Method and Experimental Based Design: An Approach to Freshman and Sophomore Engineering Design Projects

Jeffrey R. Mountain
The University of Texas at Tyler

Abstract

The benefits of group-based design activity in an engineering curriculum may be greatly enriched by careful structuring of design activities into the freshman/sophomore introductory course sequence. Focal points of this approach include: teaching a design methodology, applying that methodology to unique, product development-based problems and guiding students through discovery based experimental work to provide hard data upon which design decisions may be based. Project evaluation is focused primarily on written reports detailing the design process, and oral presentations defending the design decisions, rather than the level of success for a specific design solution. This paper presents the design project activity designed into a freshman/sophomore sequence of courses required of engineering students at The University of Texas at Tyler. The design methodology is outlined, and several projects are detailed. Examples of experimental work, and simplified analytical procedures, are presented, illustrating how project-relevant data are used to support project design decisions. Some innovative student "solutions" are presented, pointing out both strengths and weaknesses of this approach to introductory engineering design education. Rapid prototyping as a strategy to integrate the Product Realization Process into our introductory engineering curriculum is discussed. The next evolution of the course sequence, intended to both streamline and improve the design experience, is also presented.

I. Introduction

Beginning in the fall semester of 1998, The University of Texas at Tyler became established as a full, four-year university. This included admission of freshmen engineering students into the year old School of Engineering. One of the foundation principles of the expanding UT-Tyler engineering program was full, four-year contact with the incoming engineering freshmen by designing a three-semester, *Fundamentals of Engineering* course sequence common to both the Electrical Engineering and Mechanical Engineering programs of the School of Engineering. The intent of the sequence is to introduce fundamental engineering skills and provide group based, design project activities while permitting interaction between students and engineering faculty during each semester that a student is in the program. This paper will outline the structure of the course sequence, describe the design activity sequence for a group of freshmen/sophomore students and describe the experience of the next iteration of activities and lessons learned from this approach to introductory design education.

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In its initial offerings, the *Fundamentals of Engineering* (FOE) sequence consisted of ENGR 1300, ENGR 1301 and ENGR 2300: Fundamentals of Engineering I, II and III. Each course was divided into three topical modules formatted in one hour of lecture and two three-hour laboratory sessions each week. The sequence provided one module of instruction each in the following three topic areas: Introduction to Engineering and Design, Basic Computer Skills and Computer Analysis Software. Two-module coverage was provided in Engineering Design Graphics, Structured Programming and Technical Communications. Laboratory time for design activity was allocated in each topic module. The modular approach permitted students to get acquainted with faculty members from both of the departments. A Fundamentals of Engineering Coordinating Committee, composed of members from each department, was established in Fall 1999. The primary purpose of the committee was to coordinate and oversee sequence design activities.

II. First Semester Design Activities:

FOE I begins with the Introduction to Engineering and Design module. A ten-step design process is outlined, providing freshman students with an effective, easy to understand design methodology[1]. The ten steps are:

1. Identification of need
2. Problem definition
3. Search
4. Identification of design constraints
5. Establishment of evaluation criteria
6. Identify alternative solutions
7. Analysis of alternatives
8. Analysis-based decision
9. Specification of final design
10. Communication of final design

Once the methodology has been presented, students are divided into groups and a design project is assigned. Groups may be formed using several different methods: random number assignment, equal division of skills, or self-forming. For first semester freshmen, assigning groups based on division of skills appears to be the fairest method. Groups were formed based on existing computer skills, specifically word processing, spreadsheet, presentation software and CAD skills. The assessment of skills was based on a student survey. While essentially all entering freshmen posses word processing skills, the amount of spreadsheet, presentation and CAD software experience varies significantly; making some equal distribution of skills desirable.

According to Burton and White[2], freshmen engineering design projects may be categorized into eight different methods: reverse engineering, creating something useful, full scale project, small scale project, case studies, competitions, non-profit projects and redesigns of local projects. The method used at UT-Tyler is a hybrid; we sponsor a competition to create something useful. This method generally keeps costs low and fosters a high level of project interest. The project is primarily a vehicle for practicing the methodology, but results in a working prototype, rather than a "paper design." Though creation of successful prototypes is stressed, the primary pedagogical focus is successful application and documentation of the process, resulting in a written report and an oral defense of their designs.

