hand-out sheets. Thus students begin actual hands-on work at the first meeting of the class.

Week 2: In the second week, a short lesson is given on the concepts of rational design, exposing the student to the ideas of functional requirements, design parameters, and external, human and input constraints. In accordance with the heuristic approach, a list of design questions to be answered by the students in the course of disassembly and re-assembly is presented. An industrial-size butterfly valve is then disassembled in front of the class as an example of the heuristic approach to be applied to the disk drive. Several written articles pertaining to design are distributed to the class. The students continue to disassemble the drives, and are asked to then reassemble them before the end of the class.

Week 3: As expected, only a few students in each class are usually able to successfully reassemble the drives. This demonstrates the importance of sketching, blow-up drawings, wiring diagrams and notes in the course of disassembly. Photographs of the drive in various stages of disassembly are displayed as a guide for the students to complete their assemblies. Each group is then challenged to devise their own system or procedure for a successful disassembly and reassembly of the drive down to the smallest possible components. This includes disassembly of the stepper motor for the read-write head, the drive motor, and hub bearings, along with an inventory of the many small screws, nuts, bolts, and sensors. All sketch work and notes are to be done in a log book for later submission as part of the class grade. Students are also invited to bring cameras to class and to utilize the concepts of oblique, isometric, and orthographic projection with photographs. The class is typically able to work much faster during their second attempt, illustrating an example of the learning curve in the hands-on approach.

Week 4: The class continues to document free-hand sketches and notes in their log books, and a discussion is held on the various written articles distributed to the class regarding concepts of design, including the manufacturing process, recycling of materials, and environmental consciousness. In preparation for the audio-visual presentation of the following week, the class is coached for about one hour by an adjunct instructor (who is an actors' coach) on how to work with the camera rather than with a present live audience.

Week 5: Final reports are presented and commented on by the class. Each group works together on an audio-visual presentation of design concepts related to their mechanical disassembly and reassembly of the floppy disk drive. The presentation is videotaped. Individual log books with the disassembly procedure, sketches, answers to heuristic design questions, and in many cases, photographs, are also collected. Students then complete the final assembly and turn in the disk drives and tools to the instructor. The remainder of the time is used by the coach for a critique of the presentation with the help of the videotape.

The students generally comment enthusiastically about their experience in the course. For many of them, it is their first opportunity to use precision tools in a hands-on environment involving state-of-the-art engineering technology.

IV. Design Project

The other part of the course consists of a design project, the bulk of which covers the last ten weeks of the course, but it is initiated on the second week of the term to gain some lead time in preparing for the design project. The emphasis of the project is product design, as opposed to services or systems. Creativity, intuition, and cultivation of engineering "common sense" are fostered within the framework of design principles and methodologies. In particular, the patent system is investigated as a resource and as an eventual protection for the inventor. In this part of the course, students work in groups of two to four. The outcome of the project is:

1. A written report, complete with:
    a. A set of detailed design specifications including drawings for fabrication, materials, and costs of a product;
    b. A text analyzing the design process and justifying the decisions taken;
    c. Recommendations regarding safety, risk, potential problems, and further developments;
    e. Appendices including calculations, test logs and other pertinent data;
    d. A marketing plan and advertising material for commercializing the product.
2. A physical prototype of the product.
3. An oral presentation to introduce the new product.

The report, prototype, visual material and oral presentations are due on the 14th week of the course. The 15th week is devoted to the critique and review of the course.

Time and budget are limited. A prototype is required. It is therefore imperative that the products be simple. We prefer that the projects be student-conceived, but the faculty is ready to supply topics should a group be short of ideas. Once a project has been agreed upon with the instructor, students are not allowed to change projects, so they are encouraged to choose wisely and to ask for advice.

V. General Project Guidelines

- ❒ There should be a demonstrable market for the product. To check this, students identify existing products that meet a particular need.
- ❒ The product should contain less than 10 parts.
- ❒ The prototype should not cost their lunch money for the next four years.
- ❒ The product should require no basic technological breakthroughs. We do not have time to deal with large technological uncertainties.
- ❒ Although we deal with patents, students are advised to save highly proprietary ideas for another context; we want to be quite open in discussing class projects and do not wish to be constrained by sensitive information.

Students are advised to pick any product satisfying the above guidelines and to develop a product that is superior to anything currently on the market.

