



Defining Engineering Education

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A Century of Defining Engineering Education

Abstract

The broad issue question addressed in this paper is how the complex interface between engineering education and the larger contexts in which it is embedded change over time. These contexts—social, intellectual, economic, and more—define both the educational approaches taken and how various approaches are valued. These contexts are themselves inter-related, forming a complex system of which engineering education is a part. The interface between engineering education and the larger system is not unidirectional; while environmental changes can affect engineering education so too does engineering education affect the larger environment. This paper adopts a philosophical perspective in exploring some interrelationships between engineering education and the larger social-technical-economic system.

To explore the extent to which a meaningful conceptual ontology exists for dialog of the role on engineering education in society, definitions of how engineering for the purpose of engineering education are examined. Definitions of engineering education are drawn from selected policy documents from the 1918 Mann report through “The Engineer of 2020” in 2004. The focus is on understanding how engineering definitions change over time in the dialog of policy since policy makers play a large role in setting directions for engineering education. It is found that the documents contain both explicit and implicit definitions which provide insights into how and why engineering education is this way and not that. The definitions are also illuminate tensions, or misalignments, in how we currently teach engineering, the most glaring of these is a technical-social duality that increases in importance in over the 84 year span examined.

Rationale & Framework

The broad engineering education question addressed in this paper is the interplay of engineering education with the larger elements of human society. Of particular interest is how the complex interface between engineering education and the context in which it is embedded changes over time. While the breadth of the topic makes this a difficult issue to address, it is nevertheless relevant since the purpose of engineering education depends upon social, intellectual, economic, and other contexts. These contexts and the associated historical milieus determine in part what is taught and how we educate. The contexts are themselves inter-related, forming a complex system of which engineering education is a part. Here the word system is not used in the reductionist engineering sense, but the integrative sense of “a set of connected things or parts forming a complex whole”. The interface between engineering education and the larger system is not unidirectional; environmental changes can affect engineering education, but so too can engineering education affect the larger environment. It is this second aspect that is of longer

term interest and will be further addressed in subsequent publications: how do the choices we make in engineering education affect the larger structure?

The focus here is on engineering education, rather than engineering more generally, since ideally engineering education programs attempt to lead engineering practice due to their role of preparing future engineers. While one can explore the relationship of engineering education to the larger system from many different perspectives, I adopt a philosophical perspective. The reason for approaching this problem from philosophy is that these discussions—the purpose, meaning, influence, and value of engineering education as it intersects the larger system—are at this time conceptually imprecise. An assertion of the paper is that we currently lack a shared, meaningful conceptual ontology to discuss such issues which may cause us to “talk around each other” in our attempts to rethink engineering education. Philosophy provides a method to gather and translate these concepts, then begin to understand their claims and limits of these claims.

This manuscript focuses on how engineering is defined for the purpose of engineering education. This question is irrelevant to engineering practice over the short term since engineering is what it is, and definitions don’t directly affect GDP or employment. Yet for engineering educators the definitions of engineering do matter since they inform what we *should* do. Definitions also point out potential conceptual imprecisions; if we do not interpret a definition the same way then there is a potential for miscommunication and subsidiary ideas may themselves be imprecise.

Mitcham and Schatzberg point out ¹ that definitions are fundamental to philosophy, and our philosophy, whether explicit or not, determines how we educate ². More practically, definitions serve as objectives, helping to determine the ultimate aims of education. Thus, definitions may provide insights into how and why engineering education is this way and not that. In this paper I seek to better understand how engineering definitions and the documents in which they are found illuminate underlying philosophies about educating engineers, and how these definitions have changed over time. Given the influence of policy makers to set directions for engineering education, I focus on engineering definitions in policy reports.

How then do we define engineering and what are the agreed-upon conventions that let one claim they are an engineer? The seemingly simple task of defining engineering in the context of education becomes more complicated when closely examined since definitions of engineering has varied over time and are nuanced by culture and dominant forms of knowledge. This paper adapts previous work in the related area of technology to provide a framework for understanding definitions. Schatzberg and Mitcham ¹ highlight five types of definitions:

- *etymological* that give insights into the history of the definition,
- *essential* (also called intensional or coactive) that define necessary and sufficient conditions for classification,
- *prescriptive* to define something in a way that affects the actions of others,
- *linguistic* that focuses on usage to clarify deeper meanings, and

- *pragmatic* that seeks workable definitions in a context.

Another class of definitions that is less useful is *extensional* or *denotive*, that define by listing members of a class. Under this type of definition are *ostensive* definitions define by examples or case. As Davis ³ points out, many definitions of “engineer” are ostensive and thus prone to logical errors and circular arguments.

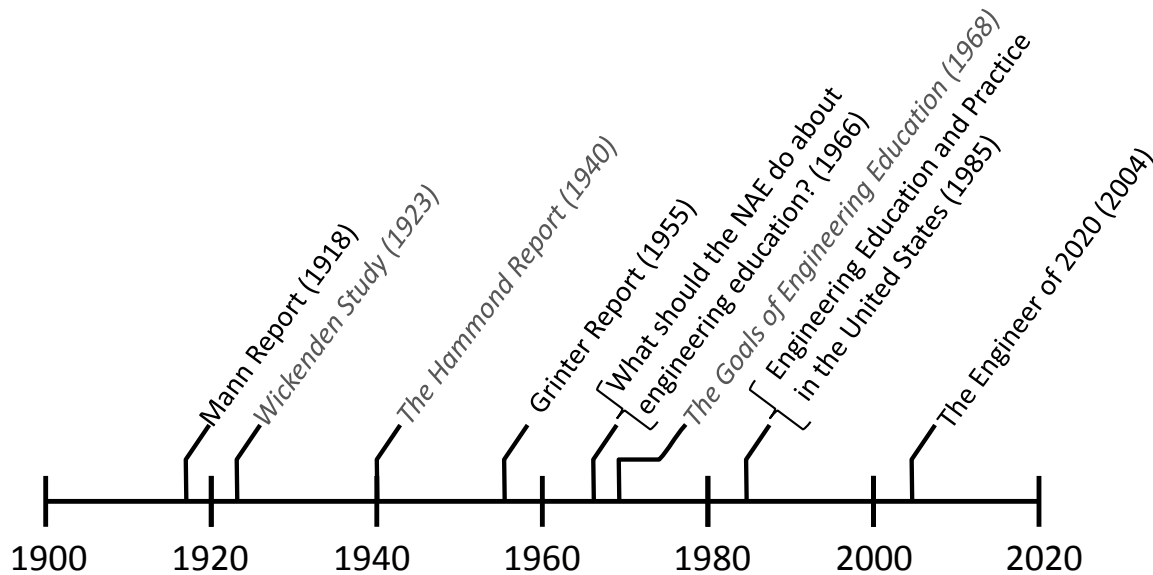


Figure 1: Temporal sequence of some major engineering education reports. *Italicized reports are not covered in this work.*

