Teaching Design to Freshmen: Style and Content

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ABSTRACT

This paper describes a freshman course in engineering design that stresses the open-ended and ill-structured nature of design in a project-based context. The projects are chosen in part for their social context and utility. The projects are supplemented by lectures on design methodology and other topics related to engineering practice. Among the deliverables required of the students are proposals, progress reports, and written and oral presentations—the latter to an external design jury as part of a design competition.

I. INTRODUCTION

There is little doubt that design is a subject of central importance to the American economy.[1] Design is also a subject that is constantly being studied and analyzed, particularly in the context of engineering education. Yet engineering educators continue to be quite concerned that design is neither properly taught nor adequately presented in engineering curricula. Recently there have been renewed calls for reconsiderations of design and its role in engineering education.[2-7] Some of these calls have produced great controversy and debate,[8] and it is hard to say that there exists anything like a national consensus on design and design education—other than that everyone ought to be concerned about the state of design education.

There are, arguably, three schools of thought in American engineering schools about the teaching of design. One is that design is experiential in nature, that "creativity cannot be taught," and that whatever discipline is imposed is done through scheduling and reporting requirements. In this view, attempts to articulate and formalize a scientific theory of design will lead to the ruin of engineering-design education because, its adherents argue, a scientific approach to engineering design will make design education into an abstract and sterile science, devoid of creativity and practical experience.[8] Perhaps in reaction to this rather traditional school of thought, a second school of thought is, unsurprisingly, made up largely of engineering scientists and other "analytical types" who feel that there is no "real" content to design education. This is because, in their view, traditional design teachers have not been able to successfully articulate the intellectual content of their courses. Thus, this second school feels that no meaningful discipline of design can emerge until it can be put into mathematical terms. Recently, a third school has emerged to argue the need for a more scientific approach to the study of design.[4] This new school articulates a need for a much broader view of design that is embedded in the notion that design is a cognitive activity that can be studied by cognitive scientists. The roots of the contentiousness attached to debates about design are quite clear.

The intellectual roots of the course described in this paper can be said to reflect some accommodation among these three positions.[9,10] That is to say, the course was developed to reflect both the experiential nature of design and the fact that design is a cognitive activity that can be aided by applying various tools and techniques. Thus, the course should allow students to exercise and express their creativity. However, students can also learn techniques that can be usefully applied to organize and advance their creative thoughts. Thus, the lectures on design methodology incorporate both prescriptive models of design as a process, and various inductive design aids and tools. It is interesting that very few American textbooks on design reflect much thought about the design process and about such inductive tools (and sketching and drawing, also important in design, suffer from a similar fate, especially in more recent books). Deductive methods are used extensively in American design courses, because case studies are very much present in most design courses. But for some reason, the inductive tools, which students can easily learn and successfully apply, are largely found in European,[11-15] but rarely in American,[16] textbooks. The point is simple. There is a discipline of design that encompasses much that can be taught to students to assist and channel their natural creativity, and perhaps it is time to reflect this in engineering curricula.[7,10]

One more seemingly controversial point needs to be made here, that is, the issue of whether or not design can be taught to freshmen in engineering programs. The major argument against is that freshmen have such a limited background that they cannot do any of the needed analyses to realize a final design. It is certainly true that most freshmen could not literally design a stepladder step for strength or stiffness, nor could they design a transistor or an integrated circuit. However, most engineering freshmen are smart enough—and interested enough, given the chance—to take chances at putting together components, matching them in a systems-like approach, recognizing performance characteristics and linking components accordingly. The experience of this course suggests freshman engineering students can do meaningful design work for carefully chosen, meaningful projects. Perhaps not all of their final designs would pass some level of professional scrutiny, but freshmen in the course described here have completed project

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designs that were built and are in active use.

The paper is organized as follows. Section I describes the rationale and organization of a freshman design course. Section II discusses the lecture content, focusing particularly on the design methodology. Section III outlines the project-based approach and some of the projects undertaken. Sections IV, V, and VI, respectively, contain the paper's conclusions, some acknowledgments, and a list of references.

