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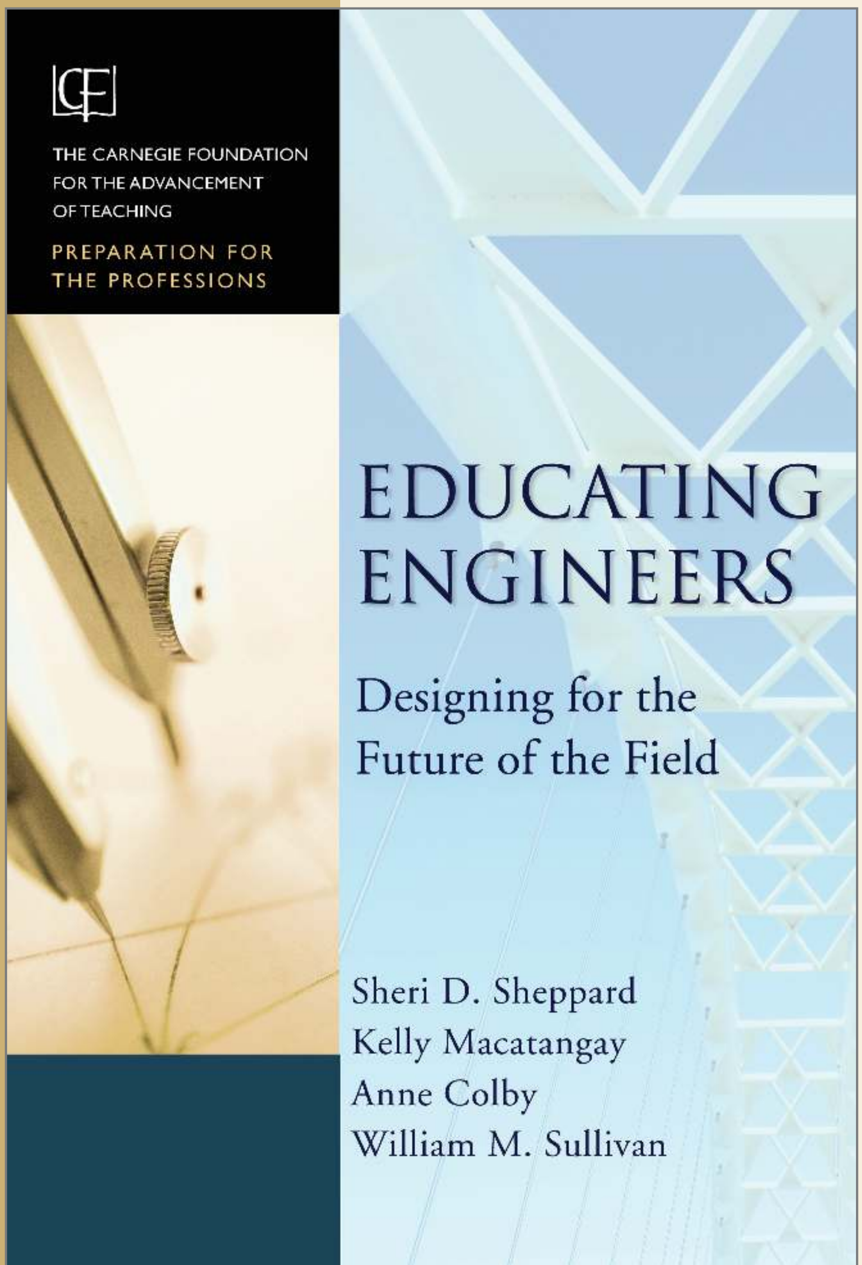

BOOK HIGHLIGHTS

Educating Engineers

Designing for the Future of the Field

The Carnegie Foundation for the Advancement of Teaching's multi-year study of undergraduate engineering education in the United States involved intensive fieldwork, including on-site observation of eleven electrical and mechanical engineering programs at a cross section of U.S. engineering schools. The examination of curricular and teaching strategies yielded questions about the alignment of engineering programs with the demands of today's professional engineering practice. While describing engineering education from within the classroom and the lab, the report on the study offers new possibilities for teaching and learning. The study was funded by The Carnegie Foundation for the Advancement of Teaching and The Atlantic Philanthropies.

About the Authors

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The Preparation for the Professions Program studies education for the professions of law, engineering, the clergy, medicine, and nursing, drawing out common themes and identifying practices distinct to various forms of professional education.

These highlights are based on the Carnegie/Jossey-Bass publication of the same title, *Educating Engineers: Designing for the Future of the Field* (Winter 2008). To order, visit the Jossey-Bass website at www.josseybass.com.