To make the process of exploring how definitions change over time manageable, a selected set of reports was chosen, shown in the timeline of Figure 1. These documents were chosen by skimming a large number of policy reports and selecting those that offered rich implicit and explicit definitions of engineering and were also often referenced by other reports. The rationale for exploring policy documents and reports is that many of them were widely read by engineering educators, university administrators, and policy makers. Thus these reports may inform an aggregate of small local choices. The effect of these choices cannot be measured but could have a potentially significant effect on the engineering education system over the long term. However the choice of these reports, or any limited set of documents, creates significant limitations. First, the paper is United States centric, ignoring documents from other countries, particularly Great Britain, that were often developed synergistically. Second, the definitions need to be fully understood in the historical context and dialogs of the time. While an effort was made to understand the definitions in context, doing so fully is beyond the scope of this paper. Next, the focus is on engineering education within four year colleges and universities rather than vocational education so historically important documents such as the Smith-Hughes Act are not considered. Finally most of the reports are final, edited copies of what were much richer, more nuanced discussions. The reports thus offer consensus views which do not fully represent the

full dialog. The consensus views are affected by participants on the panels and committees, which introduces several possible biases such as small industries being under-represented.

Definitions over Time

Etymological Basis of “Engineering”

Etymologically, engineering seems to derive from similar roots to technology, a term which was given a philosophical basis in ancient Greece^{1,4} through the root *techne*—productive skill or art—which was one of Aristotle’s intellectual virtues⁵. *Techne* includes the skills of making and creating that are in modern definitions of engineering. While engineering as defined today did not exist in ancient Greece, nor is the evolution of modern definitions obvious, the influence of ancient writings on Western thought seems to remain. Engineering has the Latin etymological root *ingeniare* which means to devise or contrive⁶. The term engineer originated in the Middle Ages and was first associated with those soldiers who dealt with military devices and constructions; architects devised civilian constructions. As pointed out by several authors^{3,7}, standing armies led to a need for officers to lead corps of engineers, and the first recognizable engineering school, École Polytechnic, was to train these officers. Similarly West Point was the first engineering school in the United States. Although most engineers are not aware of these military origins such word usages persist; the use-frequency of the word engineer has remained weakly temporally correlated with terms related to the military endeavors such as “soldier” or “war” through modern times⁸.

As the words *engineer* and *engineering* came more into civilian use the definitions begin to diverge between countries and cultures. In the English speaking world the first modern, civilian definition of engineering is generally acknowledged to arise from the charter of the British Institution of Civil Engineers. As rational science become predominant in the 19th and 20th centuries the knowledge from scientific discoveries was increasingly incorporated into industrial products and processes. Additionally, industrial production was becoming increasingly mechanized across the 19th century and this mechanization picked up rapidly during the Gilded Age so that engineers became more closely associated with industry.

1918: The Mann Report

The increasing importance of engineering to industry led to concerns about the quality of engineers and the first in-depth study of engineering education programs, the Mann Report, published in 1918 and commissioned by three engineering societies through the Carnegie Foundation out of a sense that “...*the load upon the student has become continually heavier...there is a wide spread feeling that under this pressure the great body of students fail to gain...satisfactory grounding in the fundamental sciences; and...do not fulfill the expectations of engineers and manufacturers in dealing with the practical problems with which they are*

confronted on leaving the engineering schools.” The Mann report indicates that as of 1915 there were 126 engineering colleges (compared to approximately 300 accredited schools today) and 43 institutions that taught engineering—such as the YMCA—that did not give a degree.

While the Mann report nowhere directly defines engineering or the role of an engineer, it does provide insights that laid the groundwork for modern engineering programs. Much of the language in the Mann report is still relevant, nearly one century later, and many of the issues brought up in the Mann report are still being debated. The Mann report clearly defines improving industrial production as the essential purpose of engineering, thus providing insights into the necessary and sufficient conditions for the role of an engineer and the engineering profession: “*Engineering schools are so obviously a result of the needs of industrial production that the conceptions on which they are founded are necessarily much the same for all.*” (p. 9) and “*...that their ultimate aim was increased industrial production, and that their special contribution to this end was systematic instruction in applied science.*” (p. 11). This essential definition sets out a clear purpose for engineering and the engineer, with the growth of engineering schools driven by the need to better apply science to industrial production, improving the efficiency of industry, and reducing waste.

Although secondary to the need to serve industry, a prescriptive definition of engineering that emerges from the Mann report is: “*the elevation of the mechanic arts to the rank of a learned profession*”. At the time of the Mann report fewer than half of people in engineering jobs had a degree, and while half of firms preferred a college-trained engineer one third preferred one who had practical training. In the US the engineering profession was first recognized by the Federal Government in 1916.

The main body of the Mann report attempts to determine an effective course of study to accomplish the ends of creating manpower for improving industrial production. Thus the Mann report seeks to provide both essential and pragmatic definitions of engineering for engineering education: “*...to define this common basis of all engineering as clearly as possible; that is, to make a list of all the facts, principles, and processes that are essential elements in the equipment of every engineer.*” The report purposely shies away from defining engineering so precisely, but does identify three key elements of the engineering programs of the time: “*...they all have a common core made up of three distinct parts, namely, science (mathematics, chemistry, physics, and mechanics), mechanic arts (drawing and shop), and humanities (English and foreign languages).*” (p. 89).

An issue the Mann report addresses at length is how to balance or align these elements. A particular focus of the report is how to effectively introduce the more practical elements needed for professional practice into the curriculum, in essence attempting pragmatic definitions of engineering. There are tensions that the Mann report never fully resolves around the practical vs.

theoretical or abstract vs. material elements of engineering. At the time more theoretical subjects were covered in the first two years, while more technical subjects were taught in the latter two. This structure arose from the definition of engineering as an applied science: *“The conception underlying this and all later curricula is that engineering is applied science; and therefore, to teach engineering, it is necessary first to teach science and then to apply it... Only when the student has passed a satisfactory examination on these fundamental principles and their various non-technical applications is he permitted to work on engineering projects.”* (p. 58). However the report questions this approach, defining the value of practical work early in the curriculum: *“Practical engineering work is essential for the freshman not only because it appeals to his professional ambition, arouses his enthusiasm, and gives him training in practice, but also because it helps him to master the theoretical work more fully and more quickly.”* (p. 88).

