2006-804: DEVELOPING A FRESHMAN INTRODUCTION TO ENGINEERING TEXTBOOK

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Developing a Freshman Introduction to Engineering Textbook

Abstract

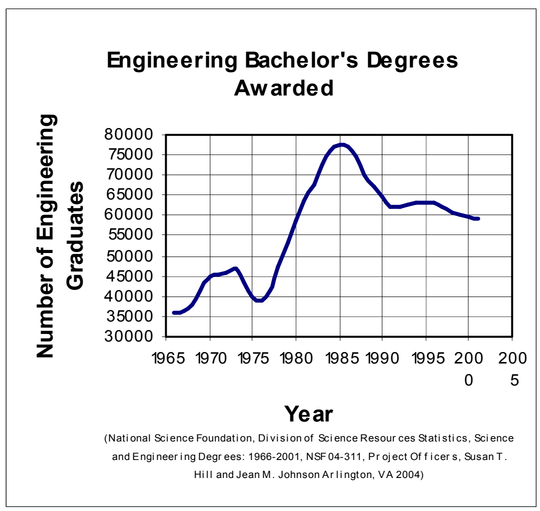
What should a freshman introduction to engineering course achieve and how will an appropriate textbook help meet the course goals? In this paper, we summarize our experiences searching for a text and ultimately how and why we decided to write our own book.

It can be said that the primary purpose of a first year introduction to an engineering course is to win the hearts and minds of first year college students who are considering an engineering career. It should not be so formal that the students are repelled or overwhelmed by technical issues while, at the same time, it should introduce some of the *basic principles* of engineering so that the students can experience what it might be like to spend their life as a professional engineer. Ideally the first year engineering course should emphasize basic principles as physical realities rather than be an exercise in abstruse terminology and/or even more abstruse mathematical formulae. An associated freshman-engineering textbook should reflect the excitement of the profession with language, topics, and examples that will stimulate young men and women. It should also assure that all students are getting the same message in a multiple section interdisciplinary course taught by more than one instructor. In addition, it should provide a supplemental guide to the various engineering majors in a limited amount of academic contact time. To state the obvious, one important property of a first year textbook should be to introduce no material that has to be *un*learned.

The approach we have developed makes a clear distinction between engineering "analysis" (what we call **minds-on** engineering) and engineering "design" (called **hands-on** engineering). The focus in the minds-on material is provided by a specific course theme: the modern automobile (which is today's highly complex "Smart Car"). Modern automotive technology clearly illustrates the need for an interdisciplinary team approach to engineering, and deals with a technology (cars) familiar (at least superficially) to all students. The focus in the hands-on material is in teaching the basic tenants of the design process and minds-on material, teamwork, resource management, and creativity.

Background

Meaningful freshman engineering courses are relatively new. Until the 1990s the first two years of engineering were devoted to developing the analytical tools needed in the last two years – mainly calculus and physics. As an aside, it's not clear why we continue to require physics since we then expand and re-teach the same subject matter as statics, dynamics, materials, thermodynamics, circuits, and so forth. By the early 1990s it became clear that there was a severe decline in engineering enrollment, and various studies pointed to first and second year student disillusionment with engineering so these



students were dropping out even before they saw one actual engineering course. Various efforts were then begun to introduce freshmen and sophomores to the exciting creative nature of the engineering profession. However, in most engineering schools the faculty had previously taught only junior and senior students, an experience that may have rendered them ill-equipped to reach or teach at the first year level. Possibly many simply tried to scale down what they had been teaching in upper level courses, a strategy likely to be met with only modest success. Many freshman engineering courses were handed off to adjuncts or graduate students or those lonely few who considered teaching important.