II. OPERATIONAL ASPECTS OF THE FRESHMAN COURSE

The particular course in question, "E4: Engineering Projects," is required of all engineering majors at Harvey Mudd College. It is typically taken in the second semester of the freshman year, although each fall there is a small trailer section of first-semester sophomores. The course is open to other majors at the college, as well as to students from the other Claremont Colleges. For the most part, though, it is the first exposure of engineering majors to the practice of engineering.

Project-based freshman courses were part of the college's curriculum from its very founding and were required of all majors. In 1991-92, the faculty of the Department of Engineering opted for a new approach to the course, now required only for engineering majors, in an effort to improve and expand its content. The rest of this paper describes the resulting new version of E4. The new approach attempts to integrate the various schools of design thought outlined above and is based on the premise that engineering design education must integrate two views:

> the traditional, based on *experiential learning* which emphasizes project management and reporting, and believes that creativity cannot be taught and should not be interfered with and
>
> the modern, based on experiential learning *within a framework of design as a cognitive process*, so as to emphasize design as discipline, with its own structure, methods and vocabulary for both process and designed objects.

The practical implementation of this integrative premise can be summarized as follows.

1. The course is project-based. However, the projects are not derived from the highly successful, upper-division Engineering Clinic program (although that had been done on occasion).[17] Instead, the freshman projects are specifically solicited from potential sponsors as stand-alone design efforts.

2. The project sponsors are largely—though not necessarily exclusively—chosen from the public service and not-for-profit sectors. The aim here is to inform students about the numerous engineering challenges available to them in arenas other than aerospace, computing, defense, utilities and manufacturing. Thus, past sponsors have included a school for the orthopedically disabled, a rehabilitation hospital, a "regular" hospital, the college, and a church-led development organization in Nicaragua. Further, unlike the Clinic program,[17] in which the industrial sponsors pay a substantial fee for the work done on their behalf, all projects in E4 are done on a *pro bono* basis.

It is worth noting here a point that will emerge in greater detail in Section IV: Sponsors are asked to select their proposed projects with great care, *and* they are asked to describe the projects in brief, general verbal statements. This is done in part to force a dialogue between the design teams and their clients, and in part to have the students learn that an important part of the design process is clarifying the design objectives and translating them into design specifications.

The sponsor is also responsible for assigning a *liaison* to its project. Serving in a role that is modeled after the corresponding Engineering Clinic approach,[17] the liaison serves to represent the client-sponsor and acts as the primary channel of communication between each design team and the sponsoring agency. This assignment is very important to the success of any design, but it is the liaison who serves as the teams' primary source of information when they are working to clarify and translate the projects' design objectives. It is a commitment of some magnitude for the sponsors, often several hours a week for an entire semester. However, in addition to the final designs produced by the teams, the liaisons also learn much that is brought back to the sponsor.

3. Several teams (perhaps three or four, depending on enrollment and staffing) work independently and in parallel on each project, and each team consists of four or five students (depending on enrollment). A design presentation and competition is scheduled for the end of the course. It provides an opportunity for the teams to explain and evaluate the design criteria they deemed most important, the design choices they made, and how they feel their designs meet the clients or sponsor's objectives. The main point of the design competition is to reinforce the point that design is truly *open-ended* (see Section III). That is, one of the purposes of the competition is to have students see how other teams responded to and interpreted the client's objectives.

It is worth noting that every effort is made to keep the competition at a level of friendly rivalry as the course unfolds during the semester and at the presentations. Students are told *ab initio* to regard other teams as *friendly* competitors. The design presentation and competition is itself increasingly becoming an "event" at the college (and this fall's project, the design of a corn degrainer for Nicaraguan farmers, also garnered substantial regional press coverage). The president of the college often serves as master of ceremonies at the presentation, and the design jurors include distinguished engineers from outside the college, as well as faculty from all the college's departments. The design juries provide nearly immediate feedback to the audience after the design presentations are made, and they evaluate the quality of both the designs (in terms of the design objectives and of "good engineering practice") and the team presentations.

4. The course includes substantive lectures on engineering design that feature descriptions of the design process, inductive design methods, and interesting case studies (the deductive approach). Among the topics introduced are ideas about handling ill-structured problems, problem decomposition, identifying dependencies among objectives and constraints, and so on. The intent is to introduce a vocabulary for talking about designed artifacts and the design process. More detail on the design theory content is given in Section III.

