Int. J. Engng Ed. Vol. 17, Nos. 4 and 5, pp. 381–385, 2001
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Balancing Capability, Enthusiasm and Methodology in a First-Year Design Program*

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*The **Engage** program is a successful new approach to first-year engineering studies that is being implemented at the University of Tennessee. This program develops the desired attributes of engineering graduates that are requested by industrial employers by introducing realistic design problems and approaches in parallel with introductory technical concepts. The resulting program integrates instruction in computer tools, graphics, statics and particle dynamics in two team-taught six-hour courses, each with parallel team design projects.*

INTRODUCTION

ENGINEERING EDUCATION is changing in response to a fundamental rethinking of the methods used in design education and industrial pressures to integrate the people skills of communication and teamwork into the curriculum [1, 2]. There is a need for a return to some of the 'hands-on' approach of earlier curricula, and a realization that the increasingly competitive marketplace has placed a premium on continuous improvement of products and processes with constant innovation. The traditional undergraduate curriculum has actively encouraged students with certain learning preferences while discouraging others [3, 4]. At **Engage**, we attempt to provide teaching and learning options to accommodate the variety of learning styles in a single consistent theme with a holistic teaching approach, that balances traditional linear, deductive teaching methods with other methods more appropriate to solving open-ended design problems. During the 1998–99 academic year the program involved 150 students and 30 design teams, and year 1999–2000 it involves our entire first-year class of approximately 480 students (96 design teams).

Recent learning theory work is consistent in arguing that engineering problems are best solved by approaching them with a sequence of different viewpoints, all of which must be given proper consideration to ensure a successful result [4–6]. Regardless of their individual preferred learning approach, students must be taught to work with a variety of other viewpoints to be a successful designer. In addition to traditional analytical practice, students need to learn complementary skills of problem formulation, visual and tactile thinking, idea generation, and communication. This set of skills is essential to successful engineering teams that use the individual member skills to master the complete design problem-solving 'cycle'. A modern curriculum must balance different instructional techniques to educate students with both analytical and effective design skills.

PROGRAM DESCRIPTION

At **Engage**, we address this balance with a design component of the curriculum consisting of team projects that increase in difficulty as the year progresses. Our goals are for the students to:

- learn that design is a natural process closely related to problem-solving skills they already possess;
- experience success as a designer;
- have a positive team learning experience;
- learn that design success is fun and somewhat compensates for the rigor of engineering study.

Students meet three hours weekly in a converted shop for this section of the first-year courses. They are teamed immediately at the start of the program and given a project that requires teamwork, planning, estimating, a knowledge of accuracy, and significant figures before any of these topics are discussed formally. The message to the students is that they already know how to solve significant problems, and we are there to show them how to organize their efforts and to teach tools they can use to increase their problem solving abilities.

Elements of the design method are formally introduced and practiced as the projects become more difficult. For these first-year students, our

* Accepted 30 July 2000.

experience has been that the appropriate design methodology must be very simple and intuitive to the students. It must correlate with problem solving methods they have used before. A specific example is the Pugh chart [7] introduced as a concept selection technique. We introduce it as a convenient way of assigning numbers to the advantage/disadvantage lists that they have all used for making decisions. For overall methodology, we use a variation on the problem-solving methods discussed in Lumsdaine [4] and Fogler [8].

Objectives for the first semester include practice in oral and written report formats, team roles, project planning, appropriate problem specifications, background searching, and idea generation. The final two projects (of five during the first semester) involve constructing a device out of simple materials and testing of the devices. The projects are tied to the topics being discussed in the other sections of the course, providing 'real' objects to be drawn in graphics and practical examples of the technical material being presented. For example, the design and construction of a foam-core chair complements the discussion of free body diagrams and 'pre-statics'. For the second semester, only two design problems are attempted, giving the students time to integrate what they have learned about design, and step through the process for each project. Additional requirements that are introduced are the use of a concept selection technique, performing basic experiments on the concepts generated or materials used, and predicting the performance of their device before testing. Matching the technical content of the course, the first project is 'static', typically a structure design where they can perform a predictive truss analysis, and the second project is 'dynamic', where their new knowledge of MATLAB programming is utilized by requiring a predictive program for a device with changeable inputs. We have used bungee egg drops and catapults for this project.

Each team has a facilitator who is at least a second-year student that has previously completed our first-year program. These facilitators provide guidance in such topics as planning, brainstorming, presentation skills, and general mentoring as they are needed during the year. The team facilitator training program, for upper level undergraduates, is designed around the constructs that 1) communication and teaming skills are learned skills that are not modeled or taught in most engineering academic and work settings; and 2) engineers are problem solvers and therefore must be taught these skills in a rules-based format that uses their learning style strengths. This program has been very popular as the student facilitators realize the many applications of the material in their own career development [9].