Despite the emphasis on practice, engineering programs are distinguished from the more apprentice-based model of medicine and law by their academic character: *“In engineering, on the other hand, altho the apprenticeship method of training was originally employed and is still in extensive use...this system of training never developed into engineering schools to any extent. The first engineering schools were founded by colleges, their professors were college-trained men, and their curricula were devised by college faculties; professors also gave practically all the instruction with very little assistance from practitioners.”* (p. 55). Thus practical work did not have the same status within universities as more academic subjects: *“Few teachers of the mechanic arts have been granted the title “Professor,” and the work itself is seldom recognized as being intrinsically of “university grade.” Yet no one denies that it is an essential element in the equipment of every engineer; and therefore it has been tolerated by engineering faculties”* (p. 75). The inclusion of shopwork was driven by the more pragmatic needs of engineering and a perceived need to align theory and practice. The report noted that there was a great deal of experimentation going on at the time to learn how to better align the practical elements of an engineering curriculum with the more traditional academic subjects. From this a definition of engineering more as doing or acting rather than knowing emerges: *“What is the minimum equipment essential to every engineer, no matter what specialty he may eventually choose? The answers to this question must be stated in terms of ability to accomplish rather than in the customary terms of topics to recite...”* (p. 65).

After reviewing a large fraction of the practices at the engineering schools of the time, the report offers a prescriptive definition of an engineering curriculum that would meet the fundamental aim of “more intelligent production”. *“A curriculum that satisfies all of the requirement mentioned above would include...actual participation in real industrial work...engineering laboratory work, including drawing and descriptive geometry...mathematics and science, which should be developed systematically in logical order so as to furnish the backbone of the course...humanistic studies make up the fourth type of work essential to the training of every engineer...”* (p. 92). The report goes on immediately to cite curricular deficiencies of the time:

“...lack of good English, of business sense, and of understanding of men are most frequently mentioned by practising engineers as points of weakness in the graduates of the schools. The criticisms point out two types of weakness, namely, lack of technical facility in expression, in business, and in handling men; and lack of appreciation of and interest in literature, economics, and social philosophy.” (pp. 91 and 98-100) The Mann report makes clear that pragmatic requirements garnered from practicing engineers dictate the content of “humanistic studies”, and that these are not what today would be called the humanities.

To further define “humanistic studies” a large survey of, and interviews with, practicing engineers was conducted that broadens pragmatic definition of the engineer beyond applied science: *“personal qualities such as common sense, integrity, resourcefulness, initiative, tact, thoroughness, accuracy, efficiency, and understanding of men are universally recognized as being no less necessary to a professional engineer than are technical knowledge and skill.”* (p. 106). The Mann report strongly emphasizes character as a necessary quality of an engineer. The survey and interviews also indicated that engineers needed to have knowledge of costs and how to determine value, areas addressed today by business and management programs. Additionally the development of character was seen as an emerging need: *“...it will become more and more essential that schools of engineering pay greater attention to the effect of their work on the personal development of the students.”* (p. 108). Personal development was not described it often is today in terms of self-fulfillment, rather it is seen more as a prescriptive process to better fit people to jobs, thus improving production : *“...admission to college is an important division of the central problem of education — vocational guidance. If any reasonably trustworthy method of discovering what work each individual is best fitted for can be found, the other problems of education will in large measure solve themselves.”* (p. 49). The purpose of the core curriculum—*“all the facts, principles, and processes that are essential elements in the equipment of every engineer”*—was also to help steer students into jobs for which they were fitted: *“...the work of the common core offers an excellent chance for vocational guidance; so that the student would not choose but rather be claimed by the special field for which he is best fitted. Probably nothing would contribute more to the success of the later specialized work than a systematic utilization of this opportunity.”* (p. 95). Psychological evaluation of students was also recommended.

This seemingly sets a clear tone that the purpose of engineering education is to serve industrial production, and the student should be fitted to this need. However the Mann report also discusses larger utilitarian issues related to greater social good, discussing the need for students to address considerations of economic justice, macroeconomic contexts, and moral purpose: *“There fore, one of the most important contributions that the school can make toward the education of the engineer is to guide him in developing an attitude toward life and a philosophy of living that will enable him to judge rightly as to the things humanity considers most worth while.”* (p. 111). The Mann report seeks to resolve this apparent tension by invoking the term

“worthwhile”: *“For the schools have already discovered that students learn best when they are inspired by the conviction that the work is really worth while. One of the most effective ways of making work seem worthwhile is by constantly relating it to the consideration of the whole range of values involved and all the costs. Every decision in daily life is an answer to the question whether the value is worth the cost... Hence the first message of the profession to the schools is—Motivate your work by making it worthwhile; liberate the spirit of investigation by making the game worth the candle; for character, judgment, efficiency, and understanding of men develop best in men who work with enthusiasm and intelligence at things that they believe to be worth while.”* (p. 112). Framing educational activities in terms of value and worthwhileness comes close to more recent calls for an increasing role for entrepreneurship and innovation in engineering programs.

In summary, the Mann report provides an etymological definition of engineering as a noble venture to help the United States improve industry and production and by so doing have engineering take its place beside other esteemed professions. Engineering programs were to balance scientific, technical, and humanistic studies to produce graduates with a measure of knowledge and character who could take act in their roles in industry; the focus was highly pragmatic. Although taught in universities, engineering was not to be a purely academic discipline, and should emphasize both doing and knowing. Engineers clearly worked in the human realm and were more valuable in their practice if they could manage both human and material resources. The concluding sentence neatly summarizes these definitions: *“...the modern conception of the professional engineer, not as a conglomerate of classical scholar ship and mechanical skill, but as the creator of machines and the interpreter of their human significance, well qualified to increase the material rewards of human labor and to organize industry for the more intelligent development of men.”*

1955: The Grinter Report

Like the Mann report, the Grinter report was published in a time of rapid economic expansion and growing American hegemony. The purpose of the Grinter report was to *“...recommend the pattern or patterns that engineering education should take in order to keep pace with the rapid developments in science and technology and to educate men who will be competent to serve the needs of and provide the leadership for the engineering profession over the next quarter-century.”* The Grinter report was first released in draft form and comments from academic institutions and industry led to considerable revisions before the final version was released. The main focus of the Grinter report was on curricular content and preparation of faculty, with faculty seen as more important than curricula.

Similar to the Mann report two essential definitions—technical and social—are provided for engineering education, and by proxy engineering. Technical preparation consisted of: *“...the*

performance of the functions of analysis and creative design...mastery of the fundamental scientific principles associated with any branch of engineering...the ability to make critical scientific and economic analyses and to organize these into clear, concise, and convincing oral or written report". Socially the engineer should be prepared by: *"...the development of leadership...a deep sense of professional ethics...an understanding of the evolution of society and of the impact of technology on it; and acquaintance with and appreciation of the heritage of other cultural fields; and the development of both a personal philosophy... and a sense of moral and ethical values..."*. Although both technical and social definitions are made early within the report, the technical definitions are given much more weight throughout the remainder of the report. These definitions are prescriptive in that educators could develop them into lists of teaching objectives.

