

ATMAE WHITE PAPER
JANUARY 2014

A Meta-analysis of the
**Skills Gap
Dilemma**

*in Today's Engineering
Professions*

**DEVELOPING THE 21ST
CENTURY WORKFORCE**

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The Association of
Technology,
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Introduction

Since the start of the Industrial Revolution in 1760s, there has been a sustainable growth in the mass population's standard of living. Advanced materials, machines, production methods, quality standards, and managerial techniques have all contributed to the success of our manufacturing sector, which is a key contributor to the economic productivity and the Growth Domestic Product (GDP) of our nation. Together with machinists, machine operators, and skilled trades, engineers play key roles in the operation, success, and global competitiveness of the manufacturing sector, no matter if it is in the aerospace, ship building, chemical, or automotive industry. The U.S. manufacturing sector has been challenged extensively for more than a decade in the global marketplace to maintain the flagship of innovation and leadership.

In terms of global manufacturing output, the United States (manufacturing sector) is currently ranked below China; and in terms of manufacturing intensity; the United States is currently ranked below Germany, South Korea, and Japan (U.S. Manufacturing, 2013).

The American Society for Engineering Education's (ASEE) report on "Engineering by the Numbers" demonstrates a gradual increase in accumulative enrollments in Bachelors, Masters, and PhD engineering programs since 2002 (Yoder, 2011).

Figure 1 shows the gradual increase in the undergraduate student enrollments in engineering degrees (all disciplines) in U.S. colleges and universities. As depicted, enrollment continued its upward trend in Fall 2011 with a gain of approximately 4.8%. It is noteworthy to mention that ASEE's report does not include Engineering Technology and Applied Engineering programs in its numbers.

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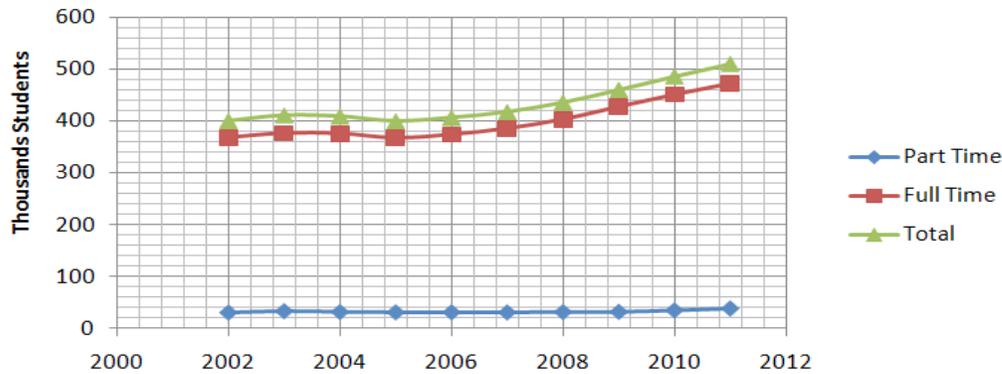


Figure 1 Undergraduate Engineering Enrollment in the U.S.

Yet, many credible news articles are reporting on the shortage of engineers in the job market. In March 2013, the Conference Board of Canada reports that the “North American societies are not graduating enough STEM students to be competitive” (Percentage of Graduates, 2013). Their report shows that, in developed countries, when comparing the proportions of all college graduates in 2010, the United States earned a grade of “D” and ranks 15th out of 16 peer countries. In another article that was published by the Huffington Post in 2012, the author and President of General Motors Foundation reports that the United States is facing a STEM talent crisis. The author cites from the U.S. Department of Labor that in countries in which the STEM fields account for more than 50% of the economic growth, only 5% of the population is hired in STEM fields. Additionally, with a majority of Baby Boomers reaching the retirement age, the STEM talent crises may get worse (Pickard, 2012).