By 2000 there were a number of freshman "introduction to engineering" texts on the market with most trying to define all the major fields of engineering. Several introductory engineering texts added testimonials from working engineers (and who are not necessarily very good at articulating the excitement of engineering to freshmen). The following list contains a sample of freshman texts currently available. They differ widely in intent and in subject coverage.

a) Studying Engineering, R.B. Landis, Discovery Press, 2000 (ISBN: 0-9646969-5-9).
b) Engineering your Future, (4 volumes), W.C. Oakes et al , Great Lakes Press, 2004, (ISBN:1-881018-78-4, 1-881018-51-2, 1-881018-74-1, 1-881018-26-1)
c) Introduction to Engineering Design, A.R. Eide, F.D. Jenison, L.H. Mashaw, and L.L. Northup, McGraw Hill, 1998 (ISBN: 0-07-018922-6).
d) Introduction to Engineering Design and Problem Solving, M.D. Burghhadt, McGraw Hill, 1999 (ISBN: 0-07-012188-5).
e) Concepts in Engineering, M.T. Holtzapple and W.D. Reece, McGraw Hill, 2005 (ISBN: 0-07-282199-X).
f) Introduction to Engineering, P. Wright, John Wiley & Sons, 2nd edn., 1994, (ISBN: 0-471-57930-0)
g) Engineering Fundamentals, S. Moaveni, Brooks/Cole, 2002 (ISBN: 0-534-38116-2).

Team Approach in Teaching and Writing

We have rediscovered at least two very important lessons in developing a freshman textbook. The first is that one person alone cannot write a broad interdisciplinary text, so a creative interdisciplinary faculty team effort is required, and second you cannot publish a textbook appropriate to its intended audience unless you test it in the classroom first. The first step is the task of assembling a suitably motivated interdepartmental group of faculty. Ideally the faculty will self-select and be a dedicated, creative, and congenial team. The second step is to develop a broad-based course theme (that which will link the various parts of the book together). Thirdly the team must agree to focus on topics of interest to, and understandable, by first year students (and, while of course, being useful to their future engineering education). One suggested constraint is to integrate as many of the ABET A-J[1,2] outcomes as possible.

Our particular textbook team was composed of four faculty who had taught the first year course using notes developed over a few prior years and who had by then developed a course theme of the "Smart Car" which, it was felt, integrated all the fields of engineering into a single end product to which all[3] the students could relate (since all are familiar with an automobile, at least to a first approximation). A “Smart Cell Phone” or “Smart House” theme would probably work just as well.

The tendons that were used to unify the text for a “Smart Car” theme are shown schematically in the Figure 2. This represents the core material of the ‘*minds-on*’ portion of the class. There is too much material shown here to be covered in one course. Various engineering principles that are the core of what is intended to be the final “take-home” are also shown with the intention that a judicious selection should be made to select material appropriate to each school’s curriculum.

