A Model for Teaching Engineering Design

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Abstract - **Engineering design is a broad, yet essential topic for students to study during their academic tenure in the engineering field. Engineering design is the set of fundamental principles necessary to successfully solve a design problem. We propose a model for effective teaching of engineering design by developing a multifaceted engineering design course, whose goals are to introduce students to basic engineering design principles and professional skill methodologies, such as client interaction, teamwork, and presentation skills. We require students to make use of computer technologies taught in-class: Alias Maya for 3D design renderings and MathWorks Matlab for computational analysis of designs. Projects with community partners fulfill the need for real client interaction and robust design problems. Students gain hands-on experience from directly applying concepts taught in the course, while community partners benefit from the projects' research and proposed solution. Over 1000 first-year engineering students have participated in this course structure since its inception in Spring 2004. We have worked with over 50 community partners yielding more than 200 semester-length projects, some of which embark on a continuation over several semesters. Our experience complemented with extended evaluations after each semester shape the course each term to yield successful results.**

Index Terms - curriculum development, engineering design, service-learning projects

INTRODUCTION

First- and second-year engineering students are required to take introductory science and mathematics courses and non-technical requirements at certain engineering programs. Technical courses are not introduced till junior year in most instances. Other programs immerse students in highly technical courses from the onset. Both methods can create environments in which students may loose interest in engineering early on. In the first approach, students may feel that they are not introduced to engineering, while in the second, students may feel overwhelmed with the technical pressures placed upon them. Many students develop "learn-and-forget" techniques in which material is placed in short-term memory and almost immediately forgotten upon completion of an exam or assignment [1]. A method to solve this issue is to welcome students in their first-year engineering programs to a class that sparks interest and intrigue in their chosen educational path [2]. For students uncertain about their choice in major, a course as such would serve as an invaluable tool in helping to pick an educational path.

This course would provide the best playground to introduce engineering design to all students, regardless of prior background experience in engineering and their proposed major. Engineering design is a crucial set of tools needed by students in any engineering discipline. Since students entering an engineering program have diverse interests in majors (Table I), the ideal course can address all disciplines at an introductory level such that students with limited backgrounds in these areas can still benefit from the experience.

Introducing engineering design via community-service learning projects is an ideal method to capture students' interest and aptitude for engineering [3]. These projects allow for the need of advanced understanding for the identification and definition of preferences, analysis of alternatives, effective accommodation of uncertainty in decision-making, and the relationship between data and knowledge in a digitally supported process. All of which are important concepts that are necessary for a successful career in engineering. Coupled in with the use of advanced computer methods for computational purposes and 3D rendering, students are provided with a chance opportunity to learn about true engineering during their first-year. We propose a successful approach that has been implemented since 2003 in which first-year engineering students are introduced to a multifaceted engineering design course, which provides a hand-on introduction to engineering.

TABLE I
DISTRIBUTION OF INTENDED MAJORS AMONGST INCOMING FIRST-YEAR ENIGNEERS.

	Academic Year		
Major	2003 - 2004	2004 - 2005	2005 – 2006
Applied Math/Applied Physics	35	42	38
Biomedical/Chemical Engineering	112	79	73
Civil Engineering	29	38	17
Computer Science/Engineering	64	46	39
Earth and Environmental Engineering	4	6	5
Electrical Engineering	37	36	19
Industrial Engineering	26	41	95
Mechanical Engineering	32	33	38
TOTAL	339	321	324

COURSE OBJECTIVES

The main objective of the course is to serve as an introduction to basic engineering design processes and complementary professional skills required for advancement in an engineering and applied science education and career. Students learn how to apply computer technologies such as advanced three-dimensional graphs and web applications in the service of design. Aligned with the technical components of design, students develop collaboration, communication, problem solving, and project management skills.

Furthermore, we are an Accreditation Board for Engineering and Technology (ABET) certified institution and thus we strive to ensure that each course addresses as many of the ABET criterion as possible. The multidimensional and multi-modal aspect of our engineering design course assures that we meet all the requirements listed by ABET.