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The first, coordinated design assignment was Project BIGSHOT (Beginner's Interdisciplinary Group Solar HOTrod). This design activity was defined by a need to develop competitive, small-scale, solar powered cars. Teams were provided with similar motors and photovoltaic cells. The competition was to be held indoors, on a two-lane, lamp lit track. The UT-Tyler approach to solar powered toy cars was a bit different from those published on the web [3,4]. Chassis, drive train and cell mount designs evolved from matching the motor to the power source and load based on empirical data gathered from individual components. The cars were required to fit within a specified enclosing volume. "Backyard engineering," the expedient and comfortable approach frequently preferred by students, was highly discouraged. Experimental activities and targeted instruction were provided to insure sufficient data and analytical skills to affect a method based design. Regularly scheduled written reports, highlighting application of the design methodology, were required. Interim reports formed the basis for a final written report and oral presentation.

Experimental work focused on the characteristics of the power source and the motor. Students discovered the non-linear V-I characteristic behavior of photovoltaic cells by conducting experiments to map their solar cells under varying loads and excited by incandescent light. The light source was similar to the one to be used in the competition.

Students conducted additional experiments to determine the torque/speed/power characteristics of their electric motors. Using a similar DC motor as a generator, electrically loading the generator output from short circuit to open circuit, obtaining motor speed, input/output current and voltage data, the motor efficiency and motor torque at each speed could be estimated.

Subsequent class and lab instruction on spreadsheet use enables students to determine operating points where the photovoltaic power output matched the required motor input power. In addition, a simplified modeling strategy is provided that is used to estimate the required drive wheel torque as a function of car mass, wheel and axle radii. This modeling scheme provides sufficient analytical capability to determine a drive train; matching the available torque to the estimated torque required. While this model provides only a rough approximation of the torque required, (it neglects dynamics forces), it is sufficiently simple to be readily understood and sufficiently conservative to allow teams of first and second year students to enter reasonably competitive car designs. Figure 1 shows one of the successful solar car designs.

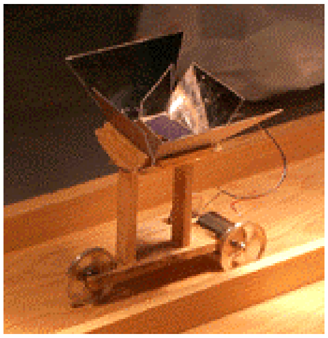

Figure 1. A final solar car design for first semester freshman group design project.

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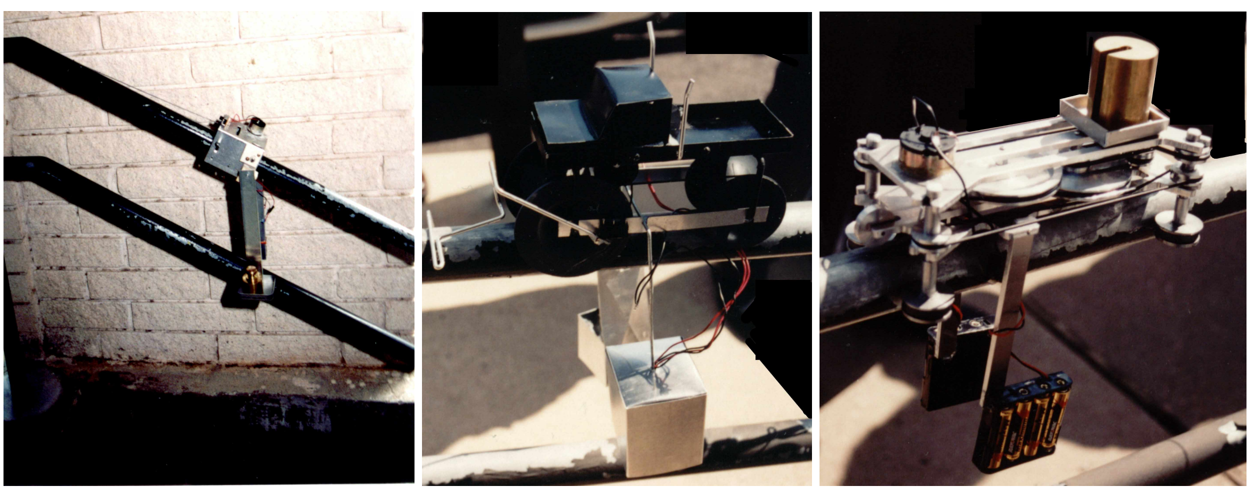
III. Second Semester Design Activity:

In the FOE II second semester project was called the "Rail Rider" and was assigned during the first class meeting of the semester. The product to be realized was a monorail delivery vehicle capable of hauling a 500-gram load up an incline in the fastest possible time. Rail Riders were to turn off the motor upon reaching the horizontal section at the top of the rail. A different, more powerful motor was provided for each team. In addition, a prize was established for the team with the most esthetically pleasing and innovative design.

