

PROFESSIONAL RESPONSIBILITY: THE ROLE OF ENGINEERING IN SOCIETY

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Abstract

We argue that the practice of engineering does not exist outside the domain of societal interests. That is, the practice of engineering has an inherent (and unavoidable) impact on society. Engineering is based upon that relationship with society (inter alia).

An engineer's conduct (as captured in professional codes of conduct) toward other engineers, toward employers, toward clients, and toward the public is an essential part of the life of a professional engineer, yet the education process and professional societies pay inadequate attention to the area. If one adopts Skooglund's definition of professional ethics (1) (how we agree to relate to one another), then the codes of professional conduct lay out a road map for professional relationships. As professionals, engineers need to internalize their codes and to realize that they have a personal stake in the application of codes as well as the process of developing the codes. Yet, most engineers view professional codes as static statements developed by "others" with little (or no) input from the individual engineer. Complicating the problem, questions of professionalism (such as ethics) are frequently viewed as topics outside the normal realm of engineering analysis and design. In reality, professional responsibility is an integral part of the engineering process.

Introduction

The essence of engineering is design. B. V. Koen (2)

This article examines the relationship between engineers and society, and engineers' professional responsibilities given that relationship. This examination is particularly important for engineers in the execution of their professional responsibilities, and for students preparing to enter fields of engineering.

A review of the literature yields a series of discussions on the definition of an engineer, descriptions of the design process, and of "what engineers do" (3-6). Articles and books also explore topics such as the professional ethics of engineering and legal aspects of engineering (7, 8, 9). Recently, Davis presented a useful historical perspective of engineering ethics (10). Yet, differences exist as to what engineers do (e.g. Spier (11) vs. Koen (3)). This article examines relationships between engineers and society, and though it touches on topics relevant to the definition of engineering, it does not attempt to develop a new definition.

The Role of Engineering in Society: Engineering Design

Some will say that I'm an academic and that I'm supposed to be a scientist, but I have this craving to be an engineer. Waldron (12).

The National Research Council recently recognized the need for improvement in both engineering design and engineering design education (13). Although there are numerous articles on engineering design (14-18), we will concentrate on the interaction between engineers and society.

One of the first sources of confusion, particularly among those who are not engineers or scientists, is the distinction between science and engineering (10). The primary role of science is to develop knowledge and understanding of the physical universe (11). As pointed out by Davis (10) and others, an important distinction is that this pursuit of knowledge (science) may occur largely without regard to societal need (or to societal implications). The direction of scientific research has been described by some as curiosity-based research which is not necessarily driven by the values of society. Societal values (and resulting priorities) do not necessarily define the bounds, direction or scope of scientific curiosity.[†] This is not a criticism of science, for such is the nature of "inquiring." Furthermore, it is often not possible to determine relevance of a particular field of scientific inquiry to the future needs of society.^{††} Given this curiosity-driven process, the base of scientific knowledge about the physical universe may be represented by an amoebae-like structure uneven in its extent in the various directions with current scientific research efforts acting to extend its coverage (fig. 1).

Figure 1.

The utilization of scientific knowledge over time establishes that some of the knowledge is immediately relevant to societal needs while other parts are less immediately relevant (society may never realize the relevance of a particular scientific inquiry). While the congruence of societal need with scientific knowledge is much more complex than indicated in this article, it may be represented for the purpose of this discussion by a Venn diagram as seen in figure 2. The authors maintain that it is this overlap of scientific knowledge with societal need, more

[†] One could pursue many areas of science without regard to societal implications. One may contrast the pursuit of science with the pursuit of law which is entirely value based. Free of the values of society, one could argue that there can be no legal profession.