5. The course includes both lectures and readings on the

ethical and social contexts of engineering, some of which also bear quite heavily on the impact of engineering design. In addition, the course emphasizes team dynamics and the interactions required of individual team members needed to make the team effort work. This is an important aspect of engineering education at Harvey Mudd, and it is strongly emphasized again in the Engineering Clinic.[17]

III. LECTURES ON ENGINEERING DESIGN

The heart of E4 is the collection of design projects: In the *E4 Handbook*[18] that is distributed at the beginning of the course, the students are told that the projects will take up at least 60% of their effort. However, the weekly lectures are also essential to the success of the course. Most of the early lectures focus on design theory, after which various design case studies are presented. Spread out over the semester are lectures, videotapes, and discussions on team dynamics, and on ethical and legal issues in engineering design and practice. From the beginning, the lectures focus on the meaning of design, descriptions of the design process, and some of the inductive tools that are useful in design. For example, from both the *E4 Handbook* and the first lecture, the students learn that:

> "Engineering design problems are typically *open-ended* and *ill-structured*, by which we mean that, respectively:
>
> (1) There are usually many acceptable solutions to a design problem (so uniqueness does not apply); and
>
> (2) Solutions for design problems cannot normally be found by routinely applying a mathematical formula in a structured way.
>
> Indeed, a major part of the engineering design problem is *the clarification and translation of the client's requirements into a set of performance specifications which the designer uses to achieve a successful design.*
>
> These performance specifications are thus used to design an artifact or object whose performance can be measured against both the performance specifications and the client's view of his/her requirements. The E4 design competition is intended to help us *learn how different teams interpreted their client's requirements and to analyze how these interpretations influenced their designs.* The design competition will require formal presentations by each team (see below) and evaluation by a design jury.. . . .
>
> As noted above, the major part of your effort should be focused on *producing a design*, which means *defining the specifications which allow the designed artifact to be manufactured or built.* "

Design a safe ladder.

What is a "safe ladder"?

○ Will the ladder be used on level ground (only?)?

○ How high should someone be able to reach?

○ How tall a person . . . ?

○ How heavy a person . . . ?

○ How many steps . . . ?

○ How are the steps to be spaced?

○ . . . .

○ What is the "design load" on a step?

○ What is the "allowable load" on a step?

○ Of what material is the step made?

○ . . . .

○ Can the designed ladder be assembled?

○ . . . .

○ Is the design economically feasible?

○ Is the ladder really safe?

Figure 1. A foil used to stimulate discussion about translatingand clarifying a client's design objectives.

Thus, the students are told up front that there is no "right answer." In a sharp departure from their other coursework, there is no known solution which they have to find. Rather, they need to devise or invent something whose initial description is vague. Then they must cast that description into a set of design specifications that serve as a target against which their designs can be measured and evaluated. The very vagueness of the project descriptions is intentional (see Section IV), because the student design teams are forced to work with the client(s) in a very active way to clarify the project's objectives.

One way this point is brought home is through an interactive dialog with the students centered around an hypothetical project to design "a safe ladder." The dialog is conducted as an overhead (or transparency or foil) is uncovered in a line-by-line fashion (Figure 1). Through this simple example the students quickly recognize that what seems a simple enough verbal statement is in fact just a doorway into a rather complicated process of refining and clarifying the overall objective so that it can be decomposed into meaningful subordinate objectives and goals. Further, the students see that there are many interested parties in the process, and each has a role and a viewpoint (e.g., one suspects that the engineering department and the legal department might define safety rather differently), and that it is better to try to bring together the diverging views of a product before the design is built, rather than after. This example is just complex enough for the students to see that there are serious calculations that must be done correctly if a safe ladder is to be built. It helps reinforce the idea that they must translate the clients words into meaningful design specifications that can be calculated and measured.

In fact, in their project work, the student design teams are asked to produce fabrication specifications that would allow some person(s), unknown and unconnected to the design team or the course, to actually build their designed artifact. This is a point that is reinforced, because it speaks to the point that fabrication specifications must be complete and unambiguous, as well as correct. One test of the fabrication specifications is, then, that the designed artifact can be completely assembled without any further input from the design team. While this sounds like a tall order for freshmen, it is in fact manageable for the right projects (cf. Section IV). It is also a useful exercise for the students to think about even when they cannot fully implement a set of fabrication specifications.