Structured experimental work involved characterization of the motors and obtaining detailed measurements of a handrail adjacent to a three-step incline that would serve as the test rail for the competition. Each team member was required to create a CAD solid model of the test rail in order to reinforce their CAD skills and determine the geometric constraints associated with the project. The motor characterization data was obtained at a single input voltage in the middle of an allowable range. Student groups developed torque/speed curves for other operating voltages based upon DC motor modeling equations developed during class lecture sessions. Unstructured lab time was available for student groups to meet and perform additional experimental and construction work. As with the first semester course, the academic focus is primarily on the application of the methodology and development of group skills rather than the success of the actual prototype. High quality, formal written documentation and oral presentations highlighting the process were expected and delivered. The expectation of high quality of academic deliverables was additionally reflected in the quality of prototypes produced by the student teams. Three of the solutions to the rail rider problem are illustrated in Figure 2. While all solutions tended to produce prototypes with suspended battery carriers, keeping the center of mass low, it is apparent that a variety of drive wheel and drive train configurations evolved.



a. b. c.

Figure 2. Rail Rider Solutions: a) worm driven rail rider with rubber wheels located illustrating the grade of the test rail, b) belt driven rail rider truck with apple-core wheels and c) belt driven, four-wheel drive design using magnetic drive wheels and carrying the 500-gram load.

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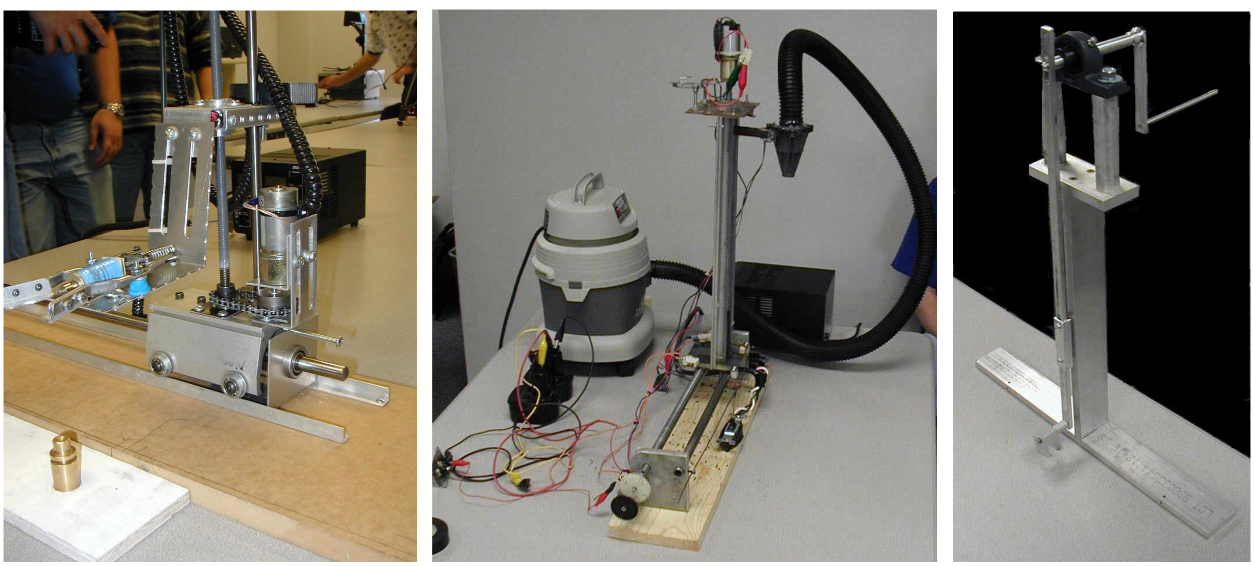
IV. Third Semester Design Activity:

In FOE III a seemingly simple task was presented to our first semester sophomores: develop a system that would quickly, efficiently and elegantly pick and place a grooved brass cylinder from one designated location to another, clearing a designated obstacle within the work cell. While no specific power source was required, direct manual placement was not allowed. The work cell was equipped with locator pins so that different solutions could quickly and accurately couple for demonstration. Working drawings of the work cell were provided for reference.