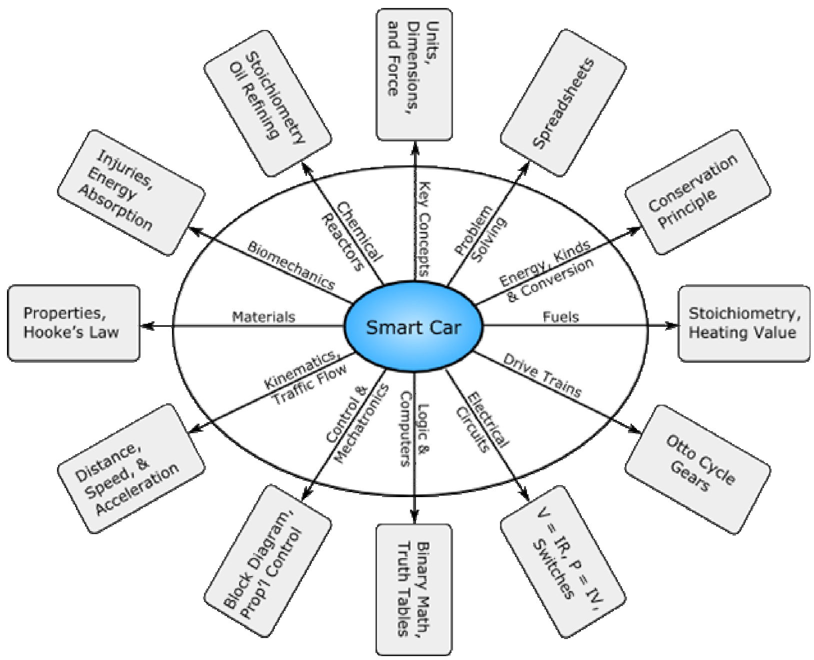


Figure 2

The faculty team each wrote outlines of chapters for the applications of their particular fields of endeavor that are exploited in designing the modern automobile. Subsequently all the chapters were re-written[4] to achieve a degree of stylistic conformity. These were certainly not intended to be all inclusive chapters that discussed everything a mechanical, or an electrical, or a chemical, or a civil engineer does, *etc*., but they did demonstrate how 1) modern technology is interdisciplinary and 2) how engineering fundamentals cross all fields of application.

The practicum or ‘*hands-on*’ portion of this course was implemented by having a series of classes that taught the design process, teaming, organizational methods, presentation skills, and how to record archival data. But it was primarily a competition in which the students built some kind of vehicle (wheeled, walking or floating, tethered, remote controlled, or autonomous) that had demanding physical challenges as well as culminating in a head-to-head competition against the creations of other student teams. This was the most popular part of the course for most students but in fact, they learned many skills even as most enjoyed the process.

Teaching the Teachers

Early versions of the various chapters needed to be filtered to be free of unnecessary jargon, implied knowledge, and leaps of logic. As described in some detail below, this was achieved by heuristically teaching each other. Indeed this was one of the most important lessons learned in developing a textbook with material written by faculty from various engineering departments.

One of the first significant barriers faced by an interdisciplinary team is that they only want to teach material in which they are acknowledged experts. They *think* they only know X, (*e.g.*, mechanics) and feel they *cannot* teach Y or Z (*e.g.*, controls or digital logic). In our early trials with this course we acquiesced to this philosophy and had faculty teach only their area of expertise in a multi-section course. This meant that the students had perhaps five or six different instructors during the course, with each with a different lecture styles, homework expectations, and grading policies. It was a disaster! Student evaluations were strongly negative, contrasting one professor against another and giving the course very poor student evaluations.

To fix this problem it was necessary to get each faculty to teach the *entire* course, not just in their own area of expertise. While there was faculty apprehension at first, to state the obvious, 1) they all have PhDs, so they have the capacity to relearn[5] freshman level material, and 2) they are teaching freshmen who present a *tabula rasa* and consequently cannot embarrass them in class. Ultimately these arguments were convincing, and in the end, when we compared the performance of different sections of the course, *none performed better in their instructor's area of expertise than any other section*.

Most of the faculty had never taught freshmen (or even non-majors) before, so there were two new problems. First, how to get faculty to be comfortable teaching the entire course with much of the material from outside their area of expertise, and second how to get them to "bring it down" to the freshman level? Both of these problems were solved by having each faculty member "teach" the material they developed for the course to the entire faculty who were teaching the course. The premise that that was pursued was that if the faculty could not understand this material, then neither could the freshmen. And unlike freshmen, the faculty was not afraid to ask questions of each other and to indicate areas that need expanding or clarification. Using this technique obscure jargon was filtered out, all technical concepts were clearly defined at their most fundamental level, and that the materials' depth was made appropriate. This also made the entire faculty comfortable with teaching material outside their areas (because they had been "taught" it by someone else). These "faculty-to-faculty" lectures occurred during the summer prior to the course proper and were occasionally difficult sessions, but the "if we don't get it, neither will they" feedback ultimately worked well. Later when new faculty was brought into the course they were asked to sit in on the course during a previous term or on lectures earlier in the week. By this time most of the faculty resistance to interdisciplinary teaching had dissipated.

Staff Organization

Contrary to what one might think, teaching first year students is not easy. This was their first course out of high school and, an engineering course to boot with its need for precision of language and of material; many first year students had never seriously done homework before. Some had ever worked outside of class.