Another early lecture topic is the definition of the word "design." Such defintions abound, in both the literature of engineering design and that of design in other contexts.[10, 19] Two definitions of design are presented in the first E4 lecture. The first is due to Herbert A. Simon[20]:

"An artifact can be thought of as a meeting point—an 'interface' in today's terms—between an 'inner' environment, the substance and organization of the artifact itself, and an 'outer' environment, the surroundings in which it operates."

The second definition is[10, 19]:

"Engineering design is the systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraints."

These two definitions are intended to foster several notions about the designs the teams will undertake and design in general. The particular notions are that in addition to being open-ended and ill-structured, engineering design problems are typically:

- very much dependent on the environment in which the artifact is intended to perform, so that
- the designed artifact must be viewed in a systems context, and
- the design process is *at least in part* a thoughtful one in which systematic and organized thinking can aid the creative process

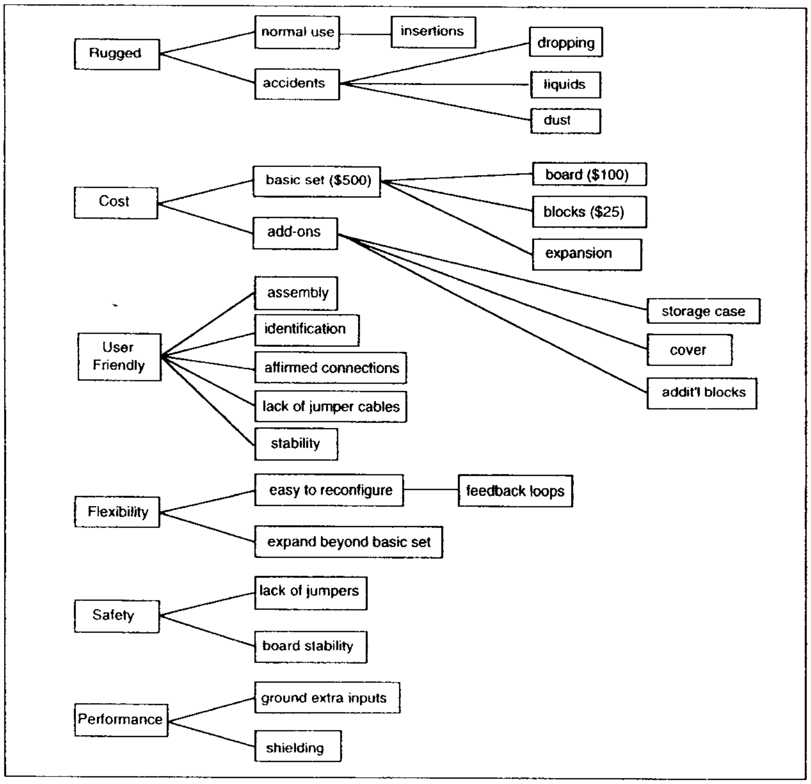


Figure 2. An objectives tree produced by a freshman group designing a building block analog computer kit.[21]

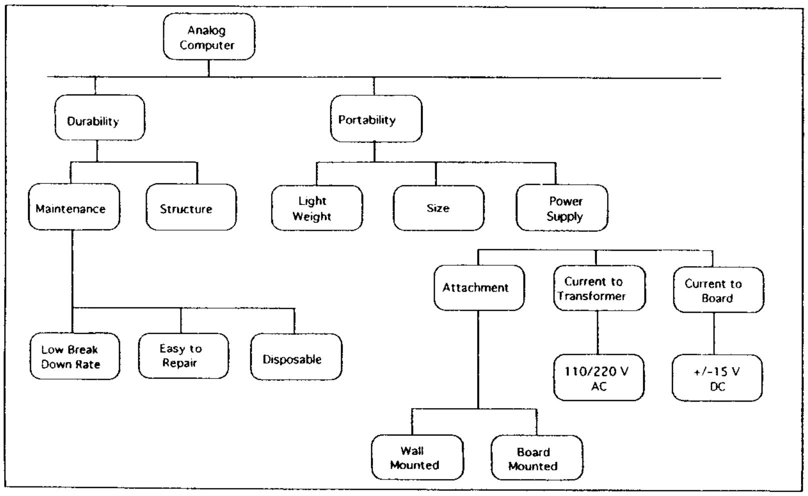


Figure 3. An objectives tree produced by a freshman group designing a building block analog computer kit.[22]