^{††} This does not mean, of course, that professionals in the pursuit of science do not encounter questions of ethics. Much of science, indeed, does have close ties to society. We argue that engineering, by its very nature, must address topics associated with societal values

specifically, the application of scientific knowledge to the needs of society, that is the domain of engineering (inter alai) (see below). Clearly, the extent of human enterprise is much more complex than is represented here. If, for example, it is in the interest of society to increase our store of scientific knowledge, then engineers and scientists who ply their trade in the frontiers of scientific research are both serving societal need. Nevertheless, our contention is that the central focus of the engineering profession is the application of scientific knowledge to meet societal needs.

Figure 2.

This analogy can be extended by superimposing the distinction of the creative versus the analytical aspect of the human enterprise (19). We can represent this aspect of the human intellect by another Venn diagram shown in figure 3. As indicated in the diagram, one may pursue creative efforts without involving analytical skills, and one may apply analytical skills without entering the domain of creativity. For example, as engineers apply commercial software to the solution of an engineering problem, the application of analytical skills, *per se*,[†] may involve little or no creativity.

Figure 3

One may superimpose these two Venn Diagrams and use the resulting diagrams to examine engineering enterprise as shown in figure 4.

Figure 4

[†] The engineer may use creativity, of course, in how the analytical results are applied or interpreted.

Considering the intersection of scientific knowledge with societal need (designated as the domain of engineering), the authors will discuss three sectors, shown as A, B, and C.

Sector A represents the intersection of purely analytical talents with the engineering domain. This may be used to represent engineering science, an ability to model complex systems and predict their response to various inputs under various conditions.[†] This segment of engineering has, of course, been the subject of intense development over the last half century and has benefitted most directly from the availability of fast digital computers.

Sector C, the intersection of our creative capacity with the engineering domain, can be viewed as representing those sudden intuitive leaps often responsible for revolutionary advances in technology called “significant novelty” by Spier (11) as well as those aspects of engineering, not yet fully supported by engineering science, that remain more art than science.

The third sector, B (the intersection of knowledge and need with both creative and analytical capability) can be used to represent engineering design and much "real world" problem solving. This sector includes activities ranging from developing innovative products and processes, to creating an innovative bridge design, to developing a new control process for petrochemical production. This vision of engineering design as the quadrilateral intersection represented by Section B is consistent with statements expressed by Pahl and Beitz (20), Dixon (21), and Penny (22).

Current approaches to teaching used in engineering schools have been designed more for developing analytical skills (Sector A) than creative skills (23). The Accreditation Board for Engineering and Technology (ABET) identifies engineering as "that profession in which

[†] The Accreditation Board for Engineering and Technology states that "...engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other." *Criteria for Accrediting Programs in Engineering in the United States*, Section IV.C.3.d.(3), 1995-96. Accreditation Cycle, Engineering Accreditation Commission, Accreditation Board for Engineering and Technology, Inc., 111 Market Place, Suite 1050, Baltimore, Maryland 21202.

knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind " (emphasis added). ABET further recognizes that "a significant measure of an engineering education is the degree to which it has prepared the graduate to pursue a productive engineering career that is characterized by continued professional growth" (24). One can conclude that analytical skills are essential tools for engineers[†], but are not sufficient for a complete engineering education. An education that only uses classroom problems in which all variables are accurately known and only one correct answer exists not only misrepresents the situations engineers encounter in their jobs, but also does little to stimulate creativity. A trend toward using open-ended problems in the engineering classroom is a healthy step in the direction of more complete and relevant engineering education.

This four-circle representation of human endeavor (fig. 4) also offers a useful perspective for other enterprises. Sector 1, the intersection of analytical skills with societal needs outside the bounds of scientific knowledge might include economics and philosophy while sector 3 may encompass the arts. Sector 2 may be used to represent those societal needs outside the bounds of scientific knowledge that required both analytical and creative skills, perhaps including public policy, business administration, and music.

The view of engineering presented in this paper differs from the view of "method" presented by Koen (3), and the notion of "significant novelty" presented by Spier (11). Spier argues, "There is a product that results from the activity of an engineer" and interprets the term "product" broadly (we presume to include processes). Our emphasis, however, is not on the product, but the engineer's interaction with society.