It was important to have weekly staff meetings to get feedback on student progress. Weekly staff meetings allowed experimentation in the classroom to get immediate feedback. It also allowed the creation of common exams and grading schemes.

Classroom Experimentation

Finding out what works and what doesn't is a non trivial exercise. Seasoned teachers are needed to avoid making fundamental teaching mistakes that clouded classroom pedagogy. At first the exams were too easy but the standards were raised by using continuous feedback. Each year we had a different design theme and objective, all related to the general course theme (the Smart Car).

We also experimented with guest speakers chosen to added real-world experience in modern engineering topics. This was generally less successful because, even though the speakers were coached about the level of the audience, most of them could not relate to freshmen. Their talks were often jargon filled and over the students' heads, and as a result the students were confused and bored. The students filled out an evaluation card for each speaker to help us understand who reached them and who didn't. They were also encouraged to add comments about the presentation. Using this technique we were able to bring back speakers that could communicate well with the students.

Minds-On and Hands-On Experiences

Both theory and experimentation are important in an introduction to engineering textbook, but how to do both effectively? By integrating simple design projects into the lecture process one can expose students to both theory and application in simple ways. For example, the course was divided into two distinct parts – two hours per week of lecture and three hours per week of design studio. The lectures covered basic theory in the various topics of the course (as chosen from Figure 2), and the design studio covered the basic elements of design (which are basically the same for all engineering fields); they include problem definition, brainstorming, teamwork, etc. Various student team design-build-test projects were developed during the course culminating in a course-wide final design competition.

The Design Studio

Students tended to like the design studio more than the lectures for obvious reasons – they got to use their hands to create something meaningful, and besides, it was fun! Enthusiasm builds during the course as sections compete against each other in their design. The final design competition involved a substantial design-build-compete project that concentrated in the last half of the course. Keeping the final design in synchronization with the course lecture material can be a real challenge. But, if the course theme is broad enough it is possible to have sufficient parallelism between the formal 'minds-on' lectures and the Design Studio 'hands-on' exercises. In our case, as noted previously, the course premise was the interesting and highly interdisciplinary theme, "Smart Car" and which introduced many of the fields of engineering (mechanical, electrical, civil, materials, *etc*.). Therefore our final design studio projects were focused on model vehicle competitions that exploited the material learned in the balance of the course. For example one year, the design competition had wheeled vehicles simultaneously push a loaded tray in opposing directions with a scoring scheme that favored both how quickly you could reach the tray as well as how far you could plant it into the rival team's area. This dual strategy required a balance of speed vs. torque and thus an understanding of gearing.

Each student team was given a package of materials from which to construct their final design[6]. The nature of the final design changed each year, so upper class friends were of little help. Each year the level of design sophistication expected of the students was raised a little, and each time they met and exceeded the faculty's expectations. The challenges moved from tethered to radio controlled designs to autonomous control. The photograph at the right is an entry in the 2003 radio controlled walking machine final competition.

The following table summarized the design studio structure that we developed for our freshman engineering course.

Week	Topic
1	Introduction to engineering design - 'The Tower of Doom' (hands-on exercise). Qualities of a good designer, the need for a systematic approach to design. Design process Step 1: Define the problem to be solved; Step 2: Determine the design requirements; Step 3: Generate alternative design concepts.
2	Generation of alternative designs for complex systems: design philosophy and functional decomposition. Introduction to teaming - 'Waste Ball' (hands-on exercise). Design process Step 4: Evaluating alternative concepts
3	Characteristics of good teams - 'Survival' exercise. The role of ethics - definition, case studies, and professional code of ethics. Keeping a Design Notebook
4	Major design project introduced. Design Notebook review by instructor. Design competition rules and list of parts and materials presented.
5	Design process Step 5: Detailed design – drawings, experiments, and calculations. Design process Step 6: The design oral defense.
6	Design oral presentations
7	Soldering and gluing - wiring diagram of the motor, relay, and diode assembly.
8	Design for manufacture assessment. Competition robot assessment for level of functionality. The final design report requirements.
9	Performance testing - competition robot assessment of individual robot performance.
10	Final competition – single elimination tournament held in the student center.

