Evolution of American Engineering Education

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Abstract

Throughout the history of American engineering education change has been the only constant. The rapid expansion of engineering education started in the land-grant schools established under the provisions of the Morrill Act of 1862 (Marcus 2005). It was then that engineering found a firm place in academia, and a four-year curriculum was adopted as the standard for an engineering degree. However, different forms of formal or informal engineering education did exist prior to the Civil War. Initially, engineering was taught informally as skills handed down from practicing engineers who were mostly European immigrants. Later it was integrated into the curriculum at academies to train engineers to meet the regional economic need. The academies offered a more formal training as part of the high school education. Furthermore, there were several patterns of formal college level engineering courses in the pre-Civil War era. Most historians have ignored different forms of practical engineering courses offered by the antebellum colleges (Reynolds 1992).

This paper gives an overview of engineering education in America from its inception to the present. Based on the major changes of format and the curriculum content of engineering education, the historical time line can be divided into four major segments. These segments are: 1) the time period prior to Morrill Act of 1862, 2) the post-Civil war and prior to World War II, 3) after World War II and 4) the most recent movements to integrate engineering in K-12.
Engineering Education Prior to the Land-Grant Act

In the 1800’s most colleges only offered “classical” educations. The classical education was focused on teaching Latin and study classical literature. It was mainly to educate male, future clergy or politicians.

However, several antebellum colleges as well as some academies offered engineering courses. The objective of these institutions was to teach socially relevant practical curriculum to meet current regional or local needs. Prior to that, practicing engineers had learned by working alongside an experienced engineer by apprenticeship. Since there were not enough experienced engineers in every region of the US, antebellum colleges started offering their own type of one-year engineering courses to meet the demand of the region.

With the expansion of the transportation networks especially after the War of 1812 civil engineers were very much in demand. However, it must be noted that engineering education of that era was not standardized. It was very different from the current engineering curriculum and had many different formats (Reynolds 1992). Reynolds in his paper on “The Education of Engineers in America before Morrill Act of 1862” has identified six different formats/patterns of engineering education that are as follows:

- Military Style
- Polytechnic Style
- “Partial” or “Select” Option
- Option of Engineering within a B.A. curriculum
- Engineering Education as a “scientific” Curriculum (B.S. Degree)
Engineering Education in Scientific Schools division of Classical Colleges

Table 1 contains examples of each institution type. Each of these patterns is described following the table.

**Table 1. Engineering Education prior to Civil War in US**

*Source: Reynolds paper (Reynolds 1992)*

<table>
<thead>
<tr>
<th>Type of Engineering Education</th>
<th>Examples of institutions</th>
<th>Years of education</th>
<th>Degree awarded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Military Academy Style (Starting in 1802)</td>
<td>West Point Academy (1802), Virginia Military Institute (1839), Citadel (1843), the U.S. Naval Academy in Maryland (1845), National Scientific and Military Academy in Brandywine (1853), the Scientific, Military Collegiate Institute (1850)</td>
<td>1 year</td>
<td>H.S. Diploma</td>
</tr>
<tr>
<td>Polytechnic Style (Starting in early 1820's)</td>
<td>Gardiner of Main (1823), Rensselaer Institute (1824), Polytechnic College of Pennsylvania (1853), Brooklyn Polytechnic Institute!1855) and Cooper Union(1859), Nugget(1857) and Greene Polytechnic (1859)</td>
<td>2-4 years</td>
<td>H.S. Diploma</td>
</tr>
<tr>
<td>“Partial” or “Select” options (Starting in late 1820's) “</td>
<td>University of Vermont (1828), Columbia University (1830), New York University (1837), Princeton (1832 -1838), Rutgers (1841), Brown (1845), University of Rochester (1856), University of Pennsylvania(1856), Cincinatti College(1836), Washington College (1832), University of Virginia (1836- 1841)</td>
<td>1-2 years</td>
<td>Certificate</td>
</tr>
<tr>
<td>Option or an Engineering course in within the B.A. Degree (Starting in early 1830s)</td>
<td>University of Virginia (1833), College of William and Mary (1835), Alabama (1837), University of Georgia (1834), East Tennessee College (1840), University of Maryland (1840- 1854), University of Mississippi (1848), University of Missouri (1850-1856)</td>
<td>1 or 2 course only</td>
<td>B.A. degree with engineering elective</td>
</tr>
<tr>
<td>“Scientific Curriculum “ (Starting in late 1830's)</td>
<td>Columbia university (1836), Brown (1850), Wesleyan University (1839), University of Missouri (1856), Washington University of St. Louis (1857), Michigan Agricultural College(1855).</td>
<td>2-4 years</td>
<td>B.S. or Bachelor of Philosop hy degree</td>
</tr>
<tr>
<td>Scientific Schools within Classical Colleges (Starting at 1840s)</td>
<td>Lawrence Scientific School at Harvard University (1847), Yale’s scientific school,(1846) later named after industrialist Joseph Sheffield(1859), and Dartmouth Chandler’s scientific school(1852)</td>
<td>2-4 years</td>
<td>B.S.</td>
</tr>
</tbody>
</table>