Consultation with faculty members regarding the borrowed use of component parts was encouraged. A limited number of component parts could be fabricated provided students submitted fabrication drawings and signed work orders to our fabrication lab manager. These procedures maintained a high level of student/faculty interaction, provided access to a broad range of component parts and added real world manufacturing constraints. It was initially anticipated that relatively simple, inexpensive solutions would evolve. But, many student teams chose to develop elaborate, custom fabricated devices. Students perceived high quality and sophisticated prototypes would be expected since that was the expectation for previous projects. The project inspired student creativity with a problem relevant to engineering in a manufacturing environment. Cartesian coordinate, polar coordinate and simple rotary machines were devised. Electric, pneumatic and manual power sources were used to actuate locomotion.   Gripping devices included electro-magnetic fingers, vacuum devices and C-channels.   Figure 3 shows some pick and place solutions.



a. b. c.

Figure 3. Solutions to the pick and place problem: a) a Cartesian solution using two-fingered, solenoid actuated gripper, b) a Cartesian solution using a vacuum based gripper and c) a rotary machine solution based on work cell / part geometry, utilizing a C-channel gripping device and hand-crank operation.

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V. Lessons Learned:

Surveys of participating students, review by faculty members and comments solicited from junior college transfer students have been used to assess the projects. Transfer students indicated that the projects represented a valuable preparation tool for their current coursework and that a similar type of design experience would be beneficial for them. This feedback has prompted us to enhance our junior college transfer transition course with a team-based, design project.

Faculty review of project presentations initially revealed one major concern with using a speed to cost ratio performance index during the solar car competition. This performance index led to the use of toothpick and Popsicle stick car frames, functional, but poorly constructed and very unappealing. Product development costs are an important consideration, but future projects have included a budgetary constraint, rather than a cost-based evaluation criterion for competition.

Feedback from participating students was obtained by survey following completion of all project requirements. The surveys indicated that most students displayed high levels of enthusiasm, enjoyed the challenge and appreciated the learning experience. They also indicated that time devoted to last minute, end-of-semester, prototype completion might have detracted from their final examination performance. Poor application of time management techniques was identified as the primarily reason for the end-of-project overload. Future course offerings have included a revised schedule of deliverables; scheduling the competition at least two weeks before the end of the semester. Based upon the quality of the third semester projects previously described, the slight advance in schedule has had little effect on the quality of the final prototypes.

Mid-project oral presentations and written reports provide the groups with timely feedback and force early preparation of deliverables. This approach has been praised by industry advisors and further reduces the level of last minute preparations required to complete the projects.

VI. First-Semester Freshman Project – A Second Iteration:

For the most recent FOE I project, student groups were to design and build a working prototype of a toy tractor to pull a miniature sled. The sled was designed to increase the frictional load as the tractor and sled progressed down the track, similar to a "real world" tractor pull competition. Student groups were provided with a sheet metal chassis and an electric motor. Battery voltage and overall tractor width were the primary physical constraints. In addition, a towing eye, provided by a hole in the chassis, was required to be reasonably level with the eye on the sled. This prevented lifting of the sled as a means of limiting the progressive friction effect.

Following the announcement of the project, brainstorming sessions were conducted with each class section to suggest experimental work that would provide meaningful data and assist in the designs. Included among the suggestions were: an experiment to determine the force required to move the sled, a motor torque/speed characterization study and some instruction on drive train design. Although instructor facilitation guided the students towards these particular experiments, the students were allowed to suggest the experimental procedures; allowing them to feel like

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partners in the process, rather than students performing predetermined experiments. The force required to produce impending sled motion was estimated, as was the maximum force required during a competitive pull. Each student used the force meter to produce data points and all of the data was collected for the lab section. The data for each set of measurements was randomly distributed, providing a hands-on experience to introduce means and standard deviations as tools for estimating population characteristics. This also provided a set of choices to use when estimating the torque required to move their tractor and sled. The motor characterization experiment was conducted as previously described.

The Beginner's Interdisciplinary Group TRActor Pull (Project BIGTRAP) built upon the lessons learned during previous FOE projects. As mentioned previously, cost of materials was to be a design constraint, project planning using either a Gantt or a PERT chart was required, the scheduled date for the competition was two weeks prior to the end of the semester and mid project oral presentations were made. Although the project planning activity was intended to put the students on an evenly paced schedule, the majority of the project construction activity still occurred within a week of the competition. Final oral presentations were made during finals week. The requirement of a mid project presentation provided a foundation for the final presentations, which decreased the amount of last minute preparation and improved the quality of the presentations.