Design Milestones

There is one big problem in getting freshmen continuously engaged in the design process - procrastination! Students have an unfortunate tendency to wait until the last minute before starting a large design project. In order to get them working and keep them working throughout the course, a weekly or biweekly "design milestone" was set so that the students knew exactly what they have to do each week. For example, an effective sequence was as follows:

- Design Milestone # 1: ***Clarification of the Task***. This is basically a clear statement of the problem and any design constraints.
- Design Milestone #2: ***Generation of Alternatives***. Provide documentation of various alternative design solutions.
- Design Milestone #3: ***Evaluation of Alternatives and Selection of a Concept***. Show how all the alternatives were evaluated and a final design chosen (e.g., using a decision matrix).
- Design Milestone #4: ***Detailed Design and Oral Design Defense***. Present a detailed final design to the instructor and defend it orally. It is only after this milestone is completed that the students can begin building their design.
- Design Milestone #5: ***Design for Manufacture Assessment***. Assess the final design for manufacturability.
- Design Milestone #6: ***Performance Testing***. Test the various design components and the final design to make sure it meets the specifications.
- Design Milestone #7: ***Final Design Report***. Submit a complete design report.

Each milestone contained gradable material to be handed in when the milestone was due. This process kept the students on task throughout the design process and prevented a last minute scramble to get it done.

Putting Together and Testing a Book Manuscript

The following suggestions may seem obvious, but ultimately they were won at considerable cost and with attendant difficulties. The first lesson is that writing a book is *not* simply like writing a very long scholarly paper. The elements of sustained continuity, of connectivity, of stylistic decisions, and a host of other considerations are foremost. Writing a multi-authored text compounds the problems, but in a textbook designed for its interdisciplinary nature, it is necessary. Ultimately, there must be only one voice in the text. Someone must take on the role of lead writer and create uniform prose throughout the text. This is perhaps the most daunting task of all. It sometimes requires rewriting entire chapters to make them flow with the rest of the material. Plenty of trivia awaits the tyro author. Examples and end-of-chapter problems must be created that are suitable and interesting. Answers must be correct and provided to future faculty. Figures must be drawn and inserted at appropriate points and be of sufficient quality, and permissions must be obtained for borrowed figures. And then it is necessary test the final manuscript in the classroom.

Paying students to find errors or misprints is a good way to engage them. A couple of dollars per error is usually sufficient to find things you now read over without noticing. This is also a good way to debug the solutions manual. Asking other faculty to read it usually doesn't work because they have their own course work to deal with.

Today users of textbooks expect to have a teacher's website to be continually maintained. To be credible, it must have at least a confidential solution manual. In the case of a book with a hands-on section, it also must have a at least number of suggested different design studio competitions that can be used over at a four year cycle without repetition.

Finding a Publisher

Publishers will want to see a book proposal (or prospectus) to see if it fits their publishing needs. Each publisher has their own suggested proposal format, but they typically include 1) an outline of the text (list of chapters, special features, educational goals, approximate length etc.), 2) planned on-line supplements, 3) brief author biographies, 4) a description of competing books, and 5) the size of the prospective student audience (such as to which courses it applies - to estimate the sales market). It is not recommended to write a book proposal before completing at least several draft chapters. Writing a textbook is a long and demanding task, and in universities where only research grants and papers are the primary measure of academic success, it may be particularly difficult to finish while balancing other demands on one's time.

While a book manuscript is worth at least 10-20 published papers (it takes that much effort), there is not much credit or support from one's peers It is only a labor of love and responsibility to the teaching profession, certainly not for money or recognition except for the smallest minority.

Some practical advice: Once at least a partial manuscript is available, and a book proposal has been developed, how does one find a publisher? Editors are always looking for new books and all publishers' Internet web sites have contact information for potential authors. However, it may be more productive to go to the ASEE annual meeting and visit the publisher's booths, look at the competition, talk to editors to find out what their interested in publishing. One could, of course, do this before writing, but by the time a completed manuscript is available the market will have changed. A publishing contract should only be signed if one can commit essentially all of one's time and energy to the project.