SUMMARY

EDUCATING ENGINEERS

Designing for the Future of the Field

Sheri D. Sheppard
Kelly Macatangay
Anne Colby
William M. Sullivan

A PUBLICATION OF

THE CARNEGIE FOUNDATION
for the ADVANCEMENT *of* TEACHING

INTRODUCTION

From the environment to medicine, transportation to communication, household appliances to space exploration, engineers affect the world. Yet just as the technology born of engineering has transformed much about our world, so has it transformed the work of engineers. Amidst complex challenges of unprecedented scale and urgency, the profession of engineering has new global significance—and responsibilities. Undergraduate engineering programs, the source of the professional degree, struggle to transmit a base of technical knowledge even as it grows exponentially, leaving little room for students to develop the skills and professional identity necessary to meeting the responsibilities of engineering in this new century.

Educating Engineers, the third of a series of reports on professional education issued by The Carnegie Foundation for the Advancement of Teaching's Preparation for the Professions Program, follows *Educating Clergy* and *Educating Lawyers*. Future reports will examine the preparation of nurses and physicians.

The series continues the Foundation's long tradition of examining professional education. Beginning with the landmark Flexner Report on medical education of 1910 and other pioneering studies of education in engineering, architecture, teaching, and law, for nearly one hundred years, The Carnegie Foundation for the Advancement of Teaching has commented on and influenced improvement of education for the professions.

Informed by the findings of the Foundation's concurrent studies of professional education, *Educating Engineers* is also, like the other studies, grounded in direct observation of education in process. Initial study focused on forty schools of engineering and examination of one hundred accreditation self-study reports. Over several academic semesters, a research team visited eleven electrical and mechanical engineering programs at six colleges and universities in the United States. Public and private, part of technical institutes or situated within universities, geographically diverse and serving different populations, these 11 programs represented a cross section of U.S. undergraduate engineering education.

In reporting from the classroom and laboratory, *Educating Engineers* complements two important contemporary commentaries on U.S. engineering education: *The Engineer of 2020* (National Academy of Engineering, 2004) and *Engineering for a Changing World* (Duderstadt, 2008).

OVERVIEW OF U.S. UNDERGRADUATE ENGINEERING EDUCATION

Professionals, explains Carnegie President Emeritus Lee Shulman in his foreword, provide a worthwhile service in the pursuit of important human and social ends; possess fundamental knowledge and skill; develop the capacity to engage in complex forms of professional practice; make judgments under conditions of uncertainty; learn from experience; and create and participate in responsible and effective professional communities.

Engineers, as do physicians, nurses, lawyers, clergy, and other professionals, work within ever-increasing complexity and changing conditions. As the external environments for engineering practice have changed, so too has the substance of the work—the problems engineers address and the knowledge they draw on to do so. At the same time, their relations to work and the workplace as well as to their colleagues are also changing dramatically.

The undergraduate engineering program is a crucial moment for professional formation: unlike law, medicine, and the clergy, engineering's first professional degree is the undergraduate degree. However, although engineering schools aim to prepare students for the profession, they are heavily influenced by academic traditions that do not always support the profession's needs. From the time that the formal training of engineers in the United States was first patterned after the French model—a curriculum of basic sciences, technical subjects, and humanities, with theory taught before application—through the middle of the twentieth century, engineering education struggled to establish its place in the academy and earn the recognition of practitioners, both responding to and being shaped by the values of the academy.

ALTHOUGH ENGINEERING SCHOOLS AIM TO PREPARE STUDENTS FOR THE PROFESSION, THEY ARE HEAVILY INFLUENCED BY ACADEMIC TRADITIONS THAT DO NOT ALWAYS SUPPORT THE PROFESSION'S NEEDS.

The solution has always been to add more rather than to consider the overall design. Thus, although the 1,740 undergraduate engineering programs in the United States vary in their emphases and serve diverse student populations, they are remarkably consistent in their goal: U.S. engineering education is primarily focused on the acquisition of technical knowledge.

A jam-packed curriculum focused on technical knowledge is the means for preparing students for a profession that demands a complex mix of formal, contextual, social, tacit and explicit knowledge.

The case of engineering education, however, is not unique. The Carnegie Foundation's studies of the education of lawyers, clergy, physicians, and nurses have also found that professional education has been dealing with the challenge of integrating knowledge and practice in a way that more fully prepares students to enter the profession.