COURSE STRUCTURE

The course is offered both semesters, fall and spring, and is a mandatory course for all first-year students in the engineering school. The class meets once a week during the academic term, typically fourteen weeks, for approximately three hours each session. Class time is split into two parts: a lecture on professional development and project management skills and an instructional workshop-type lecture session on the use of computer tools helpful for engineering design. We teach students how to use Mathworks Matlab for computational analysis and Alias Maya for 3D image modeling and renderings. Since we do not want to overwhelm the students with instruction in both software packages simultaneous, we have decided to instruct in Mathworks Matlab during the first half of the course and Alias Maya for the latter part. This arrangement is successful since computational tools are useful for analysis of data gathered by students during their research phase for their project at the beginning of the term. The use of Maya for 3D modeling and renders is useful towards the end of the academic term when students have reached some type of solution to their project. Additionally, students are not only required to use these tools for their course final project but they are also given individual assignments to complete during the academic term.

In addition, special class time is also scheduled for individual team and advisor group meetings, midterm and final presentations, and client meetings.

COURSE LECTURE MODULES

Course lectures are divided into three modules: professional development and project management, computational analysis methods, and 3D image rendering. The lectures in professional development and project management span the entire academic term while the advanced computer application topics of computational analysis methods and 3D image rendering each occur for six-week sessions subsequently.

I. Professional Development and Project Management Lectures:

This part of the class time is scheduled at the start of every class period. While we allocate a hour for this part of the class period, the essence of the lecture is approximately 25-30 minutes long. We intentionally use this method to provide students to work within their teams for the other 30 minutes on topics that were discussed during this lecture. This method allows for real-time feedback of concepts taught in class as students work on related activities. Team development is a crucial theme covered in the course. Our curriculum for these lectures revolves around the stages of team development: forming, storming, norming, performing, and adjourning [4]. Structuring our lectures around these five themes also aids in the temporal sequencing of course materials.

Forming is the onset of team development when the individual members of a team first meet and learn about the project objectives and challenges. During this sequence in the course (weeks 1 - 3), lectures describing proper assignment of team roles for handling different tasks as well as tools for performing client needs analysis are introduced as project management topics. Effective communication techniques are addressed for professional development as students are introduced to their clients.

During the storming stage (weeks 3 - 5), different solutions compete for consideration. The length of this stage will be the determination of the projects completion. Team conflict easily arises at this point as members try to convince each other of the feasibility of certain solutions over others. Conflict resolution is introduced in efforts of deterring students from deadlocking at this stage.

Decision making strategies will expedite the norming process in which each team picks a feasible final solution and start focusing on implementation strategies. Students need less guidance at this point during the semester and more teamwork time is necessary. Thus, the lectures during this time (weeks 5 - 7) become shorter and instruction is provided about different strategies to aid in the decision making process.

The performing stage occurs when students start the implementation process (weeks 7 - 12). This is considered the longest stage since implementation of the final product. Lectures focus on effective product design.

Finally the adjourning stage is when students complete their final deliverables and provide a completed package to their clients with appropriate documentation (weeks 12 - 14). Lectures focus on the important of communication: verbal and nonverbal. Table II summarizes the different stages of team development and lecture topics covered.

II. Computational Analysis Method using Mathworks Matlab:

The sequence of six Matlab lectures is grouped into 3 themes: theory, programming, and data analysis. Matlab is introduced during weeks 2 – 7 to aid students with the research phases of their community-service learning project.

TABLE II
CORRELATION BETWEEN TEAM DEVELOPMENT STAGE AND LECTURE TOPICS IN THE PROFESSIONAL DEVELOPMENT AND PROJECT MANGAEMETN LECTURE SERIES.

Week	Team Development Stage	Lecture Topics
1 – 3	Forming	• Description of Community Design Project and requirements • Identify the key elements of an iterative design process (Phases and Stages) • Professional skills required for effective design projects • Defining the Problem/Customer Needs with emphasis on preliminary research • Decision Making: Learning how to define functional requirements and design constraints based on a problem statement (Tools to support problem definition including objective trees, system sketching, and concept mapping)
3 – 5	Storming	• Formulating Solutions • Conducting a client needs analysis • Fundamentals of technical & marketing research • Idea generation and lateral thinking • Project Management Skills: Preparing task lists and Gantt charts
5 – 7	Norming	• Introduction to modeling and prototyping • Collaboration: Seeking input and feedback throughout the design process • Cognitive issues in complex problem solving; individual biases • Groupthink
7 – 12	Performing	• Implementing Design • Introduce types of design analyses: functional, market, human, aesthetic
12 – 14	Adjourning	• Presentation Skills • Packaging of final deliverable

Introduction to theory is necessary since first-year students have limited experience and knowledge in this area. Since the course is offered to students from all engineering disciplines, a series of lectures on programming is necessary to ascertain a framework of reference for knowledge in this field. Data analysis is essential for any field of engineering. Basic statistics and regression modeling are the topics of discussion for this unit. Table III provides a summary of content for each lecture.