Some examples:

Hand tools	solar egg cooker
Office accessories	bagel slicer
Backpacking accessory	paper towel holder
tape measure	walkman carrying pouch
liquid container opener	kitchen cabinet safety latch

garlic press	CD storage rack
ski waxer	food tray for automobiles
roach trap	clipboard for disabled person
bike rack	laptop computer security device
dish rack	beach chair
bike light	shopping cart
guided chopsticks for novice users	refrigerator designed for beer
bathtub water level alarm	

VI. Student-Conceived Projects

On the second week of the term the students form project groups. On the third week of the term each group of two to four students turns in a one-page written proposal and discusses it with the instructor for approval. After receiving approval from the instructor, each group turns in a project card indicating:

- ❒ students names
- ❒ project title and brief description
- ❒ students' special skills; eg., modeling, CAD (beyond the EID 101 experience), marketing skills, artistic skills or interests, etc.

After agreement and approval of the instructor, the students cannot change topics. Though apparently restrictive, this precaution saves students from endless troubles later on.

VII. Prototype

A stereo lithographic apparatus (SLA) is available in the CAE Lab to help fabricate some items which may be needed for the prototype. Before using it, however, students must check with the instructor. Use of the machine is expensive, so the design has to be thoroughly studied beforehand. Arrangements for using the machine have to be made well in advance in order to assure that the items will be produced on time. Planning ahead and discussing plans with the instructor are imperative.

The physical prototype has to be presented at the oral presentation, and a few high-quality 35 mm slides of the prototype should be included with the written report.

VIII. Oral Presentations

Each group has 15 minutes for the presentation, the prototype demonstration, and discussion.

IX. Grading:

Though the work is group work, students are graded individually for their participation. The following point allocation is used:

A. Disassembly–Reassembly project

Written report :

content	50%	15 pts.
presentation	20%	6 pts.

Oral and visual presentation:	30%	9 pts.
subtotal	100%	30 pts.

B. Product Design project

Written report:		
content	40%	24 pts.
presentation	10%	6 pts.
Prototype:	25%	15 pts.
Oral and visual presentation:	25%	15 pts.
subtotal	100%	60 pts.

C. Individual class participation

Leadership, initiative, interest	10 pts.
TOTAL	**100 pts.**

X. Textbooks

Product Design and Development by Karl T. Ulrich and Stephen D. Eppinger McGraw Hill - New York, 1995 (2nd edition, 2000)

An Introduction to US Patent Searching by Susan B. Ardis Libraries Unlimited Inc., PO 3988, Englewood, CO 86155-3988 ISBN 0-87287-856-2, 1991

XI. Revisiting Leonardo's Flying Machines

Notwithstanding the lesson gleaned from the analysis of the flying machine, the interest of students in Leonardo's machines has lead to the development of a very successful mini-exhibition of models of some of his flying machines, curated by Professor Razukas and which has been featured at the New York City Technical College Library and the Brooklyn Union Gas Company headquarters. It has also been featured on a local TV news report and in the press (NY Post).

The models were built by electro-mechanical students at New York City Technical College. Titled "The Dawn of the Age of Science and Technology – Leonardo da Vinci: Renaissance Engineer," the exhibition focuses on da Vinci's flying machine designed in about 1500. It has been seen by thousands of people in the three windows of the Brooklyn Union - Keyspan Energy Building at Jay Street and Myrtle Avenues in downtown Brooklyn, NY. The hope is that it will inspire people and encourage students to get involved in studying engineering, technology, and science.

XII. Assessment

A first assessment of EID 103 was conducted during the spring semesters of 1995 and 1996. The assessments were summative, and consisted of gathering student feedback for each of the learning outcomes of the course. The instrument used was a brief questionnaire with a set of open-ended questions. This assessment has been repeated every semester. Results are routinely disseminated among instructors for an ensuing discussion and action.

The questions included in the questionnaire referred to the following learning outcomes, or competencies: design, the use of new educational technologies, leadership skills, oral and written communication, problem-solving skills, teamwork, and non-technical knowledge. Students were asked to express their views about the educational value of EID 103 and their perceptions on personal progress in each of these competencies With only a few exceptions, students in each year seemed to have enjoyed and learned from their experiences in the course. They recognized that the course had exposed them to substantial learning experiences in the above competencies. In addition, they became aware of the importance of these competencies for their professional careers, and seemed to have developed them to a considerable extent. When asked "What is the most important thing learned?" the most frequent comments were "Interpersonal interaction," "working in groups," "enjoy doing work and not to freak out," and "look at complete picture" when doing design.