Thus, the message is conveyed that design cannot be done *in vacuo*, independent of context. Further, the process is one in which the students are expected to think about what they're doing and to exercise their minds in an organized way. The latter point has many important ramifications because students tend to think of design in terms of invention, and invention in terms of "brainstorming." Thus, without guidance, students will often eschew library research (because "no one's ever worked on this problem before") and they would prefer not to have to formalize or articulate their thinking about design possibilities.

Students should be strongly encouraged to do serious library research as they begin a project, whether it is to discover and assess prior work on their own projects and related topics or to explore the fundamental physical principles that govern the devices they are about to design. There are also specific design tools that they can apply at very early stages in their thinking to help organize and refine their thinking. These tools are *inductive* in nature, and they include[11, 10]:

Objectives trees, which represent articulations of the design objectives or goals, working downward from the most abstract—or top-level—objective, which is put at the top of the tree. Figures 2 and 3 show two objectives trees developed by different teams of undergraduates in a first-year design course in response to the following project statement given them by a client:

> **Design a "building block" analog computer kit.** Design a rugged, low-cost, easy-to-use analog computer. It should be easy to reconfigure so that it can model a wide variety of systems. The basic functional blocks that need to be implemented (e.g., addition/subtraction,

integration, etc.) have, for the most part, been determined. The focus of this project, therefore, is on the physical layout of the system, the choice of materials, and ergonomic issues.

The objectives trees in Figures 2 and 3 show the client's overall goals for the project were refined into increasingly detailed subgoals. In effect, the two design teams built two hierarchical structures in order to clarify what was wanted by decomposing the client's objectives into their component subgoals. Note how the objectives became more specific as the client's relatively abstract project statement was clarified and refined, much as in the discussion of the design of the stepladder. Also, note that as one works *down* an objective tree, one answers the question of *how* to achieve the various objectives. By way of contrast, moving *up* the objectives tree allows one to articulate *why* one wishes to achieve certain subgoals. Thus, in Figure 2 it can be seen that feedback loops are incorporated into the design to make the computer easy to reconfigure, which in turn means that it will be more flexible.

Once design objectives have been identified in greater detail, it is plausible to argue that these objectives should be ranked early on and that the rankings be used as a guide for focusing design efforts. A tool that helps achieve this is the weighted objectives method, which is implemented in a pairwise-comparison chart. Figure 4 shows the comparison chart and its companion results for the analog computer design developed by the team that developed the objectives tree in Figure 3. The objectives used in the comparison chart are somewhat different, both in terminology and in their respective depths in the tree, than are those in the tree because the design team had several extensive discussions with the client between the time the objectives tree was prepared and the time the comparison chart was constructed. The chart is a relatively simple device in which one simply lists the objectives as both the rows and columns in a matrix or chart and then compares them by pairs, proceeding in a row-by-row fashion. A *0* or a *1* is assigned, depending on how the relative importance of each objective is assessed.

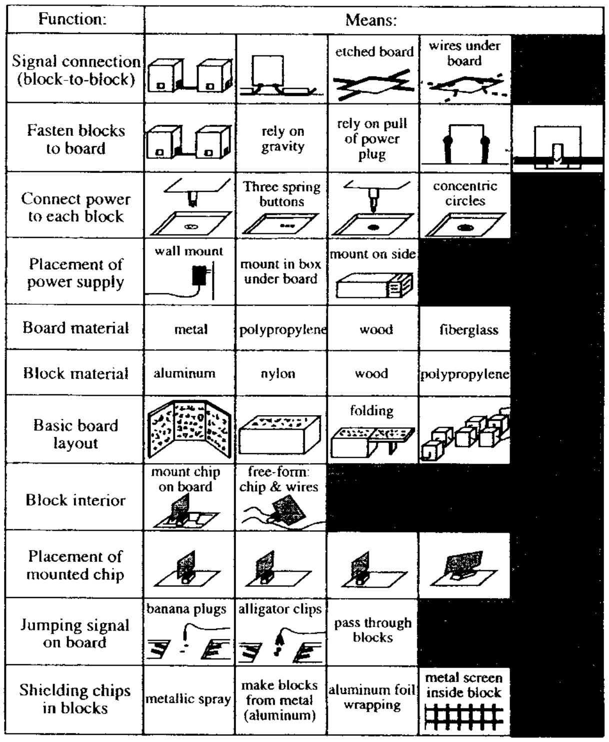
The objectives trees can also be used to identify and characterize the functionality expected of a design. A design aid called functional analysis may be helpful for focusing on *what* must be achieved by identifying and listing in an organized way the *inputs* to the designed device as well as its *outputs*.

