# An Introduction to Engineering Problem Solving and Design for High School Students in the Tennessee Governor's School for the Sciences

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## Abstract

For the last several years, recruiting efforts for the College of Engineering have become increasingly important as enrollments have declined, competition for bright high school students has increased, and the importance of non-traditional student representation in engineering has been realized. This paper describes a program, which through an immersion into the engineering design process, combines fun and competition with realistic information about the career of engineering.

The Tennessee Governor's School for the Sciences is a four-week summer program for rising high school juniors and seniors who are among the best and brightest in the state. Morning sessions of the program consist of a common curriculum for all 150 students with courses on computer skills, technical writing, and professional practices and ethics. In the afternoon, the students attend one of six specialty areas with approximately 20-30 students enrolled in each specialty. Each student attends only one specialty area for the entire four weeks.

Engineering is one of the specialty areas. Students chosen for this program have expressed an interest in engineering as a possible career choice. Essentially, the students can be divided into two groups – those who know (or think) they want to become engineers and those who want to find out more information about the engineering profession before they make a decision.

For the last two summers, the authors have been the instructors for the engineering component of Governor's School (Pionke in '96, Parsons in '97). Also during the past two years, the authors have been involved with two new curriculum initiatives: the development of a sophomore level introductory course in engineering design; and a total redevelopment of the entire freshman curriculum at the University of Tennessee (UT). The new freshman curriculum integrates graphics, computer skills, statics, and dynamics into a comprehensive course that includes an introduction to engineering design and problem solving, teamwork, and essential communications skills.

Previous engineering Governor's School programs had been a survey of offerings from the various departments and had not been highly rated by the students. Given the background of the instructors, the authors decided that the best program for the Governor's School would be an integrated program, providing an introduction to some of the same concepts and ideas that they had developed for the new freshman curriculum at UT. In this program, the concepts of what engineers do, the engineering design process and problem solving skills are presented via both "open" and "closed" design projects. Three projects are completed during the four-week program. All projects are design, build, and test. All projects are done in groups with an emphasis on teamwork as well as oral and written communications. At least two oral presentations are required. Written communications include poster papers as well as formal word-processed reports, which must include concept sketches.

Feedback provided by the students has been very positive. The students enjoyed the experience and feel that they gained a better understanding of the type of work engineers really do and their role in society. Many students from the summer '96 program have become engineering students at various colleges and universities (including UT) because of this early exposure to the engineering experience. In addition, due to positive reports by the attendees to fellow students at their respective high schools, engineering has become the most highly requested specialty of the six specialties at the Tennessee Governor's School for the Sciences.

## Introduction

The Tennessee Governor's School for the Sciences is a four-week program that is intended to provide talented high school students with an early exposure to a college experience and professional practices in several technical fields. Of the 150 students that attend the program each summer, approximately 80% of the students are rising seniors and 20% are rising juniors. All students attend a common curriculum during the morning session that includes classes in technical writing, computer use, and "thinking scientifically." Afternoon sessions are divided into six specialty courses including biology, chemistry, ecology, mathematics, physics, and engineering. Approximately 25-30 students are assigned to each specialty course and each student remains in his/her assigned specialty course for the entire four weeks.

For several years, the engineering specialty was operated "rotisserie style" where the students visited each of the eight departments in the college of engineering for three three-hour sessions. The various departments were allowed to independently develop their own program. Integration of the departmental programs was not required nor requested. Some departments did nothing more than basic lectures; others also provided demonstrations of various processes or devices germane to their discipline; and still other departments provided field trips to various business organizations or government institutions that did work relative to their discipline.

Although individually the various departments did provide *some* exposure to the kinds of activities that professionals in their respective field performed, the nine-hour time limitation resulted in only a very superficial exposure. One of the authors (Pionke) had an opportunity to teach one of these departmental sections in 1994. During this time, he discussed the program with many of the students. Most of the student's comments reflected a feeling of frustration and boredom. They stated that some of the field trips and demonstrations were interesting, but most of the in-class time was spent in a basic lecture format and this was very boring. The students did not like being "shuffled" from department to department nor was there a sense of connection with any of the instructors. Many of the students expressed a disinterest with engineering in general and in engineering at the University of Tennessee in particular. These anecdotal comments were restated and emphasized in the student formal evaluations at the end of the program.

Neither the Dean nor the Governor's School Program Officials were very pleased with the engineering specialty at this point in time. Instead of providing a positive experience and increasing student interest in engineering, the existing program had just the opposite effect. Clearly, in light of declining college enrollments, a new approach to the teaching of the engineering specialty was required.