Initial data from the pilot implementations of the **Engage** program has encouraged us that our goals are being accomplished. Seventeen percent more of the pilot students finished the first-year coursework on time and with acceptable grade point averages than under the traditional program, and scores on common final exams were eight percent higher for the **Engage** students. Qualitative student response on the design program is that it is lots of fun and lots of work. Approximately 70% of our students report a positive team experience for the first semester, and this percentage increases substantially for the second semester. We believe our approach uses early design education to create enthusiasm and teach an engineering approach to problem solving that gives first-year students a realistic exposure to the profession.

DESIGN METHOD OUTLINE: ENGINEERS SOLVE PROBLEMS!

A simple procedure appropriate for the development of solutions to 'open' or 'design' problems is presented. The students learn that design problems involve balancing conflicting constraints and may have many acceptable solutions. As stated earlier, we use a methodology based on the works of Lumsdaine [4] and Fogler [8]. Specifically:

- *Customer, client, society . . . specifies a need:* this is presented to the students in a discussion format. Students are encouraged to think about and discuss the needs that are satisfied by various common devices that they are familiar with and to think about the motivations of the designers of those products.
- *Problem specification:* material is presented on how to proceed from an identified need to problem specification or problem statement. Examples are presented and the students practice by developing problem statements from customer specified needs. For all of the design projects in the Engage program the problem specifications are developed by the faculty.
- *Background:* students are required to investigate background information related to their projects. This includes investigating how other designers have solved similar problems, gathering data related to their project, etc. The students perform this work with some guidance provided by the faculty and the team facilitators.
- *Generate alternative solutions:* students are required to generate several alternative solutions at the conceptual stage. Instruction on brainstorming techniques is provided and the team facilitators provide some assistance. The alternative conceptual designs must be presented in the design reports.
- *Concept selection:* information is presented to the students on procedures that are useful in assessing and selecting design alternatives (Pugh charts for example). The students practice these techniques on all of their projects and the selection process and criteria must be included in their reports.
- *Concept implementation:* almost all projects are

carried out through the build and test phase. Most of the projects end with a day of 'solution competition.' This is usually the most enjoyable part of the process and is attended by all the students and faculty of the **Engage** program as well as a large number of other college faculty members. The results of 'test day' must be provided in the students' reports.

- *Solution communication:* all projects require final reports. These are usually a mix of oral and/or written reports. Some projects require preliminary reports at approximately the halfway point. These are also a mix of oral and/or written reports. Figure 1 provides the required report format.

ENGAGE PROGRAM DESIGN PROGRESSION

The following is a summary of the design projects utilized in the 1998–1999 academic year. The name of the project, a short description, objectives, report requirements and objectives are provided.

Engineering fundamentals 101—engineering approach to physical phenomena

Fall Semester; team design component is 3 hrs/wk scheduled work periods for team grade (30% of 6 credit hour course). Other components of this course include instruction in computer skills (engineering graphics and computer programming, 40%) and basic engineering science (30%).

Introductory Module Project: Team Name and Logo:

- Objectives: icebreaker, team expectations.
- Required: team name and logo, hand drawn. Informal 3-minute oral reports by randomly chosen team member on team process used to develop ideas, representation of team name and logo, and interesting features.
- Duration: 1 week.

Module 1 Project: Volume of Neyland Stadium:

- Capsule description: teams required to come up with an engineering estimate of the volume of the campus football stadium.
- Objectives: engineering estimates, data gathering and error, units, introduction of written report format.
- Required: 3–5 page written report to standard report format (Fig. 1).
- Duration: 2 weeks.

Module 2 Project: Traffic Study:

- Capsule description: student teams are required to gather data and propose a solution to a campus traffic congestion problem.

The following is a simple and effective *format for an oral or written communication of a solution* to an engineering problem, based on the idea that the story is the basic building block of human communication.

Story elements	*Bridging questions*	*Report elements*
Beginning	**What is the Problem?**	**Problem Statement**
	Why is it of interest?	
	What's been done before?	**Background**
Middle	**What did you do?**	**Narrative**
	How did it come out?	**Results**
End	**What should be done next?**	**Conclusions and recomendations**

Translating this idea to a usable format:

Title page (This should include team name and logo, team member's names, title, date, class name, class team designation.)

Problem statement (This is a clear statement in your own words of the problem you are solving. It probably is not the same as the problem stated to you, which needs to be explained in the next section.)

Background/assumptions (Why is this problem of interest? Has anybody else solved similar problems? What level of assumptions are you going to make in order to approach this problem?)