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Military Style Engineering Education

The first formal engineering program in the United States was at the Military Academy at West Point, in 1802 (Emmerson 1973, Grayson 1993, Seely 1993). Initially, the academy did not offer a formal course or any regular sequence of classes. Cadets reported to the academy on a need basis and were instructed more on apprenticeship than academics. The engineering programs were modeled after French military academies, except American academies offered instruction to both military and civilians (McGivern 1960). These academies operated much like today’s high schools and had a dual purpose of preparing teachers and students who could serve as engineers in the military and in society.

By 1817 West Point under supervision of Sylvanus Thayer adopted a four-year curriculum to train engineers. This curriculum had a heavy emphasis on mathematics, science and civil rather than military engineering. In 1820 another military academy in Norwich, Vermont was established offering a similar program to soldiers and militia officers. By 1826, this academy (which was later called Norwich University), offered a program of courses labeled civil engineering.
engineering (Reynolds 1992). For more examples see table 1 at the end of this section.

**Polytechnic Style of Engineering Education**

The Polytechnic pattern is modeled after a more “democratic” British education system. These institutions offered vocationally oriented, evening classes, as well as a series of lectures and free libraries. Their sole purpose was to diffuse useful and relevant knowledge (McGivern 1960, Reynolds 1992). The early curriculum in most of the Polytechnic schools included practical applications of science, surveying, mechanics, civil engineering and some even offered agricultural chemistry, calculus and trigonometry. Although they were initially providing an equivalent to a high school education, some made an attempt at being more advanced (Reynolds 1992). Polytechnic College of the State of Pennsylvania shown below offered the first regular curricula and granted the first degrees in mining engineering and in mechanical engineering in the United States (Grayson 1980).
The third format was the “partial” or “select” patterns of engineering education. These terms refer to regular classical colleges offering engineering classes to students who were not interested in a traditional based B.A. degree. For examples of such schools see table 1.

The faculty in mathematics or physics that were interested in teaching these courses taught these “partial” programs. There was a great demand for the engineering career path which brought colleges extra income. These students did not have to meet the regular entrance requirements of the colleges. They only received a certificate of completion after finishing these partial engineering classes. The subjects most commonly taught were civil mechanics, machines and architecture. It was very much like the certificate programs that are currently offered by 2015 Conference for Industry and Education Collaboration, Copyright ©2015, American Society for Engineering Education”
some colleges or universities.

**Option of Engineering within a B.A. curriculum**

The fourth method of offering engineering education was making it an option or part of the requirements of an existing B.A. This was more prestigious than just a certificate program but was more challenging to implement, because the crowded curriculums were already under pressure to include science courses. This option was more popular by southern colleges (Reynolds 1992).

Some Colleges who had started with offering a “partial” or “select option moved toward offering their engineering courses as an option to their senior or junior students. Columbia in 1836, Rutgers in 1841 and Rochester in 1856, and Indiana University in 1850 were among such colleges. Depending on regional demand, some of these programs stopped while in others civil engineering or surveying courses became the most popular options in the B.A. programs.