Contrary to many aforementioned reports and studies in the public media and news, there are a number of reports and studies that talk about the surplus of scientists and engineers in the United States. TechJournal cites from the 2010 American Community Survey (ACS) that there are 101,000 U.S.-born engineers who are unemployed. The ACS data that is collected by the U.S. Census Bureau also reports, “there are 1.8 million U.S. born individuals with engineering degrees who are either unemployed, out of the labor market, or not working as engineers” (Many Engineers, 2012).

Modern Engineering Education

Engineering education methodology in the United States has long been a source of debate. At its heart, the contention is centered on curricular issues of practice versus analysis, depth versus breadth and the role of engineers in society. A fundamental challenge is distinctly establishing what an engineer does. With so many roles served by engineers and so many specialties and subspecialties, there is no single, acceptable answer. To attempt an over-arching statement often comes at the expense of delivering any meaningful and informative content. The definition as one who must “design under constraint” (Wulf, 1998) is a very good summary and easy to agree with. How engineers should be educated to accomplish this task is still not clear. Is there a general, best-practice methodology? We’ll use a historical perspective, primarily from the last century, to establish how education got to its current state, and what that means for its future.

Initially, engineers in the United States were primarily trained through apprenticeships. They studied under a practicing engineer to learn their chosen trade through completing specific tasks. Rather than focusing on theoretical concepts, training consisted of hands-on application of design principles through emulation. Formal engineering education in the United States started as a “collegiate education.” It was instituted by educators, not practitioners, and struggled to gain the support of practitioners (Grayson, 1980), even though the curriculum was still very much a hands-on endeavor. In the same period, European training was much more analytical. More emphasis was given to why things work, and application of mathematics and scientific principles were dominant (Bucciarelli, Coyle & McGrath, 2009). This theory-based approach is commonly referred to as engineering “science,” whereas the hands-on, application-based approach is referred to as engineering “design.” It is the pursuit of balance between science and design that continues today.

The demand for more detailed, predictive analysis in engineering grew as technologies became more complex and less intuitive. In response to this, engineering education began adopting more of the

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European character, but both empirical and analytical methods were taught. Formal education had not yet taken priority over work experience. The Morrill Land Grant Act, passed in 1862, was a decisive factor in broadening the availability of college education. This provided support for establishing universities, and the number of engineering schools expanded rapidly. "Shop work" was still a large part of the engineering curriculum at this time (Grayson, 1980).

Although a rift was steadily progressing in the early 1900s, the division of theory and practice grew most noticeably after World War II. This was in response to the numerous wartime technologies developed to maintain competitiveness. The majority of new technologies were attributed to physicists, which had advanced training in scientific and mathematical concepts. This, in conjunction with Cold War tensions and the need for technological superiority, opened up unprecedented levels of funding for engineering science programs. America sought to be ready for, not reactive to, international challenges. To tap into this money, "schools seeking to grow had to develop graduate programs to support fundamental research programs and emphasize engineering science" (Seely, 1999, p. 291). By the 1960s, the direction had deviated so far from practical design experience that practicing engineers complained of new graduates' lack of problem-solving capabilities (Seely, 2005).

Historically, education has been of primary concern in preparing engineers, and engineering is unique in its dedicated self-reflection on how it trains its professionals. This began in 1893 with the formation of the Society for the Promotion of Engineering Education (now the American Society for Engineering Education, or ASEE). ASEE's mission is commitment to, "furthering education in engineering and engineering technology."

That is accomplished through "promoting excellence in instruction, research, public service, and practice. . ." (About the Organization, 2013), and that has resulted in a number of reports suggesting the direction and content of educational practice. These formative reports, however, do not aim to assess successful delivery at an institutional level.

