
Preface

Life can only be understood backwards; but it must be lived forwards.

—Soren Kierkegaard

Whether you think you can or think you can't, you're right.

—Henry Ford

Undergraduate and graduate students enrolled in an engineering program are exposed to a great many engineering tools, methods, and theory but engineering practice is not a theoretical profession. The realities of the engineering world dictate that technological skill is only a part of what an engineer needs to succeed. Engineering practice in industry consists of more than the practical application of science to solve problems. Knowledge of mathematics and engineering theory is necessary but not sufficient to be a successful engineer.

The seminal engineering education Green Report [1] stated

In today's world and in the future, engineering education programs must not only teach the fundamentals of engineering theory, experimentation and practice, but be RELEVANT, ATTRACTIVE and CONNECTED:

RELEVANT to the lives and careers of students, preparing them for a broad range of careers, as well as for lifelong learning involving both formal programs and hands-on experience;

ATTRACTIVE so that the excitement and intellectual content of engineering will attract highly talented students with a wider variety of backgrounds and career interests particularly women, underrepresented minorities and the disabled and will empower them to succeed; and

CONNECTED to the needs and issues of the broader community through integrated activities with other parts of the educational system, industry and government.

The Green Report encouraged engineering educational institutions to incorporate a broad framework for engineering curricula that includes the following:

- Team skills, including collaborative, active learning;
- Communication skills;
- Leadership;
- A systems perspective;

An understanding and appreciation of the diversity of students, faculty, and staff;
An appreciation of different cultures and business practices, and the understanding that the practice of engineering is now global;
Integration of knowledge throughout the curriculum;
A multidisciplinary perspective;
A commitment to quality, timeliness, and continuous improvement;
Undergraduate research and engineering work experience;
Understanding of the societal, economic, and environmental impacts of engineering decisions;
and
Ethics.

Many engineering colleges and universities introduced the senior design or capstone course to help ensure that they met the challenges set forth in the Green Report.

My motivation for writing this book is to introduce students to an engineering industry model that supports the practices demanded of new engineering school graduates by business and industry. I believe I have a useful and meaningful perspective having worked in industry for 30 years before becoming a full-time professor. During this time I held positions ranging from research and development engineer, group manager, project manager to general manager. In the aerospace field I contributed to activities on the space shuttle and the Titan rocket. I participated in the development and production of radar and artillery weapon systems; and analytical instruments, systems, and services for radiation detection and radiation monitoring. I agree with the comments in the Green Report, which suggest that successful engineering professionals in industry rely on a combination of technical depth, business fundamentals, communication competencies, an appreciation for societal issues, and interpersonal skills.

Some new engineering college faculty members do not have business and industry work experience. Like all teachers their goal is to help students understand engineering concepts and help them to apply, analyze, and synthesize, create new knowledge, and solve problems. However, effective engineering teaching also requires engineering teachers to prepare students for the realities and demands of business and industry—whether or not they have familiarity with the issues in this domain. This book will guide instructors and challenge students to consider not only technical engineering considerations but also to take into account practical business concepts that influence a project and without which a project will never get off the ground. The capstone course forces students to be creative and learn design not solely from theory but from practical applications. The capstone hands-on practical experience helps prepare students for the transition to the workforce and can reinforce their value.

Boeing Aircraft took the lead in highlighting the need for developing competent engineers in their university supply chain of talent. It published a list of desired engineering attributes with the hope of helping engineering education programs to better align themselves with strategic employer needs [2, 3].

Desired Attributes of an Engineer (from Boeing Aircraft)

- A good understanding of engineering science fundamentals
 - Mathematics (including statistics)
 - Physical and life sciences
 - Information technology (far more than “computer literacy”)
- A good understanding of design and manufacturing processes (i.e. understands engineering)
- A multidisciplinary, systems perspective
- A basic understanding of the context in which engineering is practiced
 - Economics (including business practice)
 - History
 - The environment
 - Customer and societal needs
- Good communication skills
 - Written
 - Oral
 - Graphic
 - Listening
- High ethical standards
- An ability to think both critically and creatively—independently and cooperatively
- Flexibility. The ability and self-confidence to adapt to rapid or major change
- Curiosity and a desire to learn for life
- A profound understanding of the importance of teamwork.

This list contains the important competencies that Boeing believes that students need to operate in a modern engineering environment. Boeing also observed [3] that there was as much ignorance of the realities of academe on the part of industry as there is on the part of faculty about industry. This book represents an effort to assuage this problem by preparing students for the step into industry using the capstone course as the pathway.