Objective	Low Cost	Safety	Light Weight	Small Size	Reliability	Modu-larity	Total
Low Cost		0	1	1	1	0	3
Safety	1		1	1	1	1	5
Light Weight	0	0		0	0	0	0
Small Size	0	0	1		0	0	1
Reliability	0	0	1	1		0	2
Modularity	1	0	1	1	1		4

Figure 4. Weighting objectives (in a pairwise comparison chart) for a student designed "building block" analog computer kit.[22]

Thus, a proposed device is considered first as a "black box" whose inputs and outputs are defined fairly abstractly, consistent with clearly demarking the boundary between the device and its surroundings, much as in Simon's definition of design. Then the "black box" is replaced with a "transparent box" in which the overall function is decomposed into a block diagram of sub-functions whose composite functionality achieves the overall functional goal.

With the function(s) to be served by a design identified, what are the means by which these functions are to be effected? One useful tool for this stage of the process is the morphological chart, also known as the function-means table. In this table are arrayed all the functions that must be achieved against the particular means that can be used to effect each function. An illustration for the analog computer kit design is shown in Figure 5. In the left-hand column are all the functions and subfunctions that the design must produce, while in the row to the right of each function are shown or described a number of means of effecting these functions. In principle, all possible solutions can be found by adding or connecting a single means for each function listed, for example, by using an etched board for the block-to-block signal connection, relying on gravity to fasten blocks to the board, using concentric circles to connect power to each block, and so on. The design alternatives generated in a function-means table are not guaranteed to be admissible. The candidate designs may not make sense physically or economically, or they may not meet all the constraints specified for our design. However, a morphological chart does provide a framework within which students can generate and explore alternative designs, which can in turn be tested for validity and utility. Thus, such charts really do sup-



Function:	Means:				
Signal connection (block-to-block)			etched board	wires under board	
Fasten blocks to board		rely on gravity	rely on pull of power plug		
Connect power to each block		Three spring buttons		concentric circles	
Placement of power supply	wall mount	mount in box under board	mount on side		
Board material	metal	polypropylene	wood	fiberglass	
Block material	aluminum	nylon	wood	polypropylene	
Basic board layout			folding		
Block interior	mount chip on board	free-form: chip & wires			
Placement of mounted chip					
Jumping signal on board	banana plugs	alligator clips	pass through blocks		
Shielding chips in blocks	metallic spray	make blocks from metal (aluminum)	aluminum foil wrapping	metal screen inside block	

Figure 5. A morphological chart produced by a freshman group designing a building block analog computer kit.[22]

port student's creativity in a framework which can make good use of their inventiveness and brainstorming.

In addition to the discussions of the inductive design methods, there are lectures that focus on case studies in design. Two very popular such lectures are on (1) Texas Instruments' *Speak-&-Spell* toy, which serves to emphasize the integration of marketing and economics in the context of a high technology design (recall that the toy used speech synthesis at a time when the technology was much less developed than it is now), and (2) the failure of the Kansas City Hyatt Regency Hotel, which serves to illustrate the importance of communication between designer and builder, especially in terms of conveying design intent. The Hyatt Regency disaster is also educational in reinforcing the importance of even very small details in a large and complex project.

Team dynamics issues are also addressed in the weekly lectures. The most effective approaches have been through the use of professionally prepared videotapes on various issues on team interaction (e.g., "groupthink," conflict resolution, the nature of leadership, etc.). There are many such videotapes available,[21] and besides their instructive nature they serve to stimulate class discussions.