Individual assessment of student understanding is measured via a comprehensive written exam administered at the end of the lecture sequence. In addition, each community project team is required to submit a computational analysis of certain aspects of their project. This is to ensure that students understand the application of Matlab from the engineering design prospective.

TABLE III
CORRELATION BETWEEN THEME AND LECTURE TOPIC IN COMPUTATIONAL ANALYSIS METHODS LECTURE SERIES.

Theme	Week	Lecture Topics
Theory	2	Introduction to Matlab interface Basic mathematical operations Fundamental data structures
	3	Basic matrix manipulation
Programming	4	Loops
	5	Conditionals
Data Analysis	6	Data acquisition and manipulation Plotting
	7	Basic statistics Regression modeling

III. 3D Image Rendering using Alias Maya:

The onset of the Maya is during week 8 and continues through week 13. This leaves one week for students to finalize and produce their 3D rendering in completion of their community projects.

The lecture sequence in Maya focuses on the use 3D modeling and visualization techniques for product design. During the first part, students are exposed to the basic tools used for 3D design and visualization. A series of in-class exercises teaches the students the tools necessary to generate 3D prototypes. Students use these skills to analyze and understand intrinsic design qualities of objects necessary for their own community projects. They learn the technicalities associated with that particular product by reverse-engineering the design process. In the final phase students focus on producing 3D renderings for the community projects that inherit the analytical design skills learned during the semester. Table IV provides a summary of the lecture topics in the Maya sequence.

TABLE IV
LECTURE TOPICS IN 3D IMAGE RENDERING SERIES.

Week	Lecture Topics
8	Modeling with primitives
9	Drawing 2D lines
10	Drawing lines in 3D space
11	Generating surfaces
12	Editing surfaces
13	Lighting and rendering 3D models

COMMUNITY SERVICE-LEARNING PROJECTS (CSLP)

Community service learning projects (CSLP) also assist in meeting the goals of a multidimensional course. Students are given the opportunity to experience the application of design principles discussed in class and to develop professional when meeting with clients and interpersonal skills when meeting amongst their own team members. The application of course material on real-world design problems serves as one of the program's greatest caveats.

I. CSLP Project Genres

To further enhance each student's experience in the course, we propose five main genres for the types of community projects: assistive devices, civil/architectural designs, educational tools, information technology, and urban development.

The assistive devices project genre focuses on developing and redesigning equipment to comply with American Disabilities Act (ADA) standards. The civil/architectural genre focuses on design challenges in enclosed places, primarily concerning interior lighting, storage, shelving, and effective space utilization. Typical projects involve the redesign of space for a given area. Educational tools project genre is intent on enhancing current educational products on the market to meet the needs of academically challenged students from underprivileged areas. The information technology genre projects are interested in creating computer-based tools that can help community organizations. Finally, the urban development genre is primarily concerned with new innovative technologies for environmentally friendly designs.

Each genre caters to student interests in a particular engineering major (Table V) because first-year students enter the program with very diverse interests for their proposed major (Table I). The two majors, applied mathematics/applied physics and industrial engineering, are applicable each project genre. Applied mathematics/physics students possess interest and aptitude in technical computations required by the course for each project assigned. Industrial engineering students are useful for project management and for successful overseeing of team progress throughout the project.

II. Selection of CSLP Teams and Assignment to Projects

Teams are assigned for the each community project to assure that students are given the complete team development experience. Students are selected for the projects based on an assessment survey [5]. The assessment survey provides the instructors with information about each student's aptitude and interests in various subject areas. We try to balance the amount of technical and managerial expertise in every team, so that no team has an unfair advantage or disadvantage. Also we want to assign students to projects, which will capture their interest. Oftentimes lack of interest in assigned project can attribute to failure of a project.

TABLE V
ENGINEERING MAJORS ASSOCIATED TO SPECIFIC COMMUNITY SERVICE-LEARNING PROJECT GENRES. SHADED BOXES REPRESENT MATCH BETWEEN MAJOR AND GENRE.