The undergraduate or graduate capstone courses provide students with an opportunity to apply concepts and tools studied in the engineering program to the solution of a “real-world” problem. Often undergraduate institutions refer to the course as a senior design project. This book uses the terms senior design or capstone course interchangeably. Both courses cover similar material. Students work in small groups on a problem proposed by their team or a faculty mentor. They receive guidance and mentorship from faculty who have experience in completing similar activities in industry or academe. The capstone course requires students to integrate knowledge gained from previous courses including project management, business, and engineering disciplines, as well as the practical experience that they may have gained from industry. The objective is not to develop complex

engineering products or services, but rather to introduce and understand the multi-dimensional processes by which a design is selected, guided, and controlled. The instructor creates an active learning environment. The capstone course implements John Dewey's (one of the most significant educational thinkers of the twentieth century) concept of education by having a curriculum that is relevant to students' lives. Dewey saw learning by doing and the development of practical skills as crucial to education. This start-to-finish project course involves students completing the following "learning by doing" steps:

- Identifying a need for a product, service, process, or system
- Creating a team and working effectively together towards common goals
- Generating a project proposal
- Preparing a design
- Developing the product, service, process, or system
- Testing the product, service, process, or system
- Examining the business viability aspects of the project
- Preparing and delivering reports and presentations.

Capstone projects require students to get up-to-speed quickly on a variety of content areas; enhance key skills such as project management and teamwork; develop competency in gathering, analyzing, and reporting data; understand the relationship between engineering and the business environment; communicate with stakeholders; and construct a product or service. It represents an opportunity for students to interweave their learning in all these areas and to do so in real time, in an unpredictable, complex, and real-world environment.

After many years in industry as an engineer and engineering manager, I returned to the academic world as both a teacher and college administrator. For the past 5 years, I taught a graduate engineering capstone class at Fairfield University wherein I tried to share with my students' ideas that I gained dealing with industry's expectations about the engineering design and development process. The course requires that students integrate important competencies and perspectives to which they have been exposed. The course attempts to facilitate the student's transition from the academic to the professional world by drawing upon all of their skills and abilities. The course challenges the student in technical design; project management; teambuilding; oral and written presentations; time management; preparation and analysis of a schedule; budget preparations; resource management; business decision making; and the consideration of societal impacts on their work. Students work toward achieving team consensus on a diverse set of technical and business data compiled by team members. They synthesize the information in written and oral reports, while resolving conflicts that may arise. This book contains material that serves as the basis for the 1-year course that I mentor.

I evaluate students primarily on their performance in articulating the design, business, and management aspects of the project rather than on the performance of the final product or service. The technical and management processes learned in this class are most important. It is likely that the completed product or service will meet a basic requirement, but the most important course outcome is an understanding of the processes used in industry to complete a project. Learning and understanding these processes is the focus of the capstone course and this book. The typical capstone course follows the five phases shown in Table 1.

Table 1 Five phases in the capstone course

Course phase	Technical requirement	Skill development	ABET outcome
Team selection	Understand the concept: Delight the customer	Investigation: Determine a need for a product, service, process, or system Identify potential team members with an interest in working on a topic associated with the identified “need” Understand and apply team member’s strengths to the problem solution	d, f, g
Project selection	Research alternatives Confirm project need Relate client/customer’s needs to a project specification Understand the project’s societal impact Select the best alternative Investigate competitive products and services including intellectual property issues (patents, licenses, copyrights, and trademarks)	Organizing and preparing presentations Researching alternatives Oral presentation skills Resolving conflicts that arise in team settings Intellectual property research	g, h, j
Proposal preparation and presentations	Organize an approach to a design Identify objectives, constraints, and criteria Identify data needs and collection methods Evaluate alternative approaches Investigate competitive products and services Resolve intellectual property research “loose ends” Summarize the overall approach with a functional block diagram Relate client/customer’s needs to the project specification Prepare a specification Understand the societal, environmental, political, ethical, health, and safety aspects of the project. Agree on final project features and agree on what not to do	Presentation skills—ranging from speaking before an audience to the use of audio-visual aids and application software Project management skills—including collaborative work and communication within and outside the team Writing technical memos and reports Team management skills—achieving team consensus on diverse technical input compiled by different team members and synthesizing them in written and oral reports Resolving conflicts that arise in team settings Meetings with prospective clients, users, and vendors	a, e, f, g, h, j

(continued)

Table 1 (continued)

Course phase	Technical requirement	Skill development	ABET outcome
Project development	Learn new technical skills “on-the-fly” to support the project	Presentation skills, ranging from speaking before an audience to use of audiovisual aids and application software	a, b, c, e, f, g, i, k
	Learn to make appropriate technical, cost, and feature tradeoffs	Project management skills—including collaborative work	
	Make schedule adjustments	Learning to defend team’s work before outside evaluators	
	Explain schedule variance	Team management skills	
	Specification adjustments	Learn to recognize and mitigate risks	
	Prepare a bill of materials	Quickly learn about unfamiliar topics	
	Develop project test methods to confirm the product/service meets the specification	Develop the ability to discuss both technical and nontechnical engineering project issues with technical and nontechnical people	
	Succinctly discuss both technical and nontechnical engineering project issues		
	Product, service, process, or system testing by using a test verification matrix		
	Understand the human and regulatory side of the design process		
Final report, presentation, and demonstration	Understand and use appropriate industry standards		e, f, g, k
	Summarize project highlights	Presentation skills, ranging from speaking before an audience to use of audiovisual aids and application software	
	Analyze and explain reasons for technical differences between the target specification and the final product or service	Learn to defend the team’s work in front of stakeholders and outside evaluators	
	Analyze and explain schedule variance		
	Analyze and explain budget variance		
	Discuss actual outcomes compared with performance expectations and budget.		