Several aspects of definitions of engineering and engineers emerge from the Grinter report. The theme of application of science that was found in the Mann report is repeated and strengthened as the essential definition of engineering: *"The most important engineering background of the professional engineer, apart from his major field, lies in the basic sciences and the engineering sciences."* However science becomes more divorced from industrial production. In comparison to the Mann report, that often drew from practice to create more pragmatic definitions, the Grinter report downplays the importance of technical skills and other "practical work"—e.g. drafting and shop courses—in the preparation of an engineer: *"Many practicing engineers achieve results by the use of a kind of intuitive sense which, no matter how successful in practice, cannot be transformed into organized knowledge that can be taught to engineering students."* The engineer as translator of science or application of science emerges much more strongly: *"It is a responsibility of the engineer to recognize those new developments in science and technology that have significant potentialities in engineering."* The engineer is expected to be able to translate multiple scientific disciplines to practice.

Another theme that emerges with the increased importance of science is that creativity and research become the pinnacle of engineering work. Thus engineering education should focus on: *"...the development of able and responsible men fully competent to practice on a professional plane, especially those who will eventually lead the profession to new heights of accomplishment through creative practice or research."* The Grinter report defines the distinctive aspects of engineering curricula to be creative: *"Education directed toward the creative and practical phases of economic design, involving analysis, synthesis, development, and engineering research"*. Compared with the Mann report, the Grinter report is more prescriptive when it comes to the engineering curriculum: *"...mathematics and the basic sciences, the engineering sciences, the application of these sciences to the analysis and synthesis of engineering systems within the student's major field, technical courses outside his major field, and humanistic and social studies."* The Grinter report provides essential and somewhat prescriptive definitions of all these elements except humanistic and social studies. The engineering sciences, which relate

science and math to engineering problems, are to be designed to support integration of science and math to engineering problems. The Grinter report implies that there is a sequential presentation of these topics in the curriculum: *“that mathematics and the basic science shall be used proficiently in the courses in engineering science and that the latter, in turn, shall be used proficiently in engineering analysis, in the study of engineering systems, and in the preparation for creative design work”*.

While the Mann report suggested a pathway for engineering to become a high status profession focused on improving industrial production, in the Grinter report status is tied to research, design, and creativity. This is particularly true for the engineering faculty who will teach engineering sciences; creative work and research are integrated into definitions of faculty roles throughout the report. The Grinter report suggests pathways to status within the engineering profession by offering increased freedom and choice in the curriculum to “the top ten per cent of a good class”. The emphasis on top students is supported by a strongly worded set of recommendations for graduate curricula that address needs of *“outstanding students with creative talents”*. The Grinter report suggests that a graduate faculty should be distinguished from the undergraduate faculty and that graduate students should be carefully selected: *“The attitude that most students deserve a chance at graduate study is inimical to the intellectual objectives to be achieved and may be damaging in its effect upon those who are qualified for graduate study as well as those who are not.”* Independence is important for graduate students since: *“...genius is not well nurtured by the fixed curricula so characteristically prevalent today in undergraduate fields. Hence, graduate study should be flexible and custom tailored to suite the individual.”*

Although in the Mann report humanistic studies to help the engineer cope with the human aspects of industrial production was seen as a growing need in engineering programs, the Grinter report subtly de-emphasizes these aspects of engineering: *“the “new situation” often involves social and economic as well as technical elements, and these are not entirely separable. Thus the end result is not merely the numerical solution of a technical problem but is rather a decision based on a value judgment to which the quantitative technical result contributes one important element.”* In other words, the engineer is becoming more of a team player, a theme that echoes even more strongly in later reports. Throughout the Grinter report the social role of the engineer is acknowledged as important but is seen as secondary to science: *“The importance of keeping such economic and social ideas before students by example can hardly be over emphasized. Such concepts should be encompassed even though the main effort at the undergraduate level is largely restricted to developing the student’s ability to master the scientific and technical aspects of engineering education.”* Mann’s “humanistic studies” to lead men and create value becomes recognition of the value of a liberal education in the Grinter report. The definitions of the social/human aspects of engineering move from pragmatic and essential in the Mann report to almost denotive in the Grinter report. The lack of clear purpose or method for the social

definition and breadth of desired characteristics weakens this aspect of the engineer since it could describe almost any field of study: “...also an informed and participating citizen, and a person whose living expresses high cultural values and moral standards. Thus, the competent engineer needs understanding and appreciation in the humanities and in the social sciences as much as in his own field of engineering. He needs to be able to deal with the economic, human, and social factors of his professional problems. His facility with, and understanding of, ideas in the fields of humanities and social sciences not only provide an essential contribution to his professional engineering work, but also contribute to his success as a citizen and to the enrichment and meaning of his life as an individual.”

In summary, definitions of engineers and engineering in the Grinter report shift from focusing on the scientific, technical, and human elements of industrial production to the scientific basis of engineering. The goal of engineering is application of science and within engineering creative work and research occupy the highest status roles. Compared to the more pragmatic definitions of the Mann report, the Grinter report offers more essential and prescriptive definitions of engineering which de-emphasize the technical and practical elements. Engineering is defined both technically and socially. The technical definitions are precise, lengthy, and prescriptive as to curricula, the role and status of faculty, and who should proceed to graduate studies. Social definitions, on the other hand, become more generally divorced from engineering curricula.

1966: What should the National Academy of Engineering do about Engineering Education?

The National Academy of Engineering (NAE) was founded in 1964 under the umbrella of the National Academy of Science. In 1966 a conference was held to determine what role the NAE should have in engineering education ⁹. The workshop had presentations by engineering education stakeholders—industry, academia, the Engineering Council for Professional Development (ECPD, later ABET), ASEE, and others—and was followed by an open discussion. The transcript of this meeting did not delve deeply into definitions of engineering education, rather it highlights the dialectic positions and range of positions held by various stakeholders with respect to the creation of ASEE’s “Goals of Engineering Education” report ¹⁰ that was published in 1968. The transcript stands in contrast to most reports in how frank the language is, the perceived deficiencies in the draft of the Goals Report, and the extent to which the various participants supported their own agendas. Although the NAE eventually decided that it should take a leadership role in defining the future of engineering education, this role was not at all certain at the meeting since several groups such as the ASEE and ECPD advocated that the NAE not engage.