Ethics issues are successfully addressed through a combination of reading (e.g., codes of ethics of various professional societies, newspaper articles, etc.) and of student role playing of various ethical questions. One device that serves well here is to have the teacher serve as interlocutor, assigning roles or obligations to some students, and then "turning up the heat" or ratcheting up the stakes in an interactive questioning of the students. Legal issues have been the subject of some lectures, but they have largely been dependent on the availability of a local products liability litigator who, when available, gives extremely effective lectures.

Danbury School for the Orthopedically Disabled

- Design a robotics arm to feed handicapped children
- Design a computer input device for wheelchair-bound children

Harvey Mudd College

- Design a theatrical backdrop for "Shakespeare at Mudd"
- Design a wand enabling chair-bound people to pick up items from the floor
- Design a classroom device for demonstrating chaotic behavior
- Design a "building block" analog computer kit
- Design a more efficient system to monitor water usage in the college's dormitories
- Design a snack-bar cart for Hixon Court

Lanterman Developmental Center

- Design a swing for wheelchair-bound students

Pomona Valley Hospital

- Design a scanner for wounds and ulcers

CEPAD—Nicaragua

- Design a low-cost corn degrainer

Figure 6. A list ofdesign projects and their sponsors, fron the first four offerings of E4: Engineering Projects at Harvey Mudd College.

For the first two offerings of the revised E4, two books were required: Petroski's *To Engineer is Human*[24] and Meehan's *Getting Sued and Other Tales of the Engineering Life.*[25] These books provided interesting insights into the role of failure in design at a very abstract level (Petroski) and into the practice of engineering and some very concrete consequences of failure (Meehan). However, neither book provided much direct support for the design work the students were doing. As a consequence, more recent offerings of the course have used a British design book as the basic text, Cross' *Engineering Design Methods*,[11] which provides a very readable and accessible treatment of models of the design process and of inductive methods for design.

IV. AN OVERVIEW OF THE PROJECTS

The mechanics of the project part of E4 have been detailed in Section II. A list of the projects which have been done and their sponsors is shown in Figure 6. As noted earlier, all the projects have been sponsored by not-for-profit agencies, including the college. It is worth remembering (cf. Section II) that each sponsor has lent not only its name and interest, but also the services of a dedicated liaison. As the course has evolved, the criteria for selecting projects have become somewhat sharper. Initially, the major concern was that the projects be sponsored by public sector agencies and that they have some obvious social utility. As the course has evolved, additional constraints were added, especially in terms of the likelihood of design teams being able to build prototypes, or at the very least be able to simulate them with current CADD tools available in any of the college's computer laboratories or the department's Engineering Design Center. As it has turned out, the projects have had varying degrees of success.

For example, two of the projects from the first offering were the design of a swing for wheelchair-bound students for the Lanterman Developmental Center and the design of a robotics arm to feed handicapped students at the Danbury School for the Orthopedically Disabled. Arguably, both of these projects contained elements that were beyond the technical capabilities of freshman engineers. However, both led to positive developments for their sponsors (and their designers!). For the Lanterman project, some teams designed swing-like platforms to which wheelchairs could be fastened, and at least one of the designs appeared to be both cheaper and more attractive than commercially available swings. Another team generalized the design objective to a "motion device" for the wheelchair-bound, a significant outcome of the objectives clarification process, and it produced some thought-provoking ideas for the sponsors. In the latter case, while some teams developed very crude and ineffective prototypes, enough interest was generated—and sufficient viability of the concept was generated—that the robotic feeder device was made a project within the Engineering Clinic that would be worked on by juniors and seniors.

Some projects have led to completed "products" that are in use. The most notable of these is the theatrical backdrop for "Shakespeare at Mudd," an annual event wherein a colleague in the Department of Humanities and Social Sciences has a class in Shakespeare perform one of his plays in a courtyard surrounded on three sides by a campus building. The E4 project required the design of a portable backdrop which, among other things, could be erected along the open side of the courtyard to form a stage-backdrop that had at least some characteristics similar to those that would have been found in London's Globe Theatre. Thus, the backdrop should allow for various entrances and exits by actors, provide "tiring" or changing rooms, and provide other features attendant to the performance of one of Shakespeare's plays. In addition, the backdrop should be easily assembled and disassembled, easy to store, long of life, and cheap. Several interesting designs emerged, and with a small grant from his department, the Shakespearean colleague oversaw the construction of a backdrop last summer, and it will receive its first test at the end of the Spring 1994 semester.