After several discussions between the co-authors, the Dean, and the Governor's School Staff, it was decided that the new approach should satisfy several objectives. These objectives were:

- A more in-depth experience was desired with an exposure to "real engineering" problems.
- Students should be able to participate in the program and not just be observers.
- One instructor (or team of instructors) should run the entire program.
- Some exposure to the various disciplines within engineering should be retained.
- Students should be exposed to the new realities of the engineering profession that require a strong emphasis on communications and teamwork.
- Most importantly, it should be fun and interesting!

In order to satisfy these objectives, the authors were asked to reorganize and teach the engineering specialty course beginning with the summer 1996 program. The remainder of this paper describes the new course structure as well as observations and results from two years of implementation.

## The New Program

At the time of the reorganization, both authors were heavily involved with teaching senior capstone design courses. Since the summer of 1996, both authors have been part of a committee whose charge has been to restructure the entire engineering curriculum for all freshmen at UT with an emphasis on design, teamwork, and communication skills. This restructuring is in progress and both authors are part of the teaching team for this new curriculum. Also, in 1994, Dr. Parsons developed and implemented a sophomore level introduction to design course [1]. Based on their own experiences as well as a consensus of the engineering education community [2,3], the authors decided that a design-oriented course with an emphasis on engineering problem solving was the best approach to satisfy all the objectives listed above.

The core of the new engineering specialty program is constructed around three design projects. All design projects are carried out in teams of three or four students. A series of in-class discussions, lectures, and exercises are used to present supporting material and concepts in problem solving and design. In order to emphasize communications, all three design projects require both written and oral presentations. Finally, a sense of "engineering perspective" and professional opportunities are presented throughout the program.

Dr. Pionke taught the summer '96 program and he was assisted by one Ph.D. graduate student (he now holds a tenure-track position at another university). Dr. Parsons taught the summer '97 program and he was assisted by two M.S. graduate students (they are currently TA's in the new freshman program).

Design Projects

The students are introduced to the ideas of design and problem solving as natural human activities in which engineers have become remarkably adept. Readings and videos from Petroski [4] and Florman [5] are used to illustrate these points. A simple engineering design methodology is discussed as a way of approaching open-ended problems all engineers face. Text material from Lumsdaine and Lumsdaine [6] and Fogler [7] has been used, but the emphasis is always on solving simple but realistic open-ended problems of interest with the learning by doing. A typical sequence of projects would be the "mechanical dissection" of a small electrical appliance, the design and construction of a chair out of a single piece of foam-core board, followed by the design and building of a rubber band powered tractor.

The mechanical dissection is used as a starting point because the students get to see the results of good design. They are asked to try to understand how the engineers might have come up with the particular design, i.e., what problems were the designers trying to solve and how did they solve them? The students are encouraged to think of ways in which the design might be improved.

The second project (e.g., the foam-core chair) allows the students to go through the entire design cycle of design, build, and test with relatively easily understood objectives and very quantifiable outcomes. Even though the constraints on this problem are very well defined by the instructors (e.g., material choice, minimum sizes and capacity, etc.), it serves as an introduction to "open" design problems and allows plenty of opportunity for creativity. There are truly many viable ways to build a "chair" from a single piece of foam-core board.

The third project (e.g., the rubber band powered tractor) is the extension to a real "open" design project. The primary constraints are functional requirements; restrictions on size, minimum capacity, etc. have been removed. Construction materials are chosen from a "menu" provided by the instructors. Economics is introduced to the design process by offering a variety of materials, all at various costs, from which the tractor can be constructed. In addition, this project requires the students to build and test a "prototype," and then perform one iteration on their design solution.

As a supplement to the three design projects, the concept that engineers have to continuously innovate is presented throughout the program. Discussions center on the fact that not all solutions to societal needs are equal and clever ideas are rewarded in the marketplace. These discussions are reinforced with video material on the nature of creativity and material on students involved with the cleverness-first project [8].

Teamwork

A flavor of engineering teamwork is provided to the students by the project orientation of the course. Beginning with the summer '97 program, the students are given the Myers-Briggs Type Indicator [9] and a discussion of learning styles and how they effect the way people are likely to interact is then presented. At the University of Tennessee, the College of Engineering has a strong interaction with the College of Education in the area of teaching and evaluation of team behavior. Again, beginning with the summer ’97 program, an instructor from the College of Education worked with the students in the area of basic teaming skills. This instruction included survivor games, listing skills, and examination of team roles using popular culture (team roles in the Godfather movies is Dr. Parsons’ personal favorite).

### Daily In-Class Activities

The daily in-class activities are intended to convey concepts and guidelines related to the general design process as well as specific concepts and ideas related to the students’ current design project. General design-process concepts include such items as idea generation (brainstorming), idea evaluation and selection, engineering communications in drawings and reports, etc. Specific design concepts include such items as the load deflection relationship for cantilevered beams and the buckling of members in compression (the foam-core chair project).