Engineering Major \ Community Service-Learning Project Genre	Assistive Devices	Civil/architectural Designs	Educational Tools	Information Technology	Urban Development
Applied Math/Applied Physics	■	■	■	■	■
Biomedical/Chemical Engineering	■				
Civil Engineering		■			■
Computer Science/Engineering			■	■	
Earth and Environmental Engineering					■
Electrical Engineering	■				
Industrial Engineering	■	■	■	■	■
Mechanical Engineering	■	■			■

III. Final Project Deliverables

Throughout the academic term, student teams are responsible for providing weekly progress reports to ensure that course instructors and community clients can monitor team progress. Project deliverables at the end of each academic term from each team include:

- proposal of a final solution to the initial engineering design problem
- written reports and verbal presentation of the proposed solution
- 3D design renderings using Alias Maya of deliverable
- computational analysis using Mathworks Matlab of deliverable.

IV. The Wheelchair Swing: A Successful Project

In Summer 2004, we embarked on a multi-semester assistive devices project with the New York City Department of Parks and Recreation to build a playground for all children in Marcus Garvey Park. The students were to design pieces of playground equipment that could be easily used by children with different types of disabilities.

The project continued in the following semesters focusing on creating an actual physical prototype for one of the pieces of playground equipment, the wheelchair swing. The wheelchair swing allows children confined to wheelchairs to make use of a swing without the discomforts and complications of reseating themselves. Its ease of use for both the child and guardian make the swing an invaluable asset to any playground accommodating those with disabilities. The proposed design went through several iterations before the final design was completed and prototyped in Spring 2006 as shown in Figure 1.

CHALLENGES

The primary challenge in designing a multifaceted engineering design course, which revolves around community service-learning projects, is the proper identification of feasible projects for our students. We want to ensure that the projects

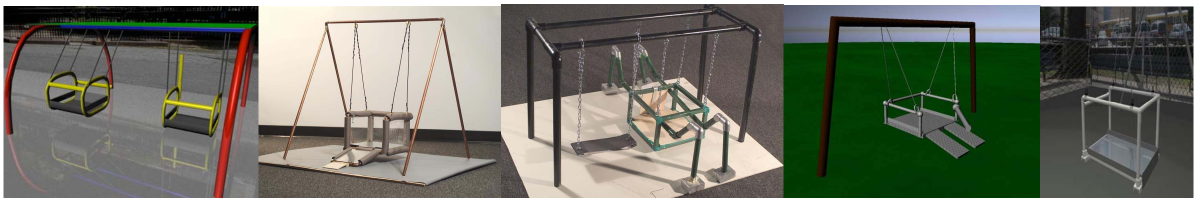

FIGURE 1
Evolution of the wheelchair swing project for the assistive devices genre. Design proposal by student teams in Fall 2004 (fisrt two pictures), Spring 2005 (third picture), modified design proposed in Fall 2005 (fourth picture) and final design (final picture).

assigned to the students are of appropriate difficulty levels. Picking an unmanageable project would discourage the students from engineering, which would defeat one of our fundamental goals of provoking enthusiasm amongst students in the field of engineering. We also need to pick projects that address all components of the course easily. Thus in picking projects for the information technology genre, we need to ascertain that there is some design problem associated to the projects. We do not want to simply assign students with the task of creating web pages and designing software, as this is not a computer science course. Furthermore, when a project requires the building of an actual prototype, our first-year students usually stumble upon a roadblock. Few students have previous experience in a machine shop and thus we typically have to provide added instructional for successful completion of these projects.

Time is a constant challenge faced in the course structure. With the given 3 hours in which we meet with our students, much of the class time is spent in lecture modules. Thus, very little time is allocated for helping individual student teams with additional assistance of their group community projects. Students can always schedule extra office hours, however, this can be difficult in arrange too since students have different schedules. Thus, it would have been beneficial if more team advising time could be allotted. Also, given the shortness of the academic term and the plethora of information we try to cover, many times the topics are rushed. A longer course, perhaps a two-part course, would be helpful in providing more flexibility in covering some of the lecture topics in greater detail. The instruction in the software packages we cover in the course would certainly benefit from such an arrangement, as students would have more immersion time.

Approximately 160 students are registered each term for this course. Thus, management of course materials such as student submissions and dissemination of necessary course materials is an arduous task. Continuous feedback is necessary for all student submissions to ensure that student work is improving. This is because of the building block nature of the course in which each assignment is an extension of the previous. The need arises to accurately and easily provide rapid feedback for all assignments. To solve this issue, we have created a very specific course management system (CMS), which creates a paperless studio [6].

RESOURCE REQUIREMENTS

In comparison to other courses, a multifaceted engineering design course as described surprisingly does not require too many additional sources. Sustainability is therefore not an additional burden on the course staff. All projects assigned to students are from community clients, thus there is no monetary investment in attaining projects for students. Costs are introduced when a project reaches the actual prototyping phase. Support for this stage in the design process can be addressed through many sources of available funding: budgets set aside by community partners, institutional support provided by the National Science Foundation (Engineering Projects in Community Service). Therefore, no additional burden is placed on the institution.