There were several key discussions about the form of engineering education that would produce engineers capable of solving then-current problems. One of the more divisive issues was whether an engineering degree should be a professional program such as law or medicine, or

serve as a liberal education in science and technology; a discussion going back to the Wickenden report ¹¹. Tensions arose over proposals to extend engineering degree programs beyond four years. The Goals Report stopped short of making this recommendation, but assumed it would occur ¹⁰.

Representatives from government, academia, and industry pushed back against the “orthodoxy” of the technical and scientific focus of engineering education reports. This orthodoxy arose, according to some participants, from the fact that engineering education reports were written by engineers. An academic dean stated: *“Engineering education has been evaluating itself in its own image for the past half century...This image deals largely with the expanding roles of the physical sciences, mathematics, and engineering. The humanities and social sciences have been regarded as peripheral fields...in my estimation we can no longer ignore these interdisciplinary aspects of education. They are definitely not peripheral; they are central to the educational needs of many engineers...the Goals Report, in its adherence to orthodoxy, does not deal effectively with these emerging domains that embody many of the dominant engineering challenges of the future.”* Government representatives emphasized the social role of engineering in policy: *“To put it bluntly, I see little in the Goals Report that reflects the current and growing requirements of the nation or of the world for engineering talent. I see little that relates such social requirements back into the requirements of the educational system.”*

The definition of engineering that emerges from that meeting has a dialectic character; there are visible tensions in defining what types of problems (technical vs. social) engineers should address and what the role of engineers was to be in the future. Interestingly, the meeting format defined engineering education through the lens of engineering as a problem to be solved. As was seen in the Mann and Grinter reports this has been a characteristic of the “genre” of engineering education reports. Throughout the transcript participants refer to problems, yet leave vague exactly what those problems are. The title of the papers that make up the report—“What should [insert name of organization] do about engineering education?”—frame an engineering education system seemingly in crisis; a crisis predicated on future predictions. It is interesting to note retrospectively that when ASEE’s “Goals of Engineering Education” report came out in 1968, there were wildly optimistic predictions for the future need and roles of engineers as well as how technology would impact human life. Artificial organs, a moon base, and personal nuclear weapons did not appear by 1984. Nor did society have thermonuclear fusion, ocean farming of synthetic protein, robot menials, and military weather manipulation in 2000.

1985: Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future

This report summarized a series of NAE panels under the umbrella of the Committee on the Education and Utilization of the Engineer the members of which took a comprehensive look at

engineering education and practice. The focus was systemic and sponsored by several government agencies, large companies, and private foundations. Several reports were generated¹²⁻¹⁴, summarized in the final report¹⁵. The final report contains both specific definitions of engineering, drawn in part from an earlier ECPD document¹⁶ as well as indirect definitions of how the practice of engineering and the role of engineers was changing. This report stays within the bounds of the genre, but diverges in several respects from earlier reports.

One difference is the recognition that engineering is defined more as a system function than a role or profession: “*the panel saw the need to define engineering in the broadest possible way so as to include all those activities that constitute the engineering function*” (p. 35). The report adopted a more systemic perspective that “*developed the concept of an engineering community consisting not just of degreed engineers but of all those involved in engineering work, support of engineering work, or engineering education, whether they be engineers, scientists, technologists, or technicians*” (p. 35). Since “*...objective definitions are essential as a basis for describing the engineering community and its constituent elements...*” (p. 49) the committee examined definitions of engineering to better understand this community, and derived the following definition:

Engineering: Business, government, academic, or individual efforts in which knowledge of mathematical and/or natural sciences is employed in research, development, design, manufacturing, systems engineering, or technical operations with the objective of creating and/or delivering systems, products, processes, and/or services of a technical nature and content intended for use.

The report noted the panel arrived at this definition, drawn loosely drawn from a 1978 document from the ECPD¹⁶, but the definition was not unanimously accepted. The panel further went on to define the larger engineering community as those who were actively engaged in engineering, engineering education, engineering support functions including management and sales, and those who has some qualifications but are not currently active. The definition was purposefully designed to be essential rather than prescriptive due to the committee’s charge to better understand the engineering system. The panel also created essential definitions of members of the engineering community that were drawn loosely from the ECPD document but were more inclusive. The ECPD definitions are shown below in figure 2 under the heading “Preparation” with the additions to the definitions made by the committee added in italics. The text above the arrow and listing of career goals comes from the ECPD report.

The report also suggests a wide spectrum of pragmatic definitions for engineers and engineering due to the changing role of the engineering in society. A new addition to definitions of engineering is that engineers should be resilient and adaptable. The change arises from the increasingly dynamic nature of engineering that results from the evolution of technology; at the time the report was written computers were coming into significant use. The theme of life-long learning found in earlier reports is more strongly emphasized. The definitions again include the

influence of economic and capital constraints on engineering work as well as engineering's impact on the economy: "...engineers must establish and maintain great sensitivity to the economic aspects of engineering; these cannot be treated as subordinate issues. To do so would jeopardize the usefulness and value of individual engineers; it would also produce engineering results that do not serve the interests of the U.S. economy to the extent that they can and should." (p. 113), echoing the Mann report. There is also the emergence of the concept of global resource scarcity as a constraint of engineering work.