Getting It Done On Time

Even with a contract, the final manuscript has to be done and submitted on time. A textbook is a major time commitment, especially one with multiple authors. The successful completion of a manuscript obviously depends on interpersonal relationships among the authors, but there is also the very important need to effectively merge the text from each author in terms of content, style, *and* production scheduling.

Beyond each author's responsibility for particular sections, the question of timely manuscript completion is paramount. A "chief" author whose responsibilities include producing a uniform writing style and meeting the various production schedules dictated by the publisher is absolutely necessary. This is a *very* demanding responsibility (producing and revising multiple drafts of the text, preparing a solution manual, preparing all the text figures in a uniform format and associated text website, interaction with editors, *etc*.) and it is recommended that the chief author either a) be on sabbatical, or b) if teaching, only teach the course for which this text is designed. One *useful* deadline was imposed by the fact that the course was only offered in the fall; this dictated an early draft for most of the final manuscript.

For this particular textbook there was an additional facet of having a *very* diverse authorship. We had two authors (PGK and GW) whose primary careers were molded in industry with the advantage that both were used to vigorously enforced deadlines and therefore took such commitments more in stride than perhaps might academic authors.

Conclusions

Writing a freshman "introduction to engineering" textbook that students and faculty find interesting and useful, that meets some ABET requirements, that has the impact of increasing engineering retention (and perhaps can even attract a few liberal arts majors), is a daunting task. It is not a task to be taken lightly.

Such a text needs to be written to, and for, the modern audience (college freshmen) and not to the distant memories of faculty. An interdisciplinary textbook written with first year students in mind with an exciting approach should provide these students with the foundation they need to participate successfully in advanced engineering courses and design projects. It is particularly important that nothing that is to be *un*learned later should be inadvertently left in the text.

Bibliography

1. According to ABET, engineering programs must demonstrate that students attain an ability to: (a) apply the knowledge of mathematics, science, and engineering, (b) design and conduct experiments and analyze data, (c) design a system, component, or process within economic, environmental, social, political, ethical, health-safety, manufacturability, and sustainability constraints, (d) function on multi-disciplinary teams, (e) identify, formulate, and solve engineering problems, (f) understand professional and ethical responsibility, (g) communicate effectively, (h) understand engineering solutions in a global, economic, environmental, and societal context, (i) engage in life-long learning, (j) gain a knowledge of contemporary issues, (k) apply modern engineering tools to engineering practice.
2 . One of the ABET criteria that we particularly endorse is that corresponding to professional ethics; ethics is needed as an integrated part of both a first year engineering course and to be distributed throughout the accompanying text rather than as a late paste-on.
3. Interestingly our experience is that male students believe they are more familiar with automobiles than female students; in reality this is at best just a superficial level of knowledge.
4. Several times!
5. Or possibly even to learn some material for the first time depending on their particular engineering subdiscipline.
6. Detailed List of Parts: The final competition entries must be constructed from the following kit provided to each student team. One each: motor with adjustable gear box, gearhead motor, relay (for use with gearhead motor), diode (for use with gearhead motor), pull solenoid, set of 6 gears, wooden dowel 3/8" x 36", balsa sheet 1/16" x 3" x 36", balsa beam 3/8" x 3/8" x 36", plywood sheet 1/4" x 12" x 12", steel rod, 1/8"D x 20", piece of string 10' long, shock cord 1/4"D x 10" long (with hooks on both ends), rubber band strip 3' long, 3" diameter mailing

tube, 2 liter (plastic) soft drink bottle (provided by contestant). Plus four 2"OD (with 1/8" shaft diameter) wheels with hubs, ten super craft sticks, and two metal hinges 1" long.. Teams are responsible for purchasing fasteners not included with their kit. Typical options for fasteners include: wood glue, epoxy, screws, tacks, duct tape, hose clamps, and shaft couplers with set screws.