

2007: Equipping Students with an Engineering Toolbox in a Capstone Design Course

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Abstract

Industries seeking engineers have increasing expectations as to how well prepared students should be when embarking on engineering practice. Any prior experience such as through internships is highly valued as it implies that the student has potentially been exposed to some real life engineering. New engineers entering the workforce may be expected to tackle many facets of engineering and to begin making a meaningful contribution as soon as possible in the execution of projects. In capstone engineering design projects we attempt to incorporate as many aspects concerning engineering practice as we believe are necessary or that we can fit into a relatively crammed course schedule. In the Industry Linked Design Project course taught in the dept of Agricultural and Biological Engineering at the University of Illinois, the concept of an “engineering toolbox” is used in equipping students with a carefully selected knowledge set that covers most of the topics and issues which an engineer may be expected to face when practicing engineering. Topics range from ethical issues and product liability to project scheduling and designing for worldwide markets. In addition, topics that could have an impact on the success of a student and his future are included, such as personal financial management and career planning. Collectively these “tools” provide students with thinking skills and knowledge that help them quickly become effective and competent engineers. These topics for the engineering toolbox are covered during a semester while simultaneously the students undertake a “real life” industry project in which they are able to apply much of what they learn. The selection of topics for the engineering toolbox has evolved over more than ten years in accordance with industry feedback and rapid technological changes. The strong connection with industry that is required for the course has helped to ensure that it remains relevant, effective and modern.

Introduction

The relationship between industry and universities is very important as graduating students negotiate the transition between academia and the workplace. Preparing students in the university environment for this transition can have a huge impact in terms of their effectiveness in their first few years in industry. Understanding and being able to meet the expectations of an industry employer at an early stage is advantageous for both sides. A greater level of productivity is provided from the employee and the employee is able to practice engineering with a much greater level of confidence and competence. The capstone design course is potentially a very effective way to create the bridge between academia and industry. Satisfying Accreditation Board for Engineering and Technology (ABET) requirements in terms design knowledge and skills provides some degree of preparation for engineering practice. Even though the format of capstone design courses varies significantly among different engineering departments, ABET requirements are addressed to some level through the objectives of these courses¹. Of particular importance are the (a)-(k) outcomes that all engineering baccalaureate graduates should possess.

Industrial needs for engineering graduates were the subject of an investigation in the early 1990's by Todd et al.², who carried out a survey to identify weaknesses in engineering graduates relative to industry perceptions. The following is a list of those weaknesses:

- Technical arrogance,
- No understanding of manufacturing processes,
- A desire for complicated and “high tech” solutions,
- Lack of design capability or creativity,
- Lack of appreciation for considering alternatives,
- No knowledge of value engineering,
- Lack of appreciation for variation,
- All wanting to be analysts,
- Poor perception of the overall project engineering process,
- Narrow view of engineering and related activities,
- Not wanting to get their hands dirty,
- Manufacturing work considered as boring,
- No understanding of the quality process,
- Weak communication skills
- Little skill or experience working in teams, and
- Being taught to work as individuals.

While substantial improvements have been made in curricula to address these issues, many may still be applicable.

The Department of Agricultural and Biological Engineering at the University of Illinois established an industry-linked capstone design course in 1985. With the aid of instructors that have had considerable experience in industry, the course has evolved into a highly effective learning experience for senior undergraduate students. Many if not all the weaknesses listed above have been dealt with in this course. An important part of the course is the inclusion of an “Engineering Toolbox” of knowledge and skills that have an impact in an industry setting. The objectives of this paper are to describe this toolbox and to discuss its benefits in preparing students for the industry environment.

Course Description

The industry-linked capstone design project course emphasizes open ended design projects that utilize principles of machine design, engineering analysis and functional operation of engineering systems. Projects are proposed by industry partners and a selection process is followed by the students. Design teams are formed, concepts visualized, alternative solutions evaluated, and geometry created using CAD systems. In most cases a prototype is built and tested or existing equipment is modified and tested. Emphasis is placed on communication skills, technical writing, and regular interaction with industry representatives. Student teams operate in a team-based industrial environment with “real-life” industrial projects.

The overall goal of the course is for students to experience modern engineering design practice and the product development process with team oriented, industry sponsored design projects. Apart from written and oral communication skill development through reports and technical presentations, students develop interpersonal skills within their teams and through interactions

with industry representatives and the course facilitator. They also are required to provide economic justification of their design as well as timelines and other project management related information. Included with the project activity are the topics that constitute the “Engineering Toolbox” that is described in the next section.