**Engineering Education as a “scientific” Curriculum (B.S. Degree)**

The B.A. was the most prestigious degree offered at the time in that era. There were concerns of adding engineering to already crowded B.A. curriculum. The elites feared the addition of engineering courses would dilute their classical education. These issues gave rise to the addition of engineering in an alternate or parallel “scientific” curriculum, which led to a Bachelor of Science degree.

The B.S. degree was not as prestigious as the B.A. and colleges had lower admission standards for it. There were two basic types of B.S. degree programs, both had a lot of science and a lot less language and Latin. One included engineering among other science courses, with
no specific focus. The other had engineering as its focus and was designed to train Civil and other types of engineers. Some colleges even offered a C.E. (Civil Engineer) degree.

Columbia University was the forerunner in offering the B.S. degree. Columbia offered mechanics, machines and civil engineering as part of the “Scientific and Literary Course” of study, which lead to the B.S. degree in 1830. Table 1 lists other examples of such schools.

**Engineering Education in Scientific Schools division of Classical Colleges**

The last basic format for offering engineering was creation of autonomous scientific schools attached to a traditional university. Rich entrepreneurs funded most of the scientific schools. They felt the demand for scientific degrees. Engineering then became one of the more concrete paths within these schools.

The scientific schools in general, established a model for transitioning the higher education from a classical model to one that incorporated both the sciences and the liberal arts. They operated independently of their affiliated parent universities and faculty and students did not mix. They were looked down upon by the elites and had lower entrance requirements in terms of Latin and other languages. After World War II most scientific schools gradually became fully integrated with their universities.

Integration of engineering into college curriculum prior to the Civil war was not an easy process. In fact, some schools terminated the engineering courses/ curriculums during the depression. This was primarily true for Civil Engineering courses due to the drop in demand for such professionals. Between the years of 1838 and 1844 the engineering programs in Princeton,
Columbia, NYU, and University of Virginia declined or disappeared. Most of these programs did not re-start until after the Civil war.

**Engineering Education after the Land-Grant Act**

The creation of land-grant colleges, more specifically the Morrill Act of 1862 gave a tremendous boost to engineering education. The purpose of the land-grant colleges was:

without excluding other scientific and classical studies and including military tactic, to teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the legislatures of the States may respectively prescribe, in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life (Code 2012,April 27).

After the Civil war the country was expanding and building railroads, roads, bridges, and ships, all of which needed to be designed and built by engineers. The land-grant colleges made it possible for interested students to get a free education in an employable field (McGivern 1960). It was by far the most effective act that congress had past thus far, in terms of enabling states to offer free higher education. The number of colleges offering engineering went from a few (about 4 by some estimates) to about one hundred by the turn of the century (Baker 1900, McGivern 1960). In addition women started enrolling in engineering land- grant schools. For example Olive Dennis earned her civil engineering degree in 1920 from Cornell. She then worked more than 20 years at the Baltimore and Ohio railroad(Bix 2004).

In engineering programs, laboratory courses and practical training such as serving an
apprenticeship was much more important than instruction until World War I (Grayson 1993). Graduates were expected to join the work force immediately, and professors were expected to have industrial experience. The research done by a small percentage of engineering professors was strictly applied. A good engineering curriculum was aimed at preparing “good practical engineers” (Marcus 2005).

The years of 1862-1872 was the decade of growth for engineering education. In terms of curriculum, at classical colleges the engineering programs started having a distinct difference from science curriculum. A four-year curriculum became the standard for engineering education (Baker 1900, McGivern 1960, Reynolds 1992).

Starting in the 1880’s and moving forward there was a shift away from shops and hands on careers and a move toward higher education. This meant the inclusion of more science and math into engineering curriculum. Some engineering faculty, such as, Robert Thurston (1885), head of Sibley College of Mechanical Engineering at Cornell University, modeled their curriculum after the European engineering schools. He reduced the hours spent in the machine shop to make time for “calculations” and basic courses in science. In addition, he emphasized research but even Thurston understood the value of practical knowledge and kept a balance between experience and research (Marston 1900), (Marcus 2005).