A grant from the National Science Foundation, coupled with a minor structural change to the FOE course sequence and a change in solid modeling software, allowed laboratory time to be devoted to an Introduction to Rapid Prototyping (RP). On a rotating basis, each design group produced an RP model of a simple motor mount that could be used to attach the motor provided to the chassis. The students visualized a rendered image of the CAD-based solid model, then produced a laminated paper version of the model using an RP system from Schroff Development Corporation. Figure 4 is a rendering of the CAD model for the FOE I motor mount.

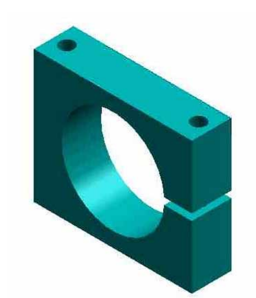

Figure 4. Rendered solid model of motor mount used in rapid prototyping exercise.

Initiating freshmen engineering students to rapid prototyping can facilitate the integration of design and manufacturing during downstream engineering coursework [5] and represents the first step towards integrating the Product Realization Process into the UT-Tyler mechanical engineering curriculum (a National Science Foundation CCLI-A&I track funded project utilizing desktop manufacturing equipment[6]). In this application, the laminated paper RP part was available to each group; serving as either a functional member of the design solution or a guide

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for fabricating a more durable model. The RP model was sufficiently strong to be used when a spur gear drive train was used, as shown in Figure 5, but not sufficient to withstand the twisting loads associated with worm gear drives. Solutions that adapted worm drives into their solutions eventually used some other type of mount. The tractor pull design project inspired numerous, unique solutions, some of which appear in Figure 6.

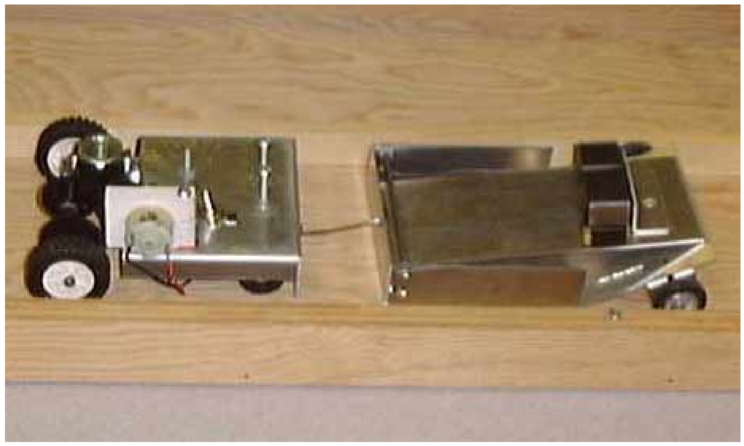

Figure 5. Tractor solution utilizing laminated paper RP motor mount and attached to advancing weight sled.

Figure 6. A variety of solutions to the tractor pull project.

VII. Future Directions:

In an effort to both improve and streamline the mechanical engineering curriculum at UT-Tyler, a new engineering fundamentals sequence has evolved, effective for Fall Semester - 2001. Prevalent, pre-existing word processor skills, combined with a decision to introduce analytical software as needed rather than provide generalized instruction allowed a streamlining of the FOE sequence. The best points of the previous FOE courses will be retained and the weaker aspects will be refined or removed. Entering freshmen engineering students from both programs will take a two credit hour course that includes Introduction to Engineering and Design, Technical

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Communications and group based design activity content. Continuing mechanical engineering students will take a two credit hour course in the second semester focusing on Engineering Design Graphics (including solid modeling and rapid prototyping) and a third, two-credit hour course focusing on structured programming. Group based design activity will be included in each of the subsequent mechanical engineering courses.

VI. Conclusions:

Design activity is common to most first year engineering programs. While novice engineering students don't posses the analytical skills to fully attack complex design problems, they may be guided to perform meaningful, product development design tasks by providing a useable design method, guiding them through project relevant experimental work augmented with presentation of simplified, analytical models and encouraging them to produce high quality products. This approach appears to stimulate creative design skills and foster an enthusiasm for the design process. Further, students perceive this approach as being relevant to their academic endeavors.

VII. Acknowledgements:

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JEFFREY R. MOUNTAIN
Jeff Mountain is an Assistant Professor of Mechanical Engineering at the University of Texas at Tyler and chair of the Fundamentals of Engineering Coordinating Committee. His teaching background includes courses in CAD-based engineering graphics, robotics and electro-mechanical system design. He received his B.S.M.E. degree in 1989, and his Ph.D. in Mechanical Engineering in 1994, from the University of Texas at Arlington.

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