The realm of standardizing and certifying the quality of engineering curricula has been dominated by accreditation agencies. "ABET was founded in 1932 as the Engineers' Council for Professional Development (ECPD), an engineering professional body dedicated to the education, accreditation, regulation, and professional development of the engineering professionals and

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students in the United States” (About ABET history, 2013). Since 1967, the Association of Technology, Management and Applied Engineering (ATMAE, formerly the National Association of Industrial Technology, or NAIT) has sought to meet industry’s workforce needs, and to provide professional development opportunities for its members to maintain the competitive edge in technology, management, and applied engineering (About ATMAE, 2013). Although there is overlap between focus areas for ABET and ATMAE, especially with ABET’s Engineering Technology Accreditation Commission (formerly TAC), the two have been primarily concerned with engineering science and engineering design, respectively. That is, ABET has traditionally stressed the analytical aspects of engineering education and ATMAE has stronger emphasis on practical technological or “hands-on engineering” skills and managerial-related knowledge. That is an oversimplification of course, as both serve to ensure graduates are imbued with practical, scientific, and interpersonal qualifications. Nonetheless, the differences are important.

Accreditation criteria are of fundamental importance to shaping graduating engineers. Each school has flexibility in meeting requirements, so “individual results may vary.” That curricular freedom allows for variations in accredited programs, but overall, there is a surprising amount of uniformity in U.S. engineering programs. The important aspect to note is that analytical, scientific understanding and practical (hands-on) technological application have split so far as to warrant different accrediting bodies. This would also indicate that graduates from programs accredited by different organizations would be employed in significantly different positions. That is often not the case. It makes sense to consider what employers are looking for and incorporate that into the holistic view of engineering education.

Engineering Shortage or Surplus?

Do we produce enough engineers in the United States or not? A meta-analysis of the literature seems to support both arguments. “Indeed, some of the most puzzling stories to come out of the Great Recession are the many claims by employers that they cannot find qualified applicants to fill their jobs, despite the millions of unemployed who are seeking work. Beyond the anecdotes themselves is survey evidence, most recently from Manpower, which finds roughly half of employers reporting trouble filling their vacancies” (Cappelli, 2012, p. 1). For many years now, companies have reported a significant gap between need and available skills held by the U.S. population (Morrison et. al., 2011). “U.S. industry has repeated the mantra ‘We need more engineers.’ Now the White House is listening, with the President’s Council on Jobs and Competitiveness declaring a national goal of graduating 10,000 more engineers a year – a jump of 14 percent from the 72,300 engineering bachelor’s degrees awarded last year” (Grose, 2012, p. 1). But is this really the case?

A 2007 article titled “Where the Engineers Are” stated that “it is common in many industries to offer signing bonuses to encourage potential employees to accept a job offer. We found, however, that 88% of respondents to our survey did not offer signing bonuses to potential engineering employees or offered them to only a small percentage of their new hires. Another measure of skill supply is the amount of time it takes to fill a vacant position. Respondents to our survey reported that they were able to fill 80% of engineering jobs at their companies within four months. In other words, we found no indication of a shortage of engineers in the United States” (Wadhwa et al., 2007, p. 7). A recent 2013 study titled “Guestworkers in the High-skill U.S. Labor Market: An Analysis of Supply, Employment, and Wage Trends” was recently published by the Economic Policy Institute (EPI). “EPI a non-profit, non-partisan think tank was created in 1986 to broaden discussions about economic policy to include the needs of low- and middle-income workers. EPI believes every working person deserves a good job with fair pay, affordable health care, and retirement security. To achieve this goal, EPI conducts research and analysis on the economic status of working America” (About EPI, 2013). The report found that only 53.9% of engineering and engineering technology graduates are finding jobs in their major field (see Figure 2).