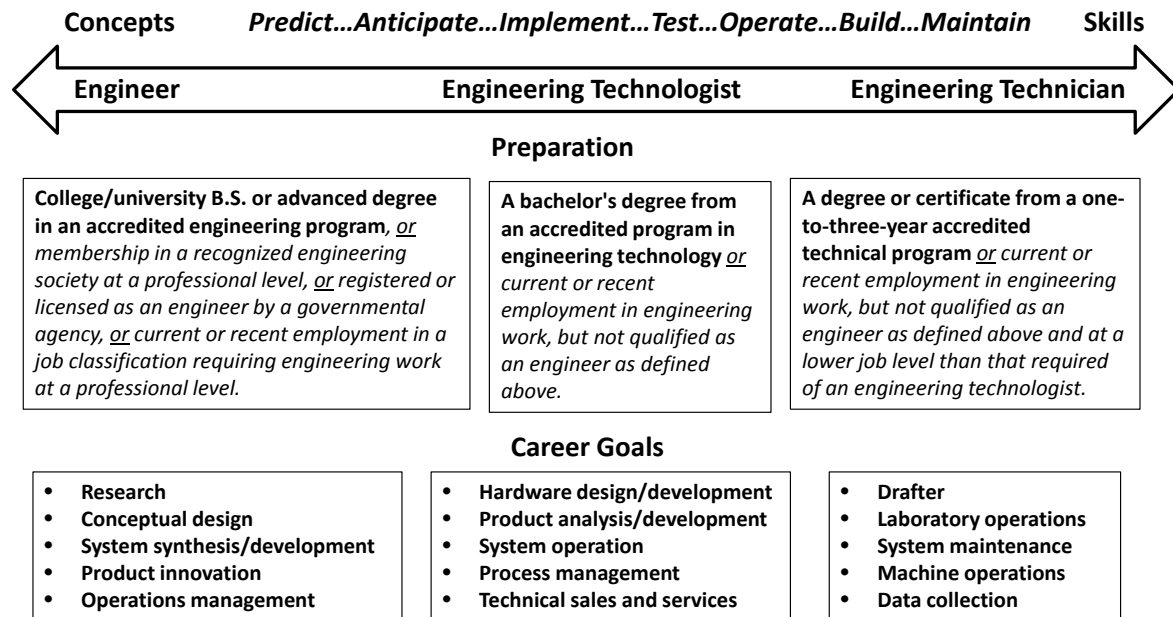


Figure 2: A partial re-creation of the ECPD's 1978 definitions of the engineering team expanded upon in the Committee on the Utilization and Education of the Engineer report. Additions by the committee to the ECPD definitions are show in italics.

The engineer is increasingly defined as part of a larger government or corporate organization: "The corporate engineer has come to predominate, with work characterized by large project teams, relative individual anonymity, and dedication to discrete bits of technology advancement in a highly specialized field." (p. 31). The definition of engineer as a member of a team is emphasized to a greater degree than in the Grinter report and teamwork becomes part of the process of preparing engineers. A tension emerges in the relation of the engineer to management with the role of engineer straddling the boundaries of manager and independent agent. The effectiveness of the engineer depends whether they utilized well or poorly by management: "The effectiveness of engineers depends upon their knowledge and capabilities. Those characteristics, in turn, are a function of experience, training, and—almost as importantly—the management approaches that prevail within the organization." (p. 121). Nevertheless the report repeats the certainties from earlier reports about the increasing role of engineers in the future: "Underlying

all these variables and uncertainties is at least one certainty: we are entering an era in which engineering will play a more dominant role than ever before.” (p. 9)

This report makes stronger connections between education and the larger system, viewing the engineering profession as vital in maintaining US preeminence in the realms of defense, economics, and quality of life. When any of these are viewed as threatened, then engineering education is “...where the cries of crisis have been most frequent and insistent. The educational system is correctly perceived as producing not just the fodder of the technology development process, but its seed corn as well. The training, skills, and knowledge of recent graduates are of critical importance to that development process, and trends that threaten their continued supply to any degree also threaten the foundations of industry and the national economy.” (p. 51). The report frames needed change around specific issues relevant at the time including a shortage of faculty, obsolete equipment, and the development of a two-tier system favoring research universities. The report also identifies for the first time that low participation by women as minorities are a key issue, in stark contrast to the gendered tone of prior reports. In terms of curriculum, the report clearly acknowledges an unresolvable tension between the need for in-depth technical development in an engineering specialty and the need for increasing breadth of an engineer’s capabilities: “...we are aware of intense pressures to modify the undergraduate engineering curriculum to include more subjects...all within the confines of a sacrosanct four-year program. Arguments on all sides are unimpeachable but they are also mutually exclusive...The arguments could be reconciled in a plan for a pre-engineering undergraduate program followed by a professional school program... because of objections to the extra costs of this approach...the committee could not reach a consensus on this vexing problem.” (p. iv)

Overall the definition of an engineer and engineering that emerges from “Engineering Education and Practice in the United States” is both essential and pragmatic. Essential in that the roles and functions of the engineer need to be defined to place her in the context of a larger economic and social system, and pragmatic in that the definitions are contextually dependent. The report paints a picture of an emerging and emergent complex system, of which the engineer is a part. The engineer must be educated to be adaptable to make the system resilient: “...these educational components will be increasingly necessary if American engineers and engineering are to maintain the flexibility and resiliency that the future environment will demand.” (p. 119). Unlike the more prescriptive tone of earlier reports, the complexity of the system and inability to predict the future leads to a recognition it is not possible to tightly engineer engineering education. The acknowledged inability to forecast did not prevent predictions for the year 2000 that predicted increasing scarcity, more rapidly advancing technologies affecting engineering work, growth in the need for engineers, and a more global economy. Interestingly the report also identified that market forces would take a longer temporal view in the future since “the time horizons of managers in most American companies and industries are short...this situation does grievous long-term harm to the United States”.

The Engineer of 2020

As with previous reports the “Engineer of 2020” was a broad effort involving academics, policy makers, and industry performed under the auspices of the NAE. The goal was—as with all previous reports—to offer a forward-looking view of engineering. The committee examined current technological breakthroughs and extrapolated needs and characteristics of the engineering profession through a process of scenario analysis. The report built upon many of the themes that first emerged in the 1985 “Engineering Education and Practice in the United States” report as well as elements of earlier reports. The report included an explicit definition of engineering: *“Engineering is a profoundly creative process. A most elegant description is that engineering is about design under constraint. The engineer designs devices, components, subsystems, and systems and, to create a successful design, in the sense that it leads directly or indirectly to an improvement in our quality of life, must work within the constraints provided by technical, economic, business, political, social, and ethical issues.”* (p. 7)

The main tone of “The Engineer of 2020”, as evidenced by the first two chapters, is to weave engineering tightly into larger technical, social, economic, and environmental contexts. Engineering definitions are seen as constantly evolving since technologies developed by engineers continually impact engineering practice. The report emphasizes flexibility and adaptability as key characteristics of engineers: *“Given the uncertain and changing character of the world in which 2020 engineers will work, engineers will need something that cannot be described in a single word. It involves dynamism, agility, resilience, and flexibility.”* (p. 56). Developing such flexibility is seen as a key challenge for engineering education: *“It is a daunting challenge for the engineering profession and engineering education to remain flexible enough to anticipate such [technological] changes or, if anticipation fails, to respond as rapidly as possible.”* (p. 9). Technological advancement by engineers impacts the profession of engineering in second order ways as well. As technologies become increasingly integrated into our society the ties between engineers and the larger social and economic contexts increase: *“Engineers must know how and when to incorporate social elements into a comprehensive systems analysis of their work...it is not just the nature of a narrow technical challenge but the legal, market, political, etc., landscape and constraints that will characterize the way the challenge is addressed.”* (p. 35)

The report makes clear that the relationship of engineering with the rest of society is multifaceted and symbiotic, and will require engineers to better understand the larger, systemic implications of their work: *“The business competitiveness, military strength, health, and standard of living of a nation are intimately connected to engineering. And as technology becomes increasingly engrained into every facet of our lives, the convergence between engineering and public policy will also increase. This new level of intimacy necessitates that engineering (and engineers)*

develop a stronger sense of how technology and public policy interact.” (p. 37). The report pragmatically defines system thinking as being increasingly needed in the more-connected context of engineering practice: *“contemporary challenges...increasingly require a systems perspective...The systems perspective is one that looks to achieve synergy and harmony among diverse components of a larger theme.”* (p. 34).