Narrative (This is the 'What did you do?' middle of the story you are telling. It includes the majority of the words and analysis. In this case, it would be appropriate to describe some of the different approaches considered and how you chose your final plan. What data, measurements, analysis . . . did you do?)

Results (What were the results of your plan? This is the appropriate place for any tables or graphs of results, as well as your error estimate.)

Recommendations and conclusions (What conclusion(s) do the data you have gathered support? Having accomplished this task, what would you do differently next time?)

Format notes: The flow of information is very important. Sketches are very helpful (a picture is worth a . . .) and should be placed in body of text where it is referred to, not in the back of the report. Same comment for graphs and tables.

Fig. 1. Report format.

- Objectives: practice on written report format, with emphasis on clear problem statement. Collection and representation of data using Excel and Matlab.
- Required: written report with computer representation and plotting of data. Data must support recommendations of report.
- Duration: 2 weeks.

Module 3 Project: Mechanical Dissection of Electrical Appliance:

- Objectives: reverse engineering of existing product with discussion of design decisions.
- Adapting report format to oral presentations, poster generation with PowerPoint.
- Required: oral poster report.
- Duration: 2½ weeks.

Module 4 Project: Stepo-Stool:

- Description: each team must construct a step stool from a single 32×40-inch piece of foamcore. Stool must have three steps of 6, 12, and 18-inch height, each with a minimum area of 75 sq. in. Stool must withstand the weight of 'light-stepper' and 'heavy-stepper' chosen from our faculty and graduate student staff.
- Objectives: practical application of free body diagrams, vectors and moments. Drawing of simple student designed device in drawing package (Mechanical Desktop). Design, build and test a simple device. Introduce design method (below) and emphasize background research and alternate idea generation.
- Required: an 'idea generation report' consisting of preliminary sketches. Written report including free body diagram and consideration of forces and moments in design.
- Duration: 2½ weeks.

Module 5, 6 Project: Rubber Band Tractor Pull

- Capsule description: each team must design, construct and test a rubber band powered tractor from a given kit of materials. Tractors are scored on their ability to transfer energy as measured by raising a weight.
- Objectives: practice with the design method. Practical example of use of free body diagrams, moments, friction, and concept of energy. Organization of an oral report. Instruction in idea generation techniques. Computer-aided drawing of complex student designed device.
- Required: tractor testing. Conceptual preliminary reports showing adherence to initial steps of design method. Final oral report of 8–10 minutes using PowerPoint slides. Mechanical Desktop representation of tractor.
- Duration: 5 weeks.

Engineering fundamentals 102—applications of statics and dynamics

Spring semester, team design component is 1½ hr scheduled work periods per week for team grade (15% of 6 credit hour course). The majority of time and credit (70%) is related to the instruction of Statics and Dynamics. The remaining 15% of time and credit is related to further development of engineering graphics and computer programming skills.

Project 1 (Statics): Bridge Over Trouble Gorge:

- Capsule description: team must design, construct and demonstrate a bridge that their team must use to cross 'trouble gorge', a span of two meters. Materials are thin wood stock (cut up paneling), cotter pins for pin connections, and twine. Materials are purchased from a company store and the bridges are evaluated on a weight supported divided by the cost of materials basis.
- Objectives: Demonstration of each stage of design process. Practical example of simple truss analysis. Truss calculations by Matlab. Economic tradeoffs in design.
- Required: Oral preliminary report. Bridge demonstration. Written final report with appropriate analytical predictions for design.
- Duration: 7 weeks.

Project 2 (Dynamics): Big Orange Sport Simulator (B.O.S.S.)

- Capsule description: team must design, construct, and test a device that simulates kicking a field goal and shooting a jump shot using a given kit of materials. Device rolls down a ramp and, while moving, must launch an egg at a goal post target or, in a separate contest, a basket target. Energy devices supplied are a change in elevation (ramp), a mousetrap, and a rubber band. Other kit materials are yardsticks, foamcore, pins, paper clips, small plastic wheels, and the like.
- Objectives: demonstration of each stage of design process. Practical example of particle dynamics, work and energy calculations. Performance prediction using MATLAB.
- Required: oral preliminary report. Simulated sports competition. Final report documenting performance prediction calculations and Mechanical Desktop renditions of device.
- Duration: 8 weeks.

SUMMARY

The **Engage** integrated approach to teaching design concurrently with computer skills and basic engineering science (statics and dynamics) as outlined in this paper works and works well. The initial comparison data presented here indicates that students develop a better understanding of engineering mechanics through the practical application of real design problems. In addition to basic design processes, they are also learning other valuable skills such as teamwork and technical communications, all of which will serve the students well in both their engineering education and their careers.

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