One interesting feature of that design was that some of the teams working on it built prototypes of wall sections, connections, and hinges. One team did a "simulation" with the IDEAS™ package of Structural Dynamics Corporation. Although the time it took for that team to learn IDEAS™ was costly, all the teams members felt that it was worth it both in terms of helping them do their design and in terms of learning a tool which would be of significant value to them in their subsequent coursework. Needless to say, their design presentation also benefitted greatly from the attractive color graphics they were able to present during the design competition.

Another successful project was the design of a corn degrainer done for an aid organization, CEPAD of Nicaragua. The project statement given the students was:

> **Design a low-cost corn degrainer.** The goal of this project is to design a degrainer for dried corn for use in rural Nicaragua. The device must be easy to use and fairly easy to put together. It must be low in cost and it is preferable that it be made of materials that are indigenous to or readily available in Nicaragua.

This project, done just this past fall, which came to the department through the efforts of a newly-graduated alumna, proved to be most interesting to the students. They were very much taken by the notion of helping poor farmers in Nicaragua, and with a project where they could both apply the design methods they learned in class and build realistic prototypes that could be demonstrated at the design competition. All of the designs were such that the productivity of the individual farmer would be dramatically increased in comparison to the hand degraining (or shelling) techniques now used. The resulting designs were, by and large, so good that all their final reports and several of the prototypes will be sent to Nicaragua for evaluation and possible production.

As noted before, each design team was required to produce several deliverables along the way, including most notably a final report. Although the students' writing skills were quite decent, especially when augmented by visits to the college's Writing Center, it did require some effort on the part of the faculty to get the students to understand that technical reports could not be structured as narrative essays. Thus, another important skill which freshman can begin to develop is that of writing technical reports.

V. DISCUSSION AND CONCLUSIONS

This paper has described a freshman course in engineering design. The course has demonstrated that design can be taught to freshmen, that inductive and deductive (case studies) methods can both be taught, and that the inductive methods can be successfully applied by freshman engineers to their design projects. The choice of projects is, of course, crucial. Key elements are that the projects must be reasonable in scope, and that if possible they should be such that prototypes can be built or simulated with CADD systems on high-end personal computers or workstations. The multiple-team approach culminating in a design competition, complete with design juries, has proved very successful in maintaining students' interest and in helping sharpen their presentation skills. The other deliverables (i.e., proposals, progress reports, and final reports) are also useful in helping students to (1) focus their thinking and (2) learn to write good technical reports. All in all, the course has proved to be successful, based on evaluations by students and the faculty (and also according to the college grapevine!).

One question that has arisen is whether this course is "moveable," that is, whether it can be done elsewhere, in engineering schools of markedly different size and student-body composition. Harvey Mudd College is small (625 students in total, about 85 engineering majors in any given year) and the student body is relatively select (the average SAT score of entering freshmen is about 1400). Thus, it is natural to wonder whether this model can be translated into the environment of a large state school, for example, with a larger and much more diverse freshman class.

While a definitive answer is not possible, it would seem that the biggest barrier to replicating such a course is one of resources, especially faculty time. The course content is not intrinsically difficult. While it does require some ability to conceptualize and to apply writing and speaking skills, it does not require an extensive background in advanced mathematics or other technical subjects. However, the course does require a lot of faculty time. Under the Mudd system, the faculty member in charge of the course (who gets the projects lined up before the semester starts and gives and/or organizes the weekly lectures) gets "credit" equivalent to teaching one course. In addition, each project would have (1) three design teams of four-to-five students working in parallel and (2) a faculty advisor who would also get one course credit. Thus, the real expense in scaling up is the willingness of the institution to expend its faculty resources in this way—especially when it comes to those faculty who are most interested in such an effort. This is definitely a course that should not be left to those uninterested in teaching freshmen or who believe that design cannot be taught to first-year engineering students. Faculty support and interest are very important, and the faculty involved must want to spend a lot of face-to-face time with small groups of students who are just beginning to learn something about what it means to do engineering design.

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