The Foundation's reports recommend that professional schools, because they are responsible for the preparation of practitioners, should aim for an increasingly integrated approach to the formation of students' analytical reasoning, practical skills, and professional judgment. Although some engineering schools have introduced programs, teaching methods, or curricular structures that attempt to integrate these professional goals, none offers a comprehensively networked approach.

THE RESEARCH QUESTIONS

Professionals act for others' benefit, not simply their own. They are, in this sense, fiduciaries, bearers of the trust of those who depend on their knowledge, skill, and judgment.

The study of U.S. undergraduate engineering education thus began with an overarching question: do the components of the undergraduate curriculum work together as cohesive, effective preparation for today's professional engineering practice?

- Where in their educational experience do students acquire and develop each dimension of professional expertise: engineering knowledge, skills of practice, and the understanding and commitment expected of today's professional engineer? How, if at all, do the traditional components of the engineering curriculum—engineering science, laboratory, and design courses—map onto these aspects of professional expertise?
- How is this learning accomplished, and who among faculty and staff is responsible for each of these dimensions? Who, if anyone, is charged with ensuring that the continuity necessary for the students' developmental trajectory is maintained?
- What counts as evidence that students are in fact moving toward competence in engineering knowledge, skills of practice, and understanding and commitment? What are the important markers of this progress, and how is such progress assessed?

In the course of the study, as the strengths and the weaknesses of engineering education became apparent, the researchers refined these questions:

- Does the current engineering curriculum and pedagogy support the integration of knowledge, skills of practice, and professional values necessary for today's professional practice?
- Many of those who complete engineering programs go into other, often related, fields. Does the undergraduate curriculum prepare them to bring that engineering perspective to the policy and other problems they might work on as professionals?

When the response to these questions suggested moving from analysis to action, the researchers considered a final question:

- How might undergraduate engineering education more align to the profound changes to professional engineering practice in this global era?

FINDINGS

In the midst of a profound, worldwide transformation in the engineering profession, U.S. undergraduate engineering education is holding onto an approach to problem solving and knowledge acquisition that is consistent with practices that the profession has left behind. Specifically, undergraduate engineering education in the United States emphasizes primarily the acquisition of technical knowledge, distantly followed by preparation for professional practice.

Although engineering education is strong on imparting some kinds of knowledge, it is not very effective in preparing students to integrate their knowledge, skills, and identity as developing professionals. This lack of integration also weakens the transfer of the engineering perspective to other areas in which engineering graduates find employment.

1. In the engineering science and technology courses, the tradition of putting theory before practice and the effort to cover technical knowledge comprehensively allow little opportunity for students to have the kind of deep learning experiences that mirror professional practice and problem solving.

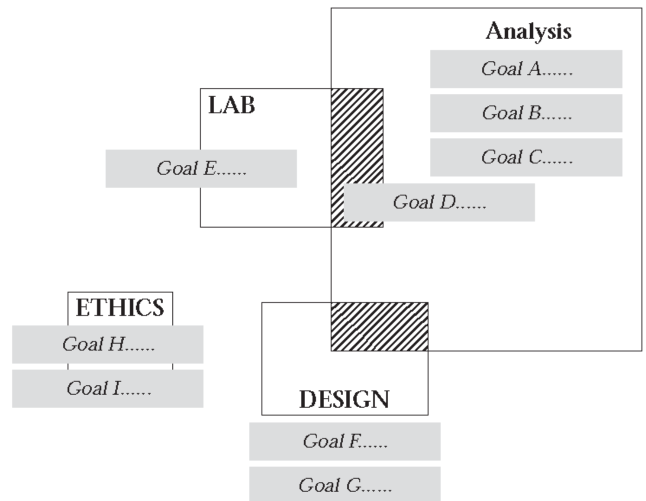
2. Laboratory and design experiences are generally treated as applications or adjuncts that follow the learning of theory in engineering science and technology courses. The lab is a missed opportunity: it can be more effectively used in the curriculum to support integration and synthesis of knowledge, development of persistence, skills in formulating and solving problems, and skills of collaboration. Design projects offer opportunities to approximate professional practice, with its concerns for social implications; integrate and synthesize knowledge; and develop skills of persistence, creativity, and teamwork. However, these opportunities are typically provided late in the undergraduate program.

ALTHOUGH ENGINEERING EDUCATION IS STRONG ON IMPARTING SOME KINDS OF KNOWLEDGE, IT IS NOT VERY EFFECTIVE IN PREPARING STUDENTS TO INTEGRATE THEIR KNOWLEDGE, SKILLS, AND IDENTITY AS DEVELOPING PROFESSIONALS.