The Engineering Toolbox

At the time that students embark on the senior capstone design course, they are expected to have completed all the core science and engineering subjects. Some repetition of course materials is likely to occur. However, this repetition takes place in the context of the design course and the relevance of the material is effectively emphasized. Table 1 lists the topics that are included in the toolbox with the topics grouped under five main themes.

Table 1 List of topics that constitute the Engineering Toolbox

<u>Product Design</u>	<u>Product and Project Economics</u>
PRO/Engineer, 3-D Solid Modeling	Engineering Economics
Finite Element Analysis (FEA)	Economic justification of designs
Reliability Engineering	Design for Cost
Structural Design	Project Budgeting
Statistical methods in design	<u>Project Management</u>
Design of Experiments	Project Scheduling
Quality Engineering	Product Development
Design for Manufacturing	Product liability
Design for Worldwide Markets	Product Safety
Intellectual Property	Product/Project Evaluation
<u>Personal Development</u>	<u>Interpersonal Skills and Ethics</u>
Personal Financial Management	Team Building
Successful Interviewing	Ethical Issues in Engineering Practice
Career Planning	

Product Design is a core aspect of the course and therefore a number of engineering “tools” are designated under that heading in Table 1. While all the students will have been exposed to CAD, some may not have learned to use the PRO/Engineer CAD software that tends to be the industry standard amongst the agricultural and construction equipment manufacturers. Similarly students will have completed at least one course in economics, but not necessarily economics applied in engineering. Cost considerations in design are of course very important as is project budgeting. Practical knowledge of the concept of intellectual property and the importance of evaluating designs with respect to the major types can impact commercialization potential.

The list of topics under Project Management in Table 1 includes product liability and safety as these aspects should be uppermost in the list of considerations for a design. Overall product and project evaluation is a key aspect of project management to ensure that students understand the importance of implementing a process of reflecting on the progress of a project and the quality of the product. In the modern engineering world, engineers rarely work in a vacuum isolated from other functions within an organization, thus it is important to teach them the concepts of the

product development process, which exposes them to business case development, sales and marketing, finance and the mindset of management. Most engineering work requires formulation of and adherence to schedules and deadlines, and thus practicing this process within the well defined academic calendar is very effective. They also learn that their client and possibly vendors have schedules that must be synchronized with their own when executing projects.

Team building under Interpersonal Skills and Ethics in Table 1 is heavily weighted as a topic in the Engineering Toolbox. As early as possible in the semester personality profiles are developed for each student and the processes of accepting, sharing and delegating responsibility and leadership are discussed. Also the skills needed to ensure team and leadership success are covered in detail. Brain teasers and a tower building competition are employed to help students work together and find out about each other's strengths and weaknesses. Knowledge of the concepts inherent in ethical and non-ethical behavior cannot be overlooked, as careers and even entire companies can be destroyed by improper behavior and actions.

The senior year usually forces most engineering students to consider their career path and personal financial management. Formulating personal development goals is a common expectation in performance evaluations of employees in industry. The Personal Development topics in Table 1 are included to provide solid tools to evaluate career path options relative to education and life skills, to hone their interview skills and to become aware of the importance and methods of personal financial management.

Toolbox Knowledge and Skills

Beginning in 1992, a coalition of universities initiated a program called SUCCEED funded by the National Science Foundation to improve undergraduate engineering education³.

Subsequently the coalition has developed a number of useful tools and published numerous documents and manuals to assist engineering curriculum and program developers. One of the manuals is aimed at curriculum innovation and renewal⁴. Five stages are identified for this renewal process, the third of which requires an analysis of the existing curriculum. One analysis technique relies on an assessment of the knowledge and skills embodied in the curriculum. Knowledge is defined by the coalition as being "the sum of what is known: the body of truth, information, and principles acquired by mankind" and skills are "the ability to use one's knowledge effectively and readily in execution or performance". "Knowledge is equivalent to understanding how something happens while skill is equivalent to making that same thing happen"⁴. In a capstone design course the emphasis is likely to be on skills rather than knowledge as the assumption is that students have been provided with most of the required knowledge in their previous years of study. However, the topics in Table 1 focus largely on knowledge that can then be used in the execution of the design projects and therefore in developing skills pertaining to project management and product development. Key skills include the following:

- Engineering design skills
 - Product design
 - Process/system design
- Engineering control skills
 - Production control
 - Cost control

- Problem solving skills
 - Problem definition
 - Solution generation
 - Decision analysis
 - Solution implementation
 - Risk analysis?
 - Economic analysis?
- Organizational skills
 - Management
 - Communication
 - Interpersonal
 - Leadership
 - Decision making

From an industry perspective these are all very desirable skills that a practicing engineer would be able to exercise. These skills will naturally be developed further in the workplace as a result of experience working on projects. However, the opportunity to develop and exercise some or all these skills in a university course prior to entry into the workplace can have a big impact on the productivity of engineering graduates and their contribution to project execution.

Meeting ABET Outcomes with the Toolbox

The eleven outcomes specified by ABET as part of Criteria 3 for Program Outcomes have been referred to as a combination of “hard” skills and “professional” skills⁵. Shuman et al.⁵ list the following outcomes as “hard” skills:

- An ability to apply knowledge of mathematics, science, and engineering (3a)
- An ability to design and conduct experiments, as well as to analyze and interpret data (3b)
- An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (3c)
- An ability to identify, formulate, and solve engineering problems (3e)
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (3k)

The remaining six outcomes representing professional skills are the following:

- An ability to function on multidisciplinary teams (3d)
- An understanding of professional and ethical responsibility (3f)
- An ability to communicate effectively (3g)
- The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (3h)
- A recognition of the need for, and an ability to engage in life-long learning (3i)
- A knowledge of contemporary issues (3j)

The engineering toolbox topics address all the outcomes to some level. In terms of hard skills particular emphasis is placed on outcomes (c), (e), (k) as (a) and (b) are addressed in detail in the earlier part of the curriculum. However, overall the toolbox focuses strongly on the professional skills that typically would not be emphasized elsewhere in the curriculum. For example designing for worldwide markets requires an appreciation of the needs and impact of engineering

solutions in a global, economic, environmental, and societal context. Product safety and liability issues are connected with professional and ethical responsibility.

Course Evaluation

Evaluation of the course is provided by several internal and external sources. Internal evaluation of the instructor is provided via standard campus-based evaluation surveys filled out by the students prior to end of the semester. Focus groups of recent students that have completed the capstone design course have also been a source of feedback on course and instructor effectiveness. The students complete mid-term and end of semester questionnaires prepared by the instructor that request comments about areas of most and least value and recommended changes to the course and its instruction. These questionnaires have provided many worthwhile suggestions for course improvements, speakers, field trips, and other course enhancements.

External evaluation is provided through obvious and less obvious methods. The obvious includes the fact that companies continue sponsoring projects, even with the business cycle and employee turnover. These companies also have the opportunity to observe students and their performance in executing a project, and often end up employing the students. These former students tend to be assigned to be project managers with future student teams.

Another important outcome measure is the quality and value of the product that students develop for their project sponsor. While the projects may not be in core competency areas, about 40% of the products are adopted and utilized within 5-10 years. Project outcomes related to improved manufacturing and material flow tend to be adopted much quicker. In addition, while some products may not end up in production, the ideas generated by students often help the industry to consider alternative solutions that may then be adapted in-house.

Generally students have considered the capstone course as one of the best courses they have taken on campus. However, it has been our experience that there is variability with respect to student appreciation for their experience right after the course is complete, depending upon the level of interest and prior experience of the student in working as an engineer. This is manifested most clearly in the willingness and effectiveness of the student working in the capstone design class setting which is very non-traditional and in which, save for the Toolbox topics, they must rely on their own and team members' skills and technical knowledge to be contributors to the success of the project. As the semester draws to a close, the likelihood for a real, earned sense of accomplishment is almost always realized, which leads to positive feedback from clients in the short run and from students in the long run.

Invitations to return back to campus to speak on Engineering Toolbox topics by our graduates have never been refused, and the remarks have been well received. Thus we actively solicit future involvement in the course and with the department by former capstone students.

Summary and Conclusions

The experience and skills that students gain in a capstone design course can provide a smooth transition into an industry environment. Apart from skills gained from working directly on projects, students should be provided with additional knowledge and skills that will help them to

be effective practicing engineers once they enter the workplace. The concept of an “Engineering Toolbox” has helped in assembling a set of topics that contribute substantially to these skills and knowledge. These topics address the areas of product design, product and project economics, project management, and interpersonal skills. In addition, topics that deal with personal development are included in order to prepare students to be successful in their careers. The engineering toolbox has become a vital part of the capstone course in the Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign and has helped students execute their projects effectively and achieve a product that has a high probability of being implemented by the company sponsor. It also addresses many of the weaknesses in engineering graduates that are perceived by industry.

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