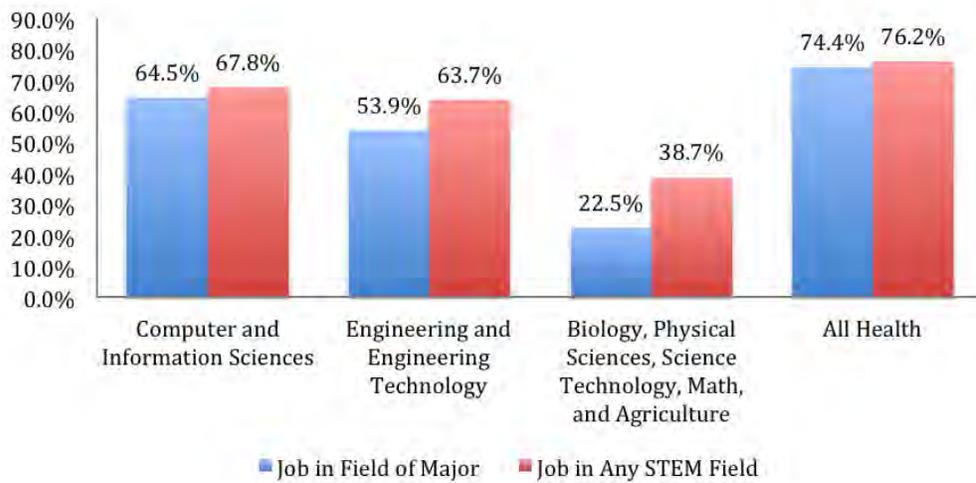


Figure 2: Occupational Field of STEM College Majors One Year After Graduation (Salzman, Kuehn, & Lowell, 2013)

The EPI study by Salzman, Kuehn and Lowell further investigated the reasons for the difficulty in obtaining STEM jobs after graduation from college programs. Figure 3 illustrates that nearly one-third (30.2%) of the survey respondents indicate that they were unable to obtain an engineering or engineering technology job within one year of graduation because of “Job Not Available.” Another 31.3% indicated that they did not find a related job because of “Pay, Promotion, or Working Conditions.”

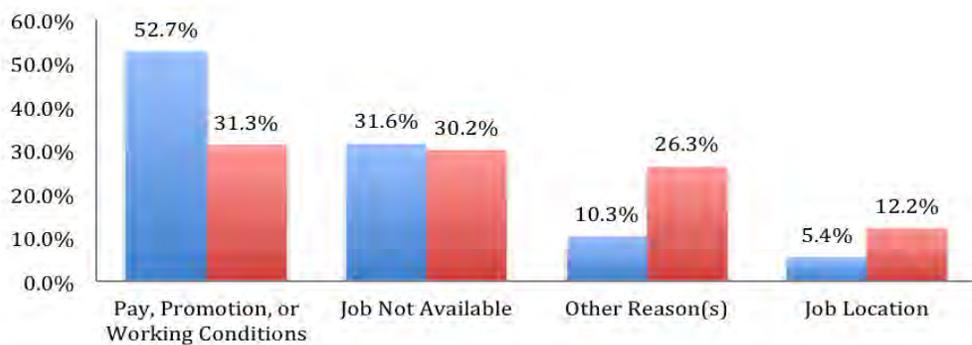


Figure 3: Primary Reason for Not Working in Field of College Degree One Year After Graduation (Salzman, Kuehn, & Lowell, 2013)

The definition of engineering or what makes an employable engineer “an engineer” in industry combined with the evolution of engineering education in academia are likely part of this confusion. The question needs to be asked: Who defines the skillset of the modern engineer? While some might point to academia (universities and accreditation agencies), others may feel that industry leads this dance because they are the ones that hire and award the various titles to their employees. The majority of engineering titles used by U.S. industry are not your typical design engineering functions (Electrical Engineer, Mechanical Engineer, Civil Engineer, Chemical Engineer, etc.). Titles such as Manufacturing Engineer, Process Engineer, Controls Engineer, Application Engineer are much more common (applied roles) and are those that may be filled by traditional engineering and applied engineering graduates. Is the problem one of sheer lack of opportunity or is it possible that all of the studies yield truth? Perhaps the problem lies in the types of engineers that we are graduating each year coupled with the actual demand stated by industry.

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Reading Between The Lines

“A generation ago, employers routinely hired people right out of school and were willing to provide almost all their skills. Apprenticeships and similar programs provided ways for the employers to essentially pay for the training themselves. Employers – and especially those who expect colleges to provide most of their skills – should also work closely with educational institutions to develop the candidates they need” (Cappelli, 2012, p. 2).