3. Concerns with ethics and professionalism, which have new urgency in today's world, have long had difficulty finding meaningful places within this historical model, for not only are programs packed solid with the technical courses, but also there are limited conceptual openings for issues of professionalism. Students have few opportunities to explore the implications of being a professional in society. Moreover, the responsibility of providing such opportunities is often left to other academic units.

4. Further, the dominant curricular model, which might be best described as *building blocks* or *linear components*, with its attendant deductive teaching strategies, structured problems, demonstrations, and assessments of student learning does not reflect what the significant and compelling body of research on learning suggests about how students learn and develop and how experts are formed.

Figure 1. Linear Components Model



Design and laboratory are undersized relative to the multiple roles they play in a student's development, including being the best proxy for a clinical experience. Considerations of professionalism—ethics, social responsibility, integrity, lifelong learning—are distant and small. Moreover, where the components connect, the relationship is unidirectional—hence "linear" components.

5. The central lesson that emerged from the study is the imperative of teaching for professional practice—with *practice* understood as the complex, creative, responsible, contextually grounded activities that define the work of engineers at its best; and *professional* understood to describe those who can be entrusted with responsible judgment in the application of their expertise for the good of those they serve.

   If engineering students are to be prepared to meet the challenges of today and tomorrow, the center of their education should be professional practice, integrating technical knowledge and skills of practice through a consistent focus on developing the identity and commitment of the professional engineer. Teaching for professional practice should be the touchstone for future choices about both curriculum content and pedagogical strategies in undergraduate engineering education.

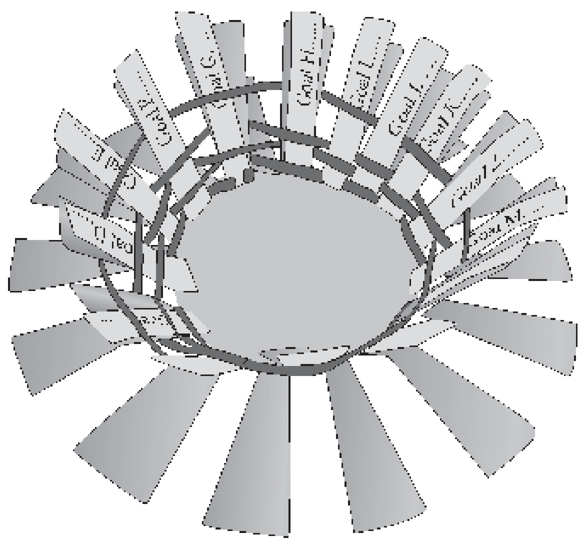
TEACHING FOR PROFESSIONAL PRACTICE SHOULD BE THE TOUCHSTONE FOR FUTURE CHOICES ABOUT BOTH CURRICULUM CONTENT AND PEDAGOGICAL STRATEGIES IN UNDERGRADUATE ENGINEERING EDUCATION.

Toward a New Design for Engineering Education

To effect such a focus on professional practice will require *remaking* undergraduate engineering education, networking the existing components in ways that strengthen and connect them into a cohesive whole.

Developing the expertise of professional practice is an iterative process. Thus the ideal learning trajectory is a spiral, with all components revisited at increasing levels of sophistication and interconnection. Learning in one area supports learning in another.

Figure 2. Networked Components Model



Accordingly, in a networked model, the traditional analysis, laboratory, and design components would be deeply interrelated: engineering knowledge remains central but is configured to include both technical and contextual knowledge; competencies of practice, laboratory, and design experiences are integrated into the whole, as are professionalism and ethics. The overarching goal of the program would be to position students for a lifetime of continuous learning and growth.

In other words, to draw on Shulman's encapsulation, professional, undergraduate engineering programs would be designed to position students to begin providing a worthwhile service in the pursuit of important human and social ends. They would begin a lifetime of pursuit of knowledge and skills as they continue to develop the capacity to engage in complex forms of professional practice, learning to make judgments under conditions of uncertainty, learning from experience, and creating and participating in responsible and effective professional communities.

Bringing Professional Practice Forward

To accomplish this goal, both curriculum and teaching strategies must be carefully crafted to enable aspiring engineers to move from thinking like students to thinking like beginning professionals. Effecting such a change in engineering education is, in essence, a design problem. Accordingly, to guide the redesign of engineering education, the report's authors offer a set of principles.