The report repeats, in considerably more depth and detail, the scarcity language of the 1985 report. The report conveys a sense of real and present societal, global, and environmental threats that engineers will need to confront: *“The engineer of 2020 will be faced with myriad challenges, creating offensive and defensive solutions at the macro- and microscales in preparation for possible dramatic changes in the world. Engineers will be expected to anticipate and prepare for potential catastrophes...”* (p. 24). Thus this report adopts the same crisis tone of the genre, but frames the crisis in global terms rather than through economic competition, US preeminence, or status for engineers.

These definitions are both prescriptive, to effect change in engineering programs, and pragmatic. Unlike earlier reports, “The Engineer of 2020” spends relatively few words prescribing what engineering programs should do, rather it sets aspirational goals for engineers that would meet the predicted trends and needs. The definition for capabilities of engineers to include teamwork and communication skills is strengthened so that that engineers can collaborate across multidisciplinary teams. The emphasis on systems includes social and economic elements: *“Because of the increasing complexity and scale of systems-based engineering problems, there is a growing need to pursue collaborations with multidisciplinary teams...attributes for these teams include excellence in communication...and an understanding of the complexities associated with a global market and social context.”* (p. 35). Leadership also enters into the desired characteristics of engineers since the tighter coupling between social, economic, and technical systems will offer *“opportunities for engineers to exercise their potential as leaders, not only in business but also in the nonprofit and government sectors”* (p. 55).

Like earlier reports, “The Engineer of 2020” is clear that the tensions between these new definitions of engineers and the traditional definitions are difficult to navigate. As with all prior reports the technical-social duality is not resolved since both are vital: *“At its core, engineering employs principles of science, mathematics, and domains of discovery and design to a particular challenge and for a practical purpose... Just as important will be the imperative to expand the engineering design space such that the impacts of social systems and their associated constraints are afforded as much attention as economic, legal, and political constraints”* (p. 54). The report briefly mentions three possible avenues to reduce these tensions—*“(a) cutting out some of the current requirements, (b) restructuring current courses to teach them much more efficiently, or (c) increasing the time spent in school to become an engineering professional”* (p. 40)—and assumes some combination of these will be required. The report offers the recurrent meme of a

longer engineering degree program, but ultimately concluded more radical changes may be required. The report echoes themes of earlier reports on the importance of life-long learning and continual professional development: *“Engineers are going to have to accept responsibility for their own continual re- education, and engineering schools are going to have to prepare engineers to do so by teaching them how to learn.”* (p. 24)

Discussion & Dialog

As was pointed out in several of the reports, engineering education has a lasting habit of self-examination. In analyzing the selected reports for implicit and explicit definitions of engineers and engineering, one of the most striking features is that there are more similarities than differences across the 86 year span examined. This is not surprising since engineering education reports almost form a genre, with later reports building upon earlier efforts and thus exhibiting common elements. One of these elements is extrapolating future needs to identify a present crisis or problem. This clearly emerges from all the reports, but can also be seen by comparing the frequency of key words across the reports to bibliographic records of word frequency of other literature of the same decade. Using Google’s NGram tool and TextStat to identify words in context within the reports, the words “problem(s)” and “need(s)” appear much more frequently: 14× and 10× more frequently respectively in the Mann report, 5× and 9× in the Grinter report, 4× and 6× in the 1985 NAE report, and 6× and 4× in the “Engineer of 2020”. Another element that ties the reports together is that a rapidly growing demand for engineers is predicted in each case since more engineers will be needed to address the future crisis.

Barring variations in language, the definition of engineering remains fairly constant in each report, and in fact has not changed too significantly from that first proposed in 1828. The current ABET (formerly ECPD) definition best summarizes the core ideas: *“... the profession in which a 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”*¹⁷. The reports—whether implicitly in the “Engineer of 2020” or explicitly in the Mann report—each address status of, or for, the engineering profession.

Despite the commonalities, differences between the reports highlight trends and cyclical ideas in the evolution of engineering and the role of the engineer¹⁸. To explore these differences through a philosophical lens the claims made by each report on three different definitions of engineering were examined:

- What is the purpose of engineering?
- What is the role of the engineer?
- How should an engineer be prepared to assume this role?

The defined purpose of engineering changed over the period of the reports. The Mann report is explicit that the engineering's purpose was to apply scientific discoveries to industrial production, particularly to improve efficiency. Efficiency gains could come through both the material and human aspects of production. A secondary but related purpose of engineering was to "elevate the mechanic arts to a learned profession", essentially establishing a science of production. The Grinter report echoed this purpose with a much stronger emphasis on engineering as the part of the economic system that applied the discoveries of basic science to material and labor saving advances. Engineering was closely coupled to science, and the report emphasized that the pinnacle of engineering was discovering and creating through research. In the 1985 report "Engineering Education and Practice in the United States" engineering is seen as a community whose purpose is to serve a necessary function in a larger social-economic-technical system. Engineering focuses on delivering technology for use in this system. In "The Engineer of 2020" this integrated role of engineering is expanded and woven more tightly into larger social, economic, global, and environmental contexts. Engineering is defined as a creative element in this system with a purpose not only to increase material prosperity, but also to avert impending crises through both technology development and technical leadership.

The role of the engineer also changes across the reports. In the Mann report the engineer supports industrial production by applying scientific principles to production, but also assumes a managerial role in utilizing labor for production. Thus the engineer is to be trained in the economic elements of production. The Grinter report states that the "*...obligations of an engineer as a servant of society involve the continual maintenance and improvement of man's material environment, within economic bounds, and the substitution of labor-saving devices for human effort.*" The role of the engineer as the person responsible for providing technical advances to a larger system begin to emerge. By 1985 the trend of the engineer as an element within a large, interconnected system emerges still more clearly, a trend the report calls the corporatization of engineering. Because projects have gotten larger, the engineer's role is more fragmented and less holistic and the engineer must master emerging technologies while simultaneously managing themselves and others so their contributions can be integrated into the system. The systemic view of this report also more clearly illuminates the shifting roles over time between engineers, engineering technologists, and engineering technicians. This topic, however, is outside the scope of this paper. By 2004 the role of the engineer is to advance technological breakthroughs. The engineer is fully embedded within the social-technical system and is expected to have knowledge that allows them to engineer elements of this system. The engineer's analytic grounding gives them the role of policy maker, leader, and ambassador of technology. The engineer's role now encompasses not just material prosperity, but large systemic problems that potentially threaten the future of mankind.