Ronald Land, a Penn State New Kensington Associate Professor, recently published an article titled “Engineering Technologists are Engineers” in the Spring 2012 issue of the Journal of Engineering Technology. In his paper, Land summarizes a conducted survey of 200 U.S. companies: “The survey results indicate that 7 out of 10 companies make no distinction between graduates [engineering or engineering technology] when hiring into engineering positions, nor do they make significant distinctions in assigning functions and responsibilities, nor do they note important differences in capabilities of either group while on the job” (Land, 2012, p. 1). This article plays a key role in the discussion of the “true need” for engineers in industry today. It is the authors’ belief that for every 10 engineers hired in industry, 7-8 of those hires require focus on process rather than product. This is the major distinction between applied engineers and design engineers. Applied engineers are those engineers that focus on process, while traditional, design engineers are trained to develop or design products. In the United States, the emphasis has been to develop far more traditional design engineers despite the converse need for applied engineers in industry.

Applied engineering education includes engineering technology, applied engineering, industrial technology, and technology management degree programs. All of these programs emphasize the optimization, implementation, and development of processes rather than the design of new products. Of course, this is an over simplification as traditional engineering programs do in fact teach process, and applied engineering programs also teach some product design. It is the emphasis or balance of theory (design) to practice (process) that is different. Both educational programs are needed in the manufacturing sector – it boils down to a skillset match.

Looking toward the future of engineering education, there is general consensus that changes need to be made. As noted in a report put out by the National Academy of Sciences, “one course, one program, one department at a time . . . is no longer a viable response if we are to build the kind of robust programs in research and education now needed to strengthen the U.S. engineering community by 2020” (National Academy, 2005). A broader reform is needed. Some issues identified are student interest, the “engineering pipeline” issue (Shuman et. al., 2002), and active engagement in education, rather than, “a seemingly endless drudgery of courses” that are disconnected from student interests and which do not include context to a larger, overall picture of engineering (Kalonji, 2005). How can we recapture the imagination of aspiring engineers and keep hold of it through (at least) four years of education? Is the student best served by a strongly analytical, engineering science education, or is it practical, technological proficiency that employers are looking for? Is it a mix of the two, and if so, in what proportions?

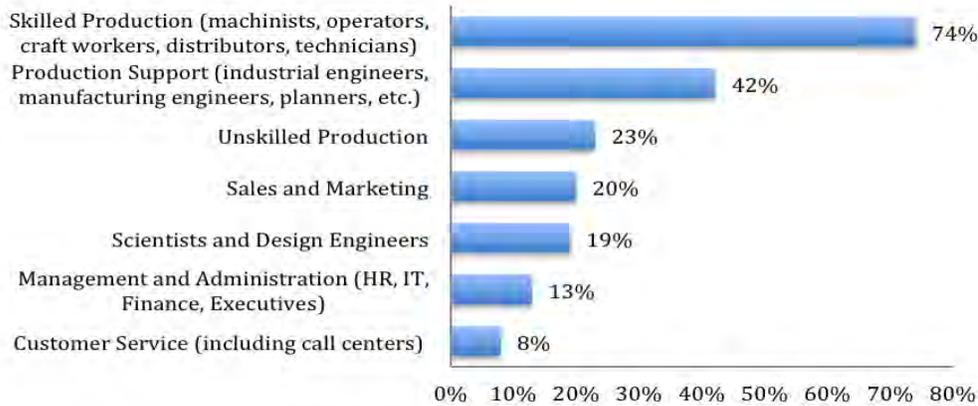
“To understand the current state of the field and, more importantly, to better anticipate what might occur in mechanical engineering over the next decade, there is no better barometer than the views of those currently practicing in the engineering profession. To that end, ASME [American Society of Mechanical Engineers] conducted an online survey in June 2011” (p 4). Their survey respondents expect engineering to evolve by becoming (1) more interdisciplinary, (2) broader – requiring more skills to work with other types of professionals, and (3) more globally aware – being able to work with people from different regions and cultures (The State, 2011).