Our course models instructional staff is varied from undergraduate students who serve as course teaching assistants to academic professors who serve as the main lecturers. Table VI shows the resource requirements breakdown for running this program for a given academic semester. Thus for an academic semester with 14 weeks, approximately 2408 hours of commitment are required.

TABLE VI
RESOURCE REQUIREMENTS BREAKDOWN FOR ONE ACADEMIC TERM.

Resource	Requirement
Teaching Assistants	4 individuals – 120 hours/week
Community Partner Outreach and Solicitation	1 individual – 40 hours/week
Lecturers	3 individuals – 12 hours/week
TOTAL	172 hours/week

Lecturers develop curricular content for their lectures and host additional office hours as needed by the students. Teaching assistants hold office hours, assist with team projects, and grade papers. Additional hours are scheduled as need for teams involved in the prototyping phase of a project. All students are given access to the machine shop on campus for their prototyping needs. Large-scale working prototypes are typically created in the machine shop on campus while smaller prototypes may be constructed in students' own premises. On occasion, our community partners have facilities available for students to use when working on a prototype for the organization.

Course Outcome

Our course model has been a definite success. The instruction in different software packages, specifically Matlab, has been an invaluable resource for all students. Matlab is becoming more prevalent amongst all engineering disciplines. While we did not instruct students in advance topics in the software packages, students are noticing that the preliminary introduction is serving as a great foundation for learning more advance methods. This is since many professors assume basic understanding of certain software packages and thus do not provide instruction in the basics. Professors have noticed a difference in the quality of student work since the introduction of software packages to our first-year engineering design course.

Furthermore, since its implementation into the engineering design course curriculum, CSLP projects have been extremely successful and well received amongst all involved: community organizations and partners, students, and instructional staff. The symbiotic relationship between the community and the students in the CSLP program help to make these projects not only interesting for students but also worthwhile for community partners.

We conduct frequent surveys to determine the success of the program amongst students, professors, and community partners. Survey results indicate that students are excited to gain practical experience in their fields of interest. Professors indicate better student understanding of advanced topics since the basic foundations are stronger in incoming students to upper-level courses. Community partners appreciate the work completed in helping the organizations.

Survey results also indicate that students are typically disillusioned about their choice of major. For instance, a student once with a proposed major of chemical engineering noted "[she] had no idea of the amount of physics that was needed in this field and the lack of basic general chemistry in the concentration." Most students share some aspect of surprise in understanding their fields of study and the true meaning of a project relating to the field. Since our goal was to introduce students to their intended fields of study, we feel that these results show success in our attempts.

We have also noticed a much lower transfer rate out of the engineering school since the institutionalization of the service-learning projects. (Unfortunately, we cannot provide exact figures on the rate, as this is confidential information for the institution.) This shows that the practical experience gained by students during their first year in the program through these projects helps to spark their interest in their intended fields. We also find that fewer students are changing between majors after their experience with CSLP. The introduction to engineering they are given allows for students to make more educated decisions in choosing a major during their second year in the engineering program.

Conclusion

Introductory first-year engineering courses are imperative to spark student interest in engineering. These courses need to be designed to cater to students with varying interests and different levels of technical background, while introducing students to engineering design as it would relate to their educational career. This is important since basic design skills are important to all fields of engineering design. Community service-learning projects are the perfect venue for such courses because students can be introduced to both engineering design principles and real world professional experiences simultaneously. Providing students the opportunity to have hands-on experience is invaluable in motivating students to see the usefulness of their chosen academic paths. Furthermore, students are required to deduce feasible solutions. Many times in courses with hypothetical design projects, students design solutions without concern for practical implementation.

Project management and professional skills are imperative in today's society. All students will find themselves working in teams/groups throughout their academic and professional careers. Introducing students to these skills at an early stage will undoubtedly aid in future projects and success.

The use of computers is important in teaching engineering design. Software packages expedite the engineering design process by providing computational tools for analysis (Mathworks Matlab) and 3D image rendering tools (Alias Maya). These tools will allow students to devise more practical solutions to engineering design problems.

Engineering design skills are mandatory and invaluable to all engineers. Providing students the early exposure to solving real-world design problems will afford them the technical and practical knowledge, which will be readily useful for future engineering problems.

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