[†] In fact one could argue, that it is the use of these mathematical and natural sciences and other analytical tools which partially differentiate engineers from other problem solving professions.

Professional Responsibility and Engineering Ethics

The rationale for teaching ethics to engineers and computer scientists seems fairly obvious. Their work (developing, designing and implementing technologies) has an enormous impact on the world. Johnson (25)

Discussion of an engineer's inherent interaction with society and societal needs, leads naturally to an engineer's responsibility to society. Since the Grinter report (26), engineering education has made significant progress in strengthening the basic sciences in engineering, including mathematics, chemistry, and physics (16). Recent trends toward increasing discussion of professionalism in the classroom notwithstanding, topics of professional responsibility (as compared to science, engineering sciences, and engineering analysis) have received surprisingly little attention in engineering education over the last several decades (27). The authors fear that professional responsibility may also have been underemphasized in the practice of engineering. This includes such topics as:

- Safety and Welfare of the Public and of Clients
- Professional Ethics
- Legal Liabilities of Engineers
- Environmental Responsibilities
- Quality
- Communications

Each of these topics relates to the interaction of an engineer to others: clients, society, employers, employees, and to the engineering profession. Regarding engineering ethics, Whitbeck argues that engineers should study engineering ethics from the perspective of a moral agent as opposed to a moral judge (28). We fully subscribe to this approach not only for teaching engineering ethics, but also for teaching (and practicing) in other areas of professional

responsibility. For engineers, engineering ethics is not a topic separate from engineering, it is part of the essence of engineering as it pertains to the professional responsibilities that the engineer has with society. The results of an NSF sponsored workshop on engineering ethics in the classroom utilized techniques from engineering design methodology to address ethical dimensions of engineering problems, designs, and interactions (27). One may consider numerous engineering design methodologies which will illustrate the point (e.g., 4, 29, 30). Pugh, for example, includes the following elements in the "engineering design core" (18).

- Understanding the Market (problem definition: societal need)
- Design Specification (specifying the needs)
- Concept Design
- Detail Design
- Manufacture
- Sell

Pugh's methodology focuses on product design, but also has applications in process design and general problem solving. Experienced engineers would not logically delay consideration of economic issues until after completion of detail design. That would not allow the engineer to consider economic and performance tradeoffs that are essential in the overall evaluation of alternative designs to be analyzed in the Concept Design element. It is just as important that engineers first approach ethical, safety, liability, environmental, quality, and communications issues in the first step of the design process, rather than allowing the design to proceed without regard to these issues. This allows engineers to address and analyze each element of the problem from the problem statement to the release of the product or service to the customer. This allows engineers to integrate (naturally) the consideration of ethical and other concerns directly into the design process and to expand the alternative designs to potentially eliminate or reduce problems, rather than simply to react to the problems.

This article started with a quote stating that "the essence of engineering is design."
ABET defines design as:

... the process of devising a system, component, or process to meet desired needs. It is a decision making process (often iterative), in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. ...it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact (31). (emphasis added)

ABET's definition of design involves engineering activities which include open-ended problems. These activities include machine design, product and process engineering, manufacturing engineering, and applications engineering. This broad definition of design includes most of engineering activities involving societal interaction. Due to their interactions with society, engineers assume the responsibility inherent in such interactions. ABET's definition acknowledges the relationship of engineering to society in the recognition of "realistic constraints" in the design process (remember that "design is the essence of engineering").[†] The National Research Council also recognized the importance of engineering in society (13). Yet engineers frequently give limited attention to the codes which guide their interaction with society (32). Skooglund proposes that professional ethics describe "how we agree to relate to one another" (33). This pragmatic definition of professional ethics can be useful in examining how engineers view their codes.