How engineering education should be preparing engineers for these roles has maintained a focus on analytic skills, math, and science in each of the reports. There are more common elements

than variations. However there was an evolution of training over the 86 year span of the reports. In 1918 preparation was defined as science, then mechanic arts, with the need for humanistic studies so the engineer could better utilize men for production. Humanistic studies also trained the engineer to administer costs and values to be able to assume management roles. Engaging students in worthwhile endeavors both developed these skills but also built character which was the most important pragmatic element of being an engineer. The Grinter report identified both technical and social needs in preparing engineers, but deemphasized the practical, tacit elements of engineering education, adopting the Aristotelian viewpoint that *techne* could be taught as a science. The Grinter report was highly prescriptive about how to prepare students, to the point of suggesting the relative proportions of science and math, engineering sciences, application, and humanities. Vestiges of this remain in ABET today. The tone of the report is more prescriptive. The words “should” and “must”—as in “engineering programs must...”—are on par with use frequency of period texts in the Mann report, but are respectively 6× and 3.5× more frequent in the Grinter report. The Grinter report also focused on the importance of research in graduate studies to prepare the most talented students. These calls did not work out exactly as the architects planned¹⁹. Overall the technical elements of education called for in the Grinter report far outweighed social elements. By 1985 the more systemic role of the engineer brings in elements of teamwork and a re-emergence of practice occurs; technical preparation is still dominant but social is ascendant. While less prescriptive in tone, this report also uses “must” and “should” two or three time more frequently than period literature. There is a stronger emergence of the theme of “lifelong learning” that was present in the earlier reports since the role of the engineer is less certain. “The Engineer of 2020” is not prescriptive in tone, choosing instead to focus on aspirations for future engineers. These aspirations build on the base of the 1985 report, strongly emphasizing the engineers need to function within a complex technical-social-economic-environmental system. Thus engineers should be taught systems engineering, how to function on teams, and leadership. The increasing management focus echoes elements of the Mann report. The theme of engineering as a launching point rather than end point of a career emerges.

Overall it is extremely difficult and uncertain to extract any meaningful trends from policy snapshots over such a long period of time. A picture, however murky, does begin to emerge by comparing commonalities and differences in the philosophical claims of the reports. This picture is one of diffusion and broadening of the engineering profession and thus the preparation needed to assume an effective role. As outlined in the “Engineer of 2020”, technology has become so tightly infused with the life of people in the developed world that it is not possible to limit the role of engineering to increasing production as in 1918, or increasing material prosperity as in 1955. There is an element of connectedness, of the engineer as operating in and constrained by the larger systems, that grow stronger in each report. This growing awareness of connectedness, first to the human world and later to the natural world, emerges when implicit definitions of engineering in the reports are compared.

A very strong, repetitive element in each report is that dual social-technical are skills needed by engineers, although this was suppressed somewhat in the Grinter report. As the view of engineering widens with each report it is increasingly recognized that it is not easy—and may not be possible in the current conception of engineering education—to integrate both the much-needed technical and social knowledge and skills. Each report contains a tension in how engineering education should be constituted from this viewpoint of social-technical duality. Cech has recently pointed out that this technical-social dualism likely contributes to disengagement of engineering students²⁰. These tensions are never resolved and only become more apparent and intractable as time goes on. Various attempts are made over time to resolve these tensions, the most persistent being suggestions to extend the duration of an engineering degree program. This proposal has been floated, and in some cases implemented, intermittently for decades and is a recurrent theme in all but the Mann report. This duality also expresses itself in fragmentation of the curriculum, which was a concern in 1918: *“If there is any one point on which practising engineers and teachers of engineering are in substantial agreement, it is that at present this specialization and subdivision of curricula has gone too far.”* The Grinter report’s focus on graduate studies is another aspect of this concern. The attempts to address this issue often have unforeseen consequences. The NAE’s 1985 “Engineering Education and Practice in the United States” report noted that the two-tier educational system that resulted from how industry and government support research; as this article is being written there is a debate occurring on whether the funding of science by wealthy private individuals may exacerbate this effect. “The Engineer of 2020” clearly expresses that this duality has become a crisis: *“Engineering education must avoid the cliché of teaching more and more about less and less, until it teaches everything about nothing. Addressing this problem may involve reconsideration of the basic structure of engineering departments and the infrastructure for evaluating the performance of professors as much as it does selecting the coursework students should be taught.”*

How will engineering education resolve this duality? This is an immediate and pressing issue; reconceptualizing engineering education to address this century-old tension is in some ways the Holy Grail of engineering education. This is, however, more of a philosophical rather than an educational, technical, or engineering question. The need for the engineer to have both technical and social expertise is vital; as former NAE president Norman Augustine stated, *“The bottom line is that the things engineers do have consequences, both positive and negative, sometimes unintended, often widespread, and occasionally irreversible.”*²¹. As first expressed in the Mann report one definition of engineering is that the engineer acts in the world, thus must be connected to others. Interestingly a philosophical question that is not addressed in any of the reports is what mandate empowers the engineer to act? This could be reframed as what is the engineer’s moral purpose? It is this question that will be addressed in a subsequent paper.

Table #1: Comparison of Some Trends Across Reports

	Mann (1918)	Grinter (1955)	E.E.P.U.S. (1985)	2020 (2004)
Purpose of Engineering	<ul style="list-style-type: none"> • Improve industrial production. • Elevate mechanical arts to a learned profession. 	<ul style="list-style-type: none"> • Apply basic science for economic advance. • Discover and create through research. 	<ul style="list-style-type: none"> • Serve necessary technical function in larger system. 	<ul style="list-style-type: none"> • Creative element of social-technical system . • Increase prosperity. • Avert catastrophe.
Role of the Engineer	<ul style="list-style-type: none"> • Apply scientific principles to production. • Manager. 	<ul style="list-style-type: none"> • Provide technical advances to larger economic system. 	<ul style="list-style-type: none"> • Member of a team that includes management and technicians. 	<ul style="list-style-type: none"> • Advance technical breakthroughs. • Leadership. • Tackle societal problems.
Preparation of the Engineer	<ul style="list-style-type: none"> • Learn science. • Apply science in mechanic arts. • Managerial skills. • Build character. 	<ul style="list-style-type: none"> • Predominately technical. • De-emphasis of social. • Two tier system-undergraduate and graduate. 	<ul style="list-style-type: none"> • Technical preparation in social context. • Able to function on a team. 	<ul style="list-style-type: none"> • Function within social-technical system. • Leadership and management.
Social-Technical Duality	The apparent social-technical duality increases over time.			
Five Year Degree Program	Each report mentions extending the degree program to fit in necessary content.			

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