Some universities such as Columbia and Harvard changed slowly, while keeping a balance between theory and practice. Engineering faculty believed that students needed to know why things worked as much as how they worked. The engineering textbooks started reflecting such a philosophy. For example, William H. Burr at Columbia University published textbooks on stress analysis and bridge design. He presented the basic principles underlying those subjects and
provided students with mathematical tools for structural analysis (Burr 1880, Burr 1883).

Although Burr and some of his colleagues understood the utility of mathematics and the value of scientific study, industrial employers were seeking graduates who could start working on projects right away after being hired. Therefore, practical knowledge continued to matter as much, if not more than science. At that time, research was not part of the engineering faculty’s normal schedule and they were not active in professional societies. It was not until the turn of the century that the emphasis on practice over theory started to shift (Seely 1999).

This shift was not just about adding more science and mathematics into engineering curriculum, but delaying the hands on and applied portion of the curriculum to year three and four of the B.S. program. Lack of a standard curriculum to train professional engineers was a great concern at the time. Therefore the Joint Committee on Engineering Education of the National Engineering Societies commissioned a study of engineering education. This study was lead by Charles R. Mann and was funded by the Carnegie foundation. This study concludes that an effective engineering education must integrate practice of engineering early on in the curriculum. The science and mathematics must be taught as integrated and applied starting from freshman year and it must include real case study examples (Mann 1918). Unfortunately examining the current engineering curriculums reveals that not much was done in that regards.

In the 1920’s engineering schools such as the California Institute of Technology, University of Illinois, Harvard and Cornell started a stronger theoretical approach to training engineers. European engineers spearheaded this transformation. Physicists such as George E. Hale and Robert Millikan who was the first president of Caltec, were instrumental in this transformation. Caltech built a scientific and mathematical approach to aeronautical
In the 1930’s some professors such as Westergaard of Harvard started pursuing research interests in addition to consulting for industries. Consulting for industries helped with attracting benefactors to fund the conducting of their academic research. It also had the educational benefit of integrating the most recent industrial trends into the courses. Examples of such research projects in civil engineering is the design of reinforced concrete paving slabs and the analysis of stress related to dams (Marcus 2005) (pages 168-170).

Most of the engineering research of this era was sponsored by the affected industry or professional societies. Civil and Mechanical were the two most dominant engineering fields. Although, the theoretical approach gained momentum in the late 1930’s, engineering research and integrating science and mathematics into American engineering curriculum did not become widely accepted till after World War II.

**Engineering Education after World War II**

By the 1940’s the war had created new opportunities for academic engineering research and the wide spread transformation of American engineering education. Large research investments, primarily from the military and the Atomic Energy Commission overshadowed the few industrial investments in engineering research (Seely 1993).

Trade associations had been the key research supporters in the 1930’s, when a few thousand dollars a year constituted a large project. After 1945 however, federal grants worth hundreds of thousands or even millions of dollars a year supported not just researchers but entire graduate programs with marvelous new facilities and state of the art
equipment. (Seely 1999)

The focus of research in the post war era was concerned with cutting edge technologies, such as computers and electronics, nuclear power, jet propulsion, rockets, and special materials. Engineer scientists were much more suitable candidates to conduct such research than practically trained engineers and as such they received priority in funding.

Many leading engineering schools, including Rensselaer Polytechnic Institute, Georgia Institute of Technology, and California Institute of Technology, were closed to women until after World War II. “The few women admitted to Massachusetts Institute of Technology (MIT) struggled against a hostile intellectual and social environment” (Bix 2004).

By the 1950’s the engineering curriculum included much more science than practical applications as part of the curriculum. Special mathematics and science courses were developed for engineering education. New engineering fields such as engineering science, engineering physics and material science engineering emerged. Establishment of the National Science Foundation (NSF) and the government’s support for research in engineering radically transformed its education. Engineering schools such as MIT, Cornell, and Stanford embraced these changes, and became more selective in recruiting the students who were able to succeed in a more science-based and research oriented curriculum. These universities were also collaborating with electronic and other industries to better serve the industries needs as well as keeping a balance between the practical and theoretical.