PRINCIPLE 1 *Provide a professional spine*

During each year of their program, students should have experience with and reflect on the demands of professional practice, linking theory and practice. Engaging in increasingly practice-like experiences, the engineering equivalent of the clinical dimension of medical preparation, would be a central feature of engineering education. This emphasis on professional practice would give coherence and efficacy to the primary task facing schools of engineering: enabling students to move from being passive *viewers* of engineering action to taking their place as active participants or *creators* within the field of engineering. In this process, the student would begin to develop an identity as an engineer.

PRINCIPLE 2 *Teach key concepts for use and connection*

Organizing engineering education around a professional spine does not imply the neglect of the traditional core, engineering sciences. It does, however, mean that engineering educators will need to make some hard choices about what kind of theoretical, scientific, and technical knowledge is fundamentally important. Moreover, it requires that engineering educators reach for teaching strategies that encourage students to develop the thinking skills of engineering practice. Those teaching key concepts can, for example, employ an inductive approach, presenting students with open-ended problems and asking them to identify the basic underlying concepts that are most applicable to understanding and solving the problem.

PRINCIPLE 3 *Integrate identity, knowledge, and skills through approximations to practice*

Students need to see what expert practice looks like, modeling or otherwise making visible both thinking and doing. Engineering educators need to find creative ways to structure and support students' beginning efforts to imitate competent performance and to provide timely and informative feedback on those performances. These practice-like experiences can point toward both analysis and design as central tasks of engineering work, with laboratory courses and attention to professionalism and ethics contributing heavily to that goal—a thoroughly integrated approach to engineering education.

PRINCIPLE 4 *Place engineering in the world: encourage students to draw connections*

Because engineering inevitably means intervening in the world, all engineering projects carry with them responsibility for the effects of those interventions. Students need powerful learning opportunities much like that of medical students on their first introduction to the clinical care of actual patients, in order to recognize that they will always need to know much more than they do, and that social and ethical connections are as important, if not more so, as electrical and mechanical ones.

A CALL TO ACTION

Redesigning undergraduate engineering education will demand an enormous effort on the part of faculty. It will involve more than learning about, designing, and implementing integrated curricular structures and active pedagogies. It will involve fundamentally rethinking the role and even the makeup of the faculty, for the educational model we are recommending makes quite different demands on the instructor than does the old model. Among other things, the new model gives more importance to teachers and researchers who are sympathetic to professional concerns and have some interest in them.

Engineering faculty are key stewards of the engineering profession. It is their job to fan the creative fire, feed technological curiosity, and foster the social responsibility of the next generation of men and women engineers. This is no small job, even with sufficient resources, recognition and rewards, as faculty must balance and integrate teaching and other educational responsibilities with those of research and service.

THE ROLE OF OTHER LEADERS AND STAKEHOLDERS

Faculty will not be able to do all this alone. Nor should they, for the effects of their effort have implications throughout the program, institution, higher education, and field of engineering. They may be key leaders, but they cannot be the sole actors. They need engagement and support from many quarters.

Campus leaders and administrators have a role to play in supporting their colleagues in transforming the engineering programs that are so important to their institutions. Administrators can connect engineering educators to those working toward similar goals. Along with financial and material resources, administrators' engaged, active support might range from connecting engineering educators to those working toward similar goals to examining policies that present obstacles to effective teaching and learning.

Higher education at large offers rich networks of faculty, campus leaders, and national organizations working to align curriculum and teaching strategies with the demands of a new century and the discoveries about learning. These organizations and networks should reach out to engineering educators around their mutual goals.

Practitioners from business, industry, and government can play several roles to assist in the effort to place professional practice at the center of engineering education. Through the professional societies, they can start or join a national call for change. Engineers can also develop local, regional, and national partnerships with the academy and professional societies. At the local level, they can work along with individual schools to redesign programs.

Industry leaders, and the leaders of national professional engineering organizations and foundations likewise can contribute at many levels, whether in the classroom or through policy and resources. They are central to the task of promoting, recognizing, and rewarding those programs and educators who boldly engage in thoughtful questioning of and experimentation with their educational practices. National organizations can provide resources and infrastructure for developing and sharing prototypes.

Moreover, national leaders can make this effort a national priority. Like a pressing professional design problem, such as developing alternative energy sources or more efficient transportation, this educational challenge deserves to be addressed in a national conversation, including debates and idea sharing among the broadest possible range of stakeholders.

A PROFESSIONAL IMPERATIVE

Because engineers affect the world in profound ways, the public—national and global—has a serious stake in the preparation of engineers to design and manage an increasingly technological world. Engineering education that integrates knowledge, skill, and purpose through a consistent focus on preparation for professional practice is aligned with the demands of complex, interactive, and environmentally and socially responsible forms of practice.

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