Development of course material (8, 9) in the last decade has allowed engineering degree programs to expand course offerings in fields of professional responsibility. Additionally, faculty have developed problems for analytical courses which include issues of professional

[†] Note that the authors are combining Koen's statement (see footnote 1) with ABET's definition of design. Although it is not clear that Koen would agree with ABET's definition of design, the author's are comfortable with the combination of the approaches.

responsibility (see Broom and Pierce, "The Heroic Engineer") (34). Though developments supporting an engineer's ability to address areas of professional responsibility are encouraging, the authors still believe that academic programs currently are producing far too many engineers who do not understand their professional responsibilities to society. Observations by Vandenburg and Khan (32) support these concerns. They state: "Given current economic, social and environmental trends and policies, the study shows cause for deep concerns (32)..." As indicated in *Engineering Education for a Changing World*, "...engineering colleges must not only provide their graduates with the intellectual development and superb technical capabilities, but following industry's lead, those colleges must educate their students to work as part of teams, communicate well, and understand the economic, social, environmental and international context of their professional activities" (35).

Engineers must develop a fundamental understanding of their professional responsibilities. Few engineers have an opportunity, however, to develop or contribute to the development of a professional code of ethics. As a result, engineers are in danger of viewing codes of ethics as static, dictated by "others" for engineering applications. Compare this to the process by which attorneys in the United States develop professional codes regulating their conduct. State bars and their members develop and periodically review their professional codes of conduct. Statewide debate about the codes can be heated and can produce significant discrepancies from state to state in rules of professional conduct. One should expect these discussions to become heated, since these codes describe how professionals (attorneys) will relate to clients, courts, the public, and other attorneys. At the end of the review process, the code describes how the parties will "relate to one another" (using Skooglund's terminology). Partially due to the process used to develop and review their codes of professional conduct, attorneys tend to internalize these codes.

The authors do not suggest that the engineering profession model itself after the legal profession; in fact, substantive differences from state to state have some serious drawbacks. Rather we suggest that engineers examine and adopt "best practices" in development of rules of

professional conduct which encourage engineers to understand and internalize their professional codes. Engineers need to develop broad fundamental understanding of their professional responsibilities. In at least one engineering college, students have developed their own codes of conduct (how they will relate to one another and the college) for their academic career (36). This experience gives the students a personal involvement with professional codes of conduct necessary in the engineering profession. These students have an opportunity to integrate their "professional code" into their daily work as engineering students. This allows students to internalize their professional responsibilities and to develop a fundamental understanding of their obligations and resulting consequences. Students at other universities and the engineering profession would be well served to learn from the experiences of these students who developed their own code.

Since it is difficult for every practicing engineer to participate in the development of national professional codes, it may be better to localize this experience for professional engineers. This can be done by developing codes for conduct at company, division, or departmental levels in traditional engineering environments. Texas Instruments and Bell Helicopter have had positive experiences developing company codes which are intended to describe how professional engineers "agree to relate to one another" (1).

We suggest, however, that the most effective mechanism is the personal involvement of each engineer in integrating the topics of safety and the welfare of the public, professional ethics, legal considerations, environmental responsibilities, quality, and communications into the methodologies which all engineers use to approach and solve problems in the ordinary course of practice. This could be considered a natural extension of "Concurrent Engineering" in which the elements of design, manufacturing, and other issues are considered concurrently in engineering methodology. The concurrent methodology would include design for manufacturing, design for reliability, design for maintainability, design for assembly, design for environment, design for safety, design for economics, etc. This supports the approach taken by Pugh in his concept of

"Total Design" (18). Some elements of integration has been imposed by regulation (such as environmental regulation).

The healthy debate among engineers (as well as clients and employers) which should naturally arise in the integration and the application of the methodologies will serve to underscore the nature and importance of the role that the engineer has in society (health, safety, and welfare of the public); the role the client has in engineering design (realistic requirements, economics, reliability, maintainability, and other associated topics of quality); the effects of engineering activity on society; and the relationship of society to engineering activities (including product liability, protection of intellectual property, environmental regulations, etc.).

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