General concepts are presented in a combination of lecture, discussion and in-class exercises. For example, on the first day of class the students are divided into teams and asked to perform a small brainstorming exercise. At the end of the exercise, the entire class and instructors discuss the results. The instructors then present some basic guidelines and rules that facilitate good idea generation. This presentation is a 20-30 minute lecture-discussion format. Then another brainstorming exercise is performed and discussed. However, the second discussion focuses primarily on how well the groups used the guidelines and rules and how well they actually facilitated the brainstorming process. All general concepts are continuously reinforced. For example, when material is presented on idea selection and evaluation, a new brainstorming exercise is performed and discussed in the context of the previously presented guidelines and rules.

Due to the very limited student background in mathematics and the basic engineering sciences, specific concepts are presented in an experimental fashion in which the students participate in the process. For example, the load displacement relationship for a cantilevered beam is determined using C-clamps, wooden yardsticks, and a set of weights. The students generate the load-deflection data for various beam lengths and then graph the data. The class and the instructor discussed the possible relationships. After the discussion, the instructor presents the solution with no mathematical derivations. Implications of the results are then discussed. Despite their limited background, the students get a general understanding of the principle and how it might apply to the evaluation and improvement of their current design project (e.g., the foam-core chair).

### Communications

Communications, both written and oral are emphasized throughout the entire program. Both forms of communications become more demanding as the program progresses. The first project requires only a poster presentation and a brief 2-4 minute “story-board” discussion by the team. The second project requires a 3-5 page summary report and a 5-10 minute oral presentation with “overheads”. The final project requires a more detailed 5-10 page design report and 10-15 minute oral report requiring the use of a presentation software package. A question and answer period follows all oral presentations, and the entire Governor’s School Staff is invited to attend the final oral presentation.

Sketching and graphing exercises are introduced early in the program to emphasize that engineers communicate extensively using various visual devices. To reinforce the point, sketches and graphs are used throughout the program in all in-class discussions and activities. In addition, all written reports and oral presentations require the use of appropriate sketches and graphs.

As stated above, all of the Governor's School participants take a technical writing class as part of their general program. Traditionally, this class has concentrated on developing and writing research oriented "term papers." For the past two years the authors have worked with the technical writing staff to tailor the writing assignments for the engineering students so that they are more in-line with a typical design report format. This has resulted in a luxury that most engineering professors (including the authors) have desired for years: a report consultant who forces the students to continuously correct their reports until they meet acceptable grammar and composition standards.

### Engineering Perspective

Engineering perspective is the name the instructors gave to their efforts to provide the students an overview of the context of the engineering profession and the responsibilities and opportunities available to those who work as engineers. Several different activities have been developed to provide this sense of engineering perspective.

Each department head is invited to talk to the students for about 20 to 30 minutes. They can present material on job opportunities in their respective fields as well as curriculum options available at the university. In addition to these presentations, a morning session is devoted to senior design projects presentations. At this session, senior design students present their current projects. This enables the Governor's School students to get a feel for the level of work undergraduates are expected to produce by the time they graduate. Also, a small number of field trips have been retained from the original program. These include trips to manufacturing facilities as well as infrastructure facilities such as steam plants.

Videos, readings, and discussions are used to provide a historical context to the engineering profession [10,11]. A historical example is taken from Petroski. The students are asked to place themselves in the 1890's (when our engineering building was new) and then consider the problem of how best to keep their loose notes together. From this point, the evolution of the paper clip is discussed, with the students designing and presenting alternate solutions and improvements. The discussions and presentations are used to reinforce the concepts of teamwork and communications.

## Summary and Conclusions

The "New Program" is now two years old and several observations have been made as well as several lessons have been learned:

- The new program meets all the stated objectives and represents a significant improvement over the previous program.

- Despite the fact that the new program is more demanding and requires the students to do a lot more work than the old "rotisserie" system, the student response is considerably more positive. Anecdotal as well as formal feedback has shown that most of the students enjoy the program and they feel that they have gained a new perspective about engineering.
- Even though the above result is true for most participants, some students still do not work very hard and are very difficult to motivate. The lack of an assigned grade for the course takes away almost all of the instructor's leverage. The instructor must rely on the "carrot" method of motivation alone.
- Many of the '96 students have entered (or will enter in the fall of '98) engineering programs at various colleges and universities (including UT).
- This program has shown (in the authors' opinion) that many of the concepts and ideas being implemented in several new engineering curriculums such as design, teamwork, etc. can be presented and taught to high school students.
- Because of the positive student response, the Dean and the Governor's School Staff would like to see the program continue in its current form. The intention is to operate the summer '98 program in the same manner with Dr. Pionke serving as the principal instructor again.

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