Up to the early 1950’s professional engineering societies were not getting involved in setting standards or policies for engineering education. Instead, they chose to grow in parallel with engineering education and followed the lead of educational institutions in terms of changes
In 1952, the Engineers’ Council for Professional Development (currently known as Accreditation Board for Engineering and Technology), became concerned about standardization of the engineering curriculum content. The concern was about not breaching the gap between the fundamental sciences and engineering instruction. In response to this concern the American Society for Engineering Education (ASEE) commissioned a study. The first draft of the report (called Grinter Report) stressed the need for more science in engineering curricula and then, more controversially, proposed two tiers of engineering instruction. One tier of schools specialized to train engineers to meet the needs of the industry. Another tier of schools would be dedicated to meeting the needs of scientific research in engineering as well as having graduate programs. The suggestion of the two tier system was omitted from the final version of the report (American Society of Engineering Education 1994).

By the late 1950’s, early 1960’s most engineering schools that wanted to grow had to develop graduate programs to support fundamental research programs. These programs had a much greater emphasis on engineering science. Their goal was not to serve industry, but rather, to attract federal research funds. By the 1960’s engineering science had dominated most American engineering curriculums. The structure and format of the curriculum had shifted back from practical knowledge to theoretical knowledge. Land-grant colleges, whose focus was to produce engineers to meet the need of local industry, had transformed into institutions with graduate programs to meet the research needs of the government and military. The industry could not compete with the financial incentives offered by NSF, NIH and other governmental agencies (Marcus 2005).

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In terms of gender, as late as the 1960’s, women still made up less than 1 percent of engineering students. However, in the last half of the 20th century, activists fought to change the perception and to gain the acknowledgment of a woman’s ability to become a good engineer. The Society of Women Engineers (SWE) which was established in 1952, spearheaded some of these activities (Bix 2004).

The research-oriented engineering education started being criticized in the late 1970’s and into the 1980’s. The 1980’s trend in engineering education emphasized general, rather than technical at the B.S. level. Some chose to continue their specialized training at a master’s degree level, or by taking continuing education courses as it applied to their career (Grayson 1980). Many employers at the time began to complain that graduating engineers at the bachelor’s degree level were not prepared to start employment. Most were lacking the practical and design aspects of the engineering practices (Marcus 2005).

In the late 1990’s a move to re-introduce more practical aspects of engineering into the education had begun. Some efforts were made to re-emphasize design in engineering schools and develop a better balance with engineering science. This move may be referred to as reinventing the wheel and going back towards the post land-grant engineering education. As a result, the accreditation agencies for engineering programs have started to work on changing the content of engineering curriculum. ABET 2000 criteria is an example of such efforts (Accreditation Board for Engineering Technology 2013). Figure 3 displays the evolution of practical versus theoretical content of engineering education over time.
Figure 3: The trends of the content of engineering education over time: Practical versus science and theory.

It must be noted that the Accreditations Board of Engineering Technology (ABET) regulates the engineering education of all post-secondary accredited engineering and technology programs in US. ABET was founded in 1932 and changed its name to the Engineers’ Council for Professional development (ECPD) in 1980 ECPD is accredited with the first engineering program in 1936 and the first technology (engineering technology) program in 1947. All of the above mentioned changes and transitions in the engineering curriculums were endorsed by ABET since it’s inception.

Currently there are three basic types of practicing engineers in the US meeting the needs of industry as well as research institutions. The three charts (figures 4-6) displayed below, are

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comparisons between these three types in terms of years of schooling as well as theoretical and practical knowledge of the field. For example engineering scientists who have the longest number of years of schooling also possess most theoretical knowledge. Their curriculum includes higher level of mathematics and science as opposed to hands on and practical knowledge. (Century College 2013).