Students commented very enthusiastically about the opportunities given to them for oral and written communication, and for practicing presentations. Most felt that, by working in groups, they gained leadership skills. In addition, they seemed to become clearly aware of the non-technical constraints (legal, political, institutional, ethical) involved in engineering design, a consequence of having them exposed to actual, concrete, real-world problems and to multiple research tasks outside the classroom. Several of the freshman design students felt their design experience in EID 103 definitely affected their desire to be an engineer. According to one of them, "if engineering is like this class, then the course is a good foundation."

Based on the assessment results and the teaching experience gained, a number of changes have been implemented in the delivery format and content of EID 103 over the past few years:

a) We have increased the number of items included in the reverse engineering process;
b) We have included some mini-lectures on relevant topics such as kinematics and simple machines (lever, gears, etc.);
c) We have forced students to prototype very early in their projects to test their ideas.

A new assessment plan for EID 103 is now under development and will be implemented in the next offering of the course. The rationale is to integrate assessment more fully into the learning process. In collaboration with the Office of Assessment, we will create a web-based course journal where the data and information produced throughout the course can be easily stored, retrieved, turned into knowledge (through collective discussion), and used for continuous improvement of the course. Analysis of the information and feedback will take into account the students' personal learning styles, as indicated in results of standardized indicators such as the MBTI.

Particular emphasis will be made on tracking process-knowledge, that is, the origins, flows, and destination of ideas considered during the development of projects. In this way, students will become more aware of their own learning process concerning engineering design. Both instructors and students will have access to each other's work-in-progress, and students will be asked to provide feedback to each other. The open-ended format and experimental character of EID 103 makes it suitable for a close integration of such formative assessment procedures into the course format. Innovative engineering work by undergraduate students generates substantial amounts of process information which is worthwhile to preserve and use in-time to help students reflect on their own learning in a coherent, systematic way.

The assessment of EID 103 has been integrated into the current effort of the Mechanical Engineering Department and the Cooper Union School of Engineering to develop a system for continuous quality improvement of the educational process, consistent with ABET 2000.

XIII. EID 103 Schedule

Week	Disassembly/Reassembly	Project
1	Introduction to course; Introduction to disk drive and tools; CD ROM of Leonardo & his flying machine. Read TB chapter 1 HW #1.	
2	Another approach to oral presentation; disassembly marking–sketching–recording. Read TB chapter 2, HW Ex. 1, Q. 2.	15 minutes- form groups of 2 to 4 students, give names to instructors. Assign proposal for project. (HW) Groups to select a project.
3	Lecture 45 minutes; Lab 1 hour 15 mins.; Read TB chapter 3.	1 hour - 1-page proposal due. Group conference w/ instructor. (HW) Identify customer needs.
4	Lecture, video (Manufacturing Insight); R.P. for manufacturer; SLA @ NJIT; Lab. Read TB chapter 4.	Introduction to Invention Machine (HW) Market research; establish Functional Requirements (FR's).
5	Videotaped oral presentations; Journal due. Read TB chapter 5.	
6	Video Lecture: Patents, Trademarks, Copyrights and Trade Secrets.	Generate product concepts. Patent search.
7	Video Lecture: Gordon Bell & Carver Mead Two Inventors on Innovation.	Select product concept. Establish Design Parameters (DP's).
8	Read TB chapter 11.	Product development. Design for manufacture. Materials selection.
	-----------------------------SPRING BREAK-----------------------------	
9		Product development Economics of production
10	Read TB chapter 10.	Design analysis. Testing for independence. Information axioms.
11		Major Design Review. The product specifications should now be established. Build prototype.
12	Coaching for oral presentation.	Complete drawings and calculations. Complete prototype. Freeze design.

13	Presentation	Oral presentation/Prototype demonstration. Written report due.
14		Critique – Written/Oral.

JEAN LE MÉE
Jean Le Mée is Professor and Chair of Mechanical Engineering at Cooper Union and Director of Curriculum Development and Innovation. He is also the Institutional Activity Leader for the Gateway Engineering Education Coalition at Cooper Union, and a member of its Governing Board.

GERARDO DEL CERRO
Gerardo del Cerro is Director of Assessment at the Cooper Union School of Engineering. He is a Ph.D. candidate in Sociology and Planning at the New School for Social Research (New York). As a research associate, he worked on the design and implementation of higher education reform undertaken by the Spanish government from 1990-2. Since October 1996, he has served as Local Evaluator for the NSF Gateway Program.

JOHN RAZUKAS
John Razukas is Associate Professor in the department of Electromechanical Engineering Technology – and its past chairman – at the Technical College of the City University of New York. He is also an adjunct professor of Mechanical Engineering at the Cooper Union.