“Traditional engineering curricula are frontloaded with math, physics, and chemistry often taught in departments outside of engineering. Competence at all three is important to engineering practice, yet too often students fail to grasp their relevance and get easily discouraged” (Matthews, 2013, p. 1). One might argue that emphasizing applied engineering education in the United States might increase the number of engineers in the field. Applied engineering programs are more hands-on and are highly desirable by industry for a host of engineering titles. “Hands-on elements also give students “real-world” experiences that translate into marketable skills” (Matthews, 2013, p. 3).

Tom Lee, an electrical engineering professor, teaches a freshmen-oriented seminar at Stanford called "Things About Stuff." In an article titled "Hot Courses: What Wows the Facebook Generation" published in the PRISM publication of the ASEE, Dr. Lee is quoted as saying "once [students] see how the knowledge they can acquire in theory classes can be applied, they find it more interesting. Lee uses the analogy of teaching people to play the violin: 'You need to put one in their hands, you can't lecture them on how to play it'" (Matthews, 2013, p. 2). "More schools are embracing active-learning techniques and entrepreneurship and giving first- and second-year students hands-on projects that can include some engineering design to keep them interested and staying put" (Grose, 2012, p. 3). So why push traditional engineering rather than applied? Most applied engineering programs spend 50-60% of their time in lab with hands-on activities (processes). The reality is that we graduate far more design engineers in this country as compared to applied engineering professionals creating a lack of desired skills in the marketplace. Confusion in the marketplace about the distinction between these two types of engineering graduates further adds to the problem.

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“The real story about employer difficulties in hiring can be seen in the Manpower data [2012 Talent Shortage Survey] showing that only 15% of employers who say they see a skill shortage say that the issue is a lack of candidate knowledge, which is what we’d normally think of a skill. Instead, by far the most important shortfall they see in candidates is a lack of experience doing similar jobs. Employers are not looking to hire entry-level applicants right out of school. They want experienced candidates who can contribute immediately with no training or start-up time” (Cappelli, 2012, p. 1). “The workforce segments that are hardest to find are those that impact operations the most and require the most training. From machinists and craft workers to industrial engineers and planners [applied engineers], the talent crunch in these areas is taking its toll on manufacturers’ ability to meet current operation objectives and achieve longer-term strategic goals” (Morrison, et al., 2011, p. 3). See Figure 4.



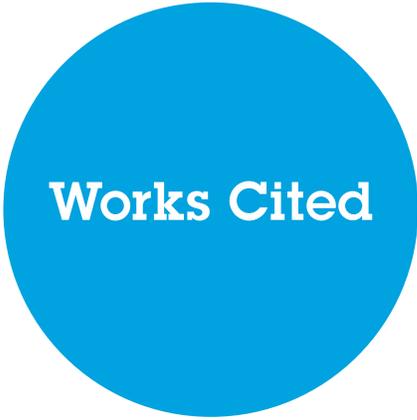
Note: Multiple selection question - percentages may not add to 100%, base used is 1123

Figure 4: Survey Data Results – Workforce Shortages having Negative Impact on Companies (Talent Shortage, 2012)



Summary

The vast majority of colleges and universities that prepare students for engineering careers in the United States predominately offer traditional Bachelor of Science in Engineering (BSE) degrees. These programs prepare students to become design engineers. An alternative path of preparation to the BSE includes the study of applied engineering or engineering technology. These baccalaureate programs are more hands-on (process oriented), often include managerial concepts within their educational preparation, and prepare students for many engineering titled positions in industry where process (including systems integration) is the focus rather than product design. The authors believe the engineering-need controversy may be explained with the balance of the engineering need in industry. Industrial companies require engineers that design products, as well as those who implement, manage, and optimize processes. There simply is no “one best type” of engineering education. There may, however, be a balance issue. How many design engineers do we need for every applied engineering professional? This may be the “real” issue at hand. The authors recommend further investigation into the question of supply and demand of engineering opportunity. It would be very interesting and useful to examine the employability of engineering technology graduates separate to that of traditional engineering. Therefore, the authors would like to call for further research to help yield more definitive answers to the complex problem.



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