Figure 4: Years of post-secondary education for Engineers
Figure 5: Theoretical Knowledge of different practicing Engineers

Figure 6: Practical Knowledge of different practicing Engineers

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Future of Engineering Education

Engineering and Technology Education in K-12. As shown in the above historical narrative, engineering education was initially introduced in academies for interested individuals who have had an equivalent of elementary education. It was practically oriented and its sole purpose was to prepare the engineering work force. As engineering education developed it required a more theoretical science and mathematics background and was integrated into a collegiate level. The graduate program and research in engineering were developed.

Currently, despite the demand for engineers, the US is not producing enough of them. One of the reasons cited for this lack of engineers is that not enough students succeed in getting their degrees. Preparation and encouragement of high school students is one major cause for the lack of interest and success in the engineering related careers. This is especially true for women and minorities (Dettelis P. 2010), (Hunter 2006) and (Kimmel, Carpinelli et al. 2007). As the result of such shortcomings, NSF and the State Education department are funneling funds toward STEM education research. The aim is to provide a K-12 education, which prepares the students for success in the engineering and science fields.

Presently, in the United States, science and mathematics are fully integrated in the K-12 education. But the engineering and technology or “ET” is missing from the STEM core curricula for K-12 courses (Dettelis P. 2010) & (Jeffers, Safferman et al. 2004). However, the future job forecast indicates an increased demand in engineering related fields.
In fact, in the late 1990’s the Office of Technology Assessment (OTA) conducted a detailed study on the state of engineering and technology; *Educating Scientists and Engineers: Grade School to Grad School* is the result of that study which was published in 1988 and then was prepared as a report for the US congress. The report stated that scientists and engineers are only 4% of the American workforce. However they possess specialized skills that are vital to the national welfare and the future economy of the nation. Unfortunately, many able students leave science during college. Only about 30 percent of baccalaureate science and engineering graduates enter full-time graduate study, and nearly half of science and engineering doctoral candidates never earn Ph.D.s. On the other hand, the demand for scientists and engineers has been rising. The Nation is well advised, therefore, to seek an adequate supply of people prepared for science and engineering careers.(U. S. Congress 1989) (summary p 3)

This report further suggests Elementary and secondary schools could do a better job of encouraging students in science and mathematics, thus expanding the talent pool.(U. S. Congress 1989) (p 7). This report and other similar reports on the K-12 deficiencies in STEM preparation lead to the National Science Education Standards (NSES) of 1996. As the result of the creation of NSES most of the states included more science and some added Technology to their K-12 programs.

More recently The National Research Council (NRC) has recognized the deficiency of “ET” in K-12 education. The 2010 NRC’s draft report on framework for science education has led to The Next Generation Science Standards (NGSS). NGSS describes the major scientific ideas and practices that all students should be familiar with by the end of high school. The importance of understanding the designed world and the need to better integrate the teaching and
learning of STEM is emphasized. Engineering and technology should be featured alongside the natural sciences (National Research Council 2013).

The NGSS is the most important policy setting instrument to motivate changes in K-12 education with regards to engineering and technology. It is important to note that having a well-qualified teacher is an important factor that may affect the future of those majoring in science and engineering. NGSS recognizes that an early display and recognition of talent is essential. In the absence of preparatory mathematics and science courses, students will be left behind, and can’t catch up if they aspire to a scientific or engineering career. For example, high school students who have not had an exposure to Physics or advanced mathematics, are not going or able to consider or succeed in engineering.

As indicated by the history of engineering education above, the Federal government is instrumental in aiding a higher education institution in conducting research and promoting engineering through the National Science Foundation and the National Institute of Health. The Federal Government can also be influential in these career decisions:

- Through targeted support of students, universities, and research, and through its pervasive influence on the American economy and research agenda at University level
- Supporting implementation of the Next Generation Science Standards for K-12, such as.
  - Financial support to states for implementation of changes

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Teacher training at National level
- Supporting collaborative projects between industry and the education department

Mainly however, K-12 reform is up to the state and regional level authorities.

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