The Accreditation Board for Engineering and Technology (ABET) [4], outcomes referred to in Table 1 as listed in Criterion 3 are the following:

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (b) an ability to design and conduct experiments, as well as to analyze and interpret data
- (c) 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
- (d) an ability to function on multidisciplinary teams
- (e) an ability to identify, formulate, and solve engineering problems
- (f) an understanding of professional and ethical responsibility
- (g) an ability to communicate effectively
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (i) a recognition of the need for, and an ability to engage in life-long learning
- (j) a knowledge of contemporary issues
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

The capstone design course serves an important role in graduate and undergraduate engineering programs. The capstone (or senior design) course covers in various degrees, all 11 of the ABET engineering program outcomes. The course provides engineering students open-ended project experiences with a variety of realistic requirements and constraints they might encounter in a rigorous project environment in industry. The teams learn by doing and reflection. Faculty mentors provide guidance and serve as advisors and coaches. The in-class discussions range from business entrepreneurship issues to technical dialogues. During class sessions, students have opportunities to learn about substantive engineering disciplines as well as reflect on the demands of professional practice.

The team accomplishes their work independently and collaboratively, primarily outside of the classroom. Class time is used for status review. The class that I mentor meets once a week. During the class we review each team's progress and gently (and sometimes not so gently) critique the team's work by asking penetrating questions about their progress and direction. The class sessions motivate the teams, if only by placing stress on the team members to show that the past week has been productive. During the class meeting, all class members may offer technical and nontechnical comments and suggestions that clarify and may expand or decrease the scope of a team's work. The constructive comments may recommend that the team meet with vendors, other professors, or experts from industry. Any topic dealing with the project is fair game including technical performance, budget and schedule questions, customer needs, test methods, and risk issues.

The class meeting simulates the weekly meeting usually held in industry between a project manager and technical project leaders. From the faculty mentor's perspective the goal of the weekly meetings goal is to make sure teams have a firm direction and actionable information, while making participants feel motivated and respected.

ABET accredits over 3,100 applied science, computing, engineering, and technology programs at more than 660 institutions in 23 nations. The engineering program accreditation criterion 5 [4] requires that engineering programs include a capstone project experience in the curriculum. Criterion 5 states the following:

Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.

The capstone course approach described in this book meets the intent of ABET general criteria 3 and 5.

Engineers Canada, through the Canadian Engineering Accreditation Board, accredits undergraduate engineering programs at Canadian higher education institutions. Students graduating from Canadian accredited engineering programs must possess attributes in the following categories [5]:

- **A knowledge base for engineering:** Demonstrated competence in university-level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.
- **Problem analysis:** An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.
- **Investigation:** An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.
- **Design:** An ability to design solutions for complex, open-ended engineering problems and to design systems, components, or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural, and societal considerations.
- **Use of engineering tools:** An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.
- **Individual and team work:** An ability to work effectively as a member and leader in teams, preferably in a multidisciplinary setting.
- **Communication skills:** An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.
- **Professionalism:** An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.
- **Impact of engineering on society and the environment:** An ability to analyze social and environmental aspects of engineering activities. Such ability includes an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society, the uncertainties in

the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.

- **Ethics and equity:** An ability to apply professional ethics, accountability, and equity.
- **Economics and project management:** An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations.
- **Life-long learning:** An ability to identify and to address their own educational needs in a changing world in ways sufficient to maintain their competence and to allow them to contribute to the advancement of knowledge.

To help meet this broad list of attributes, many Canadian universities that offer engineering degrees include a team-based technical design project in their final year. As in U.S. engineering schools, the course begins with an understanding of the engineering design requirements. The courses' expected learning outcome is based on the knowledge and skills acquired by the student in earlier and concurrent courses. Canadian colleges encourage projects that serve societal needs and involve multidisciplinary elements.

Here again, the capstone course approach described in this book meets the intent of the attributes expected of students completing a degree in Canadian engineering schools.

The Springer Web site contains many of the templates discussed in this book. Please use them in your capstone class preparations.

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The Engineering Capstone Course
Fundamentals for Students and Instructors

Hoffman, H.F.

2014, XXVIII, 144 p. 12 illus., 7 illus. in color., Hardcover

ISBN